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The Bollène-2002 experiment: innovative algorithms and evaluation of processing strategies for radar QPE in the Cévennes-Vivarais region

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1 Introduction

The Bollène 2002 Experiment was designed by DSO/Météo France and LTHE in order to evaluate the benefit of a radar volume-scanning strategy (8 elevation angles in 5 min) for radar quantitative precipitation estimation (QPE) in the Cévennes-Vivarais region. It was justified by the need to mitigate flood and flash-flood hazards in these regions where QPE is more complex because of the reduced visibility and the increased environmental noise. This communication aims at presenting a number of innovative radar QPE algorithms and the evaluation of processing strategies.

2 The Bollène-2002 Experiment

During the autumn 2002, the 3 PPIs corresponding to the elevation angles needed for the operational products in real time of the Bollène radar (Météo-France) were complemented by two sets of 5 PPIs (elevation angle from 0.4° to 18°), alternated every 5 min. This protocol allowed a good sampling of the atmosphere at a 10 min sampling interval. The data available for each 1 x 1 km² mesh of each PPI was the average reflectivity and the mean absolute reflectivity difference (MAD) averaged over the individual radar polar bins which centers fall within the corresponding Cartesian mesh.

This autumn was particularly rainy, resulting in the sampling of a significant number of rain events. Five rain events which cover a broad variety of Mediterranean rain systems were selected for our study. One of them, the catastrophic rain event of 8-9 September 2002 (Delrieu et al. 2005) was particularly exceptional with total rain amounts reaching 700 mm in 28 hours, mainly as a result of a stationary V-shaped mesoscale convective system (MCS) which affected the Gard plains. Two others (the 21 October 2002 and 21 November 2002 rain events) correspond to the passage of cold fronts within westerly meteorological regimes (maximum rain accumulations of 60 and 100 mm, respectively). The last two events (the 24 November 2002 and 10-13 December 2002 events) were characterized by widespread and long lasting rainfall with embedded convection and complex dynamics (maximum rain amounts of 150 and 300 mm, respectively).

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3 Innovative algorithms

Innovative algorithms were developed in order to identify and correct for various error sources in QPE in mountainous regions. Each of them is summarized in the following. More details are given in a paper in preparation by Nicol et al. (2006).

3.1 Radar calibration stability and detection domain

The radar calibration stability was checked with an external target provided by ground clutter. The pixels constituting the reference target were determined from the reflectivity and MAD measurements during 10 non-rainy days in a radar range between 10 and 50 km according to four criteria: a mean reflectivity in the range 45 – 55 dBZ, a time-averaged MAD less than 2 dBZ, a standard deviation of MAD in time less than 0.4 dBZ and an occurrence of reflectivity value greater than 95% of the time in the dry weather data.

Anthropic targets present in the Rhône valley and the Cévennes mountains produce significant radar returns that decrease the detection domain. The non anthropic screening effects were determined following the geometrical procedure of Delrieu et al. (1995) which is based on a digitized terrain model (DTM), assumptions about the radar wave propagation in the atmosphere and the power gain function. The screening factors also computed are expressed in terms of the correction factor (in dB value) that should be added to the reflectivity in dBZ.

3.2 Adaptative ground clutter identification

The ground clutter detection method was based on the inter-pulse variability of non-Doppler radar returns (Nicol et al., 2004). The proposed method utilizes two criteria, one which reflects the degree of pulse-to-pulse variability, and a another one which identify the strong gradients that are often present at the edge of ground-cluttered regions.

The method of Nicol et al. (2004) was adapted to the S-band Bollène radar and to the meteorological characteristics of the the region. This adaptative ground clutter identification (GCI) technique uses four clutter categories based on the analysis of the dry-weather clutter characteristics. This GCI procedure provides a robust yet adaptable means of identifying ground clutter with the following differences in relation to a purely static method based on dry-weather data only: (1) a lesser number of measurements of precipitation in regions typically affected by clutter are discarded, due to the fact that they may be recognized when dominant in these regions; (2) echoes due to anomalous propagation along with other noise sources may be identified to a certain degree.

An interpolation is applied in a final step to fill in the ground-cluttered regions (see Fig. 1).

3.3 Coupled rain type separation and Vertical Profiles of Reflectivity (VPR) identification

Several rain types may exist within a single radar image because of the variety of the rain micro-physical processes. It was proposed to implement automatic rain separation techniques before estimating and using VPR functions and Z-R relationships conditional on the rain types. The method developed is mainly backed on the algorithms proposed by Steiner et al. (1995) for the identification of convective cells and by Sanchez-Diezma et al. (2000) for the detection of the bright band, indicative of stratiform rainfall, using 3D reflectivity data only. A decision tree which allows a rather satisfactory rain type separation at close range (e.g., 80 km) was derived.

This preliminary partition is used for an in-depth characterisation of the variability of the VPR within each single rain field. In turn, the VPR analysis conditional on rain types is found to provide means for an improved partition over the entire detection domain (see Fig. 2). Like in the work of Germann and Joss (2000), we limit ourselves here to the identification of the so-called apparent mean

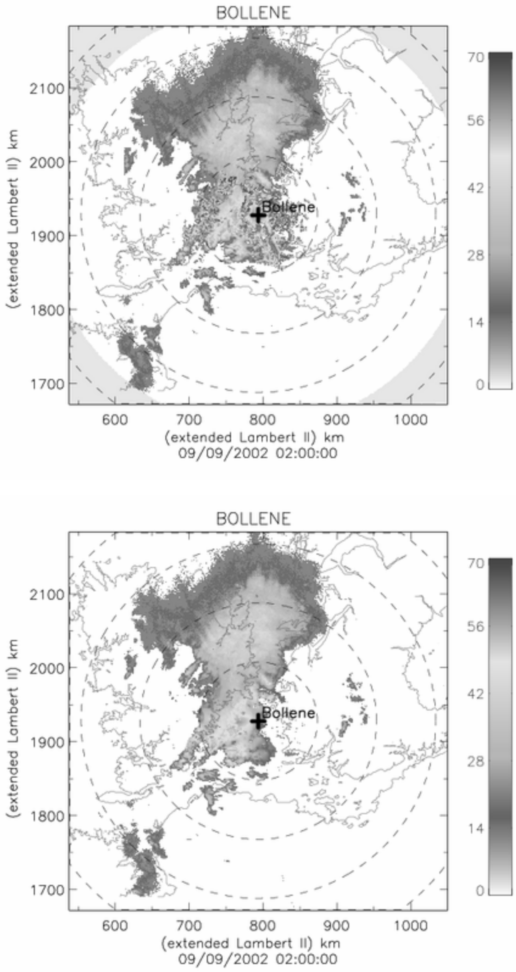

Fig. 1. Radar reflectivity PPI corresponding to an elevation angle of 0.8° the 9 September 2002, 2h: uncorrected data (top) and corrected data thanks to the adaptative ground clutter identification and interpolation (bottom).

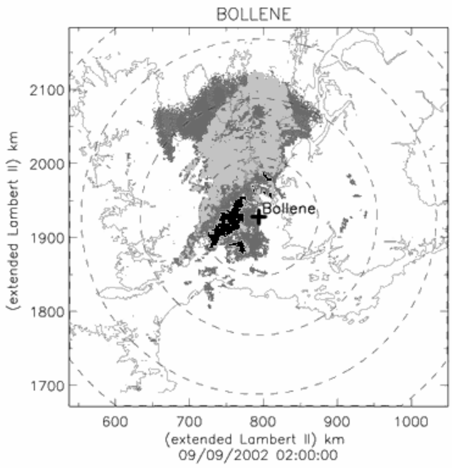

Fig. 2. Rain type separation for the same date as in Fig. 1. The black color represents pixels which have been identified as convective pixels. The light grey corresponds to identified stratiform pixels and the dark gray represents undetermined rain type.

VPR, that is the VPR estimated by averaging measured reflectivity profiles. This apparent mean VPR needs to be established at close range to the radar site in order to minimize the impact of the radar sampling effects that tend to smooth the actual VPR shape (Andrieu and Creutin 1995). The mean VPR was calculated by averaging the reflectivity values in mm^6m^{-3} for each altitude class and converting it back to dBZ (see Fig. 3).

3.4 QPE from the 3D reflectivity data

As German and Joss (2000), we propose to estimate the reflectivity at ground level as a weighted average of the corrected reflectivities observed over the vertical. The weight formulation is original since it depends on the correction factors for screening and/or VPR effects. Such formulation naturally privileges elevation angles presenting the best visibility at any location of the radar detection domain.

The NEXRAD Z-R relationships (that is for convection and for other rain types) were applied for converting the reflectivity close to the ground into a rain-rate estimate. The application may depend on the rain type separation.

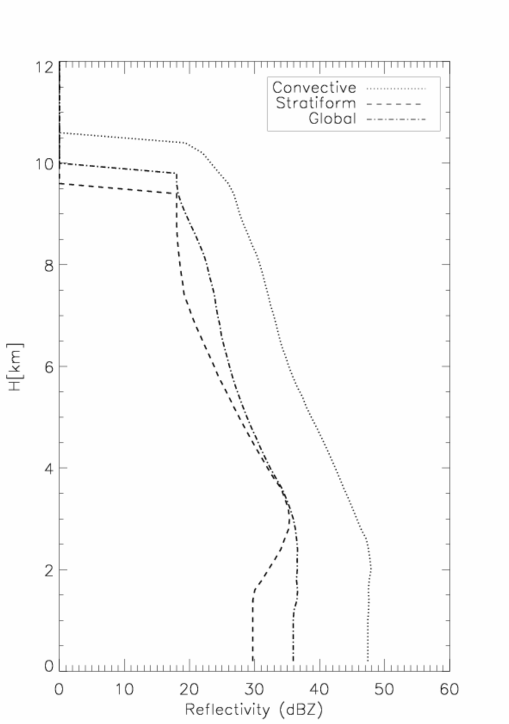

Fig. 3. VPR corresponding to global, convective and stratiform rain type for the same date as in Fig. 1.

4 Processing strategies for radar QPE

Several radar data processing strategies have been implemented in order to assess the eventual benefit of the innovative algorithms described before. A first group is related to "static" strategies (STAT1 and STAT2) since it makes only use of correction products determined prior the rain event of interest. This offers some guarantees in terms of robustness, a critical point for operational implementation. There is no PVR correction implemented in STAT1 whereas a climatological PVR is applied for STAT2. A second group, termed as "dynamical" strategies (DYN1, DYN2, DYN3), relies on the adaptative identification and correction procedures mentioned before which are hoped to significantly improve the quality of the rainfall estimates over the static strategies. For these strategies, the coupled rain type separation and VPR identification may be active (DYN2 and DYN3); two Z-R relationships may be applied according to the rain type (DYN3). As a basic approach, the processing strategy operational in 2002 (OPER) is also implemented to evaluate the relative improvement brought by the concurrent approaches. The considered strategies are summarized in Table 1.

Table 1. Processing strategies

Strategy	Radar calibration stability and detection domain	PVR	Adaptative ground clutter identifi-cation	Rain type separation and VPR identifi-cation	Rain type seperation on Z-R
OPER	no	no	no	no	no
STAT1	**yes**	no	no	no	no
STAT2	**yes**	**clim.**	no	no	no
DYN1	**yes**	**ident.**	**yes**	no	no
DYN2	**yes**	**ident.**	**yes**	**yes**	no
DYN3	**yes**	**ident.**	**yes**	**yes**	**yes**

5 Results and discussion

The processing strategies have been evaluated with rain gauge data which were not used at any level of the radar data processing. The establishment of reference rain is presented by Kirstetter et al. (2006, these proceedings). The coefficient of determination and the Nash coefficient were chosen as criteria at the hourly and event time steps and for several radar ranges. Scores have been computed for the whole of the five events and on each event.

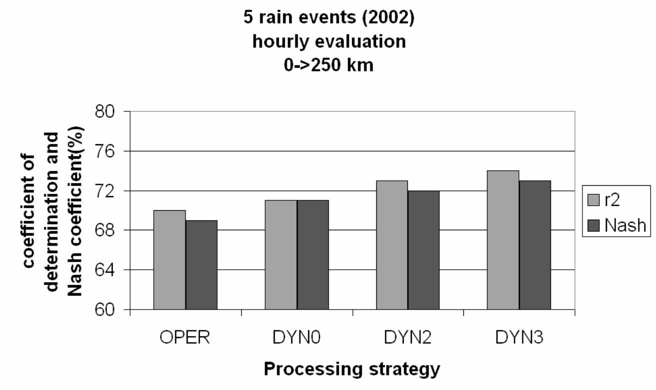

Fig. 4. Evaluation of the OPER and DYN processing strategies: Coefficient of determination and Nash criteria at the hourly time step for the whole of the five rain events.

Figure 4 presents the scores obtained for OPER and the dynamic strategies at hourly time step for the whole of the five events and for radar range between 0 and 250 km. An improvement is observed for each degree of sophistication. The Nash coefficient evolves from 69% for OPER strategy to 73% for DYN3 strategy. It shows the interest of each algorithm as the whole. Close to the radar, the results are similar with a Nash coefficient evolving from 71 to 75 %. At the event time step, the Nash coefficient evolves from 78 to 89% for radar range between 0 and 250 km and from 82 to 91% for radar range between 0 and 80 km.

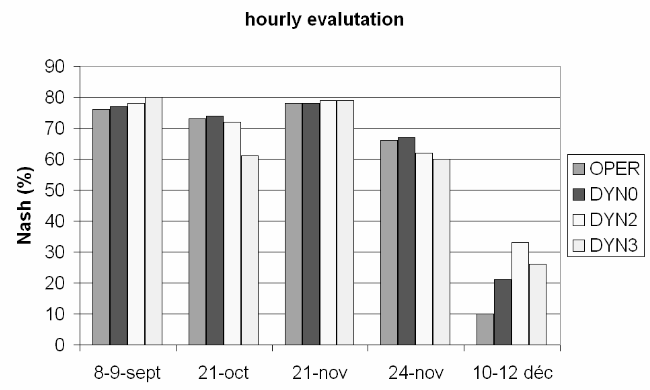

Fig. 5. Evaluation of the OPER and DYN processing strategies: Nash criteria for each of the five rain events at the hourly timestep.

Figure 5 presents the details obtained for each case study. The improvements are no more progressive according to the various strategies. The interest of the adaptative ground clutter identification is preserved but the coupled rain type separation and VPR identification clearly fails for two cases among of the five cases studied. The conditions of success have to be examined in detail. Horizontal extent of the precipitation system and coherence of the VPRs of a determined type may be key factors. Applying a rain type dependant Z-R relationship improves rainfall estimation only for the dramatic rain event of 8-9 September 2002. It emphasizes the potential of the DYN3 strategy but the difficulty to choose the appropriate set of Z-R relationships.

6 Future directions

The future work will try to improve the VPR identification by an adaptation of the VPR inversion method proposed initially by Andrieu and Creutin (1995), and lately developed by Vignal and Krajewski (2000), to the case of time-varying geographical support in order to filter the radar sampling effects which are becoming very significant as long as the region of interest extends far from the radar site.

It is also planned to extend the processing strategies presented in this communication for the exploitation of several radar systems.

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