14R.6 THE PANTHERE PROJECT AND THE EVOLUTION OF THE FRENCH OPERATIONNAL RADAR NETWORK AND PRODUCTS : RAIN-ESTIMATION, DOPPLER WINDS, AND DUAL-POLARISATION

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1. INTRODUCTION

The French meteorological radar network was originally designed, around 1990, for rain detection purposes. France was covered by 13 radars operating in a very simple way : a relatively low rotating speed of the antenna of 5°/s , an elevation angle lower than 2° with a maximum of three rounds every 5'. These radars were neither Doppler nor dual-polarized.
After 1995, It became more and more evident that radar quantitative rain measurement could be used to prevent flooding effects and a first attempt was the HYDRAM project (Cheze and Helloco, 1999) which produced a quantitative precipitation estimate (QPE), and this product is still operational.

But this product suffers from well known problems : vertical profile effects (VPR), ground clutter, anaprop, shielding effects, and the relationship between reflectivity and rain rate (ZR relation). The PANTHERE Project (Projet Aramis Nouvelles Technologies en Hydrométéorologie Extension et Renouvellement), launched in 2002, is a joint effort between Météo-France and the French Ministry of Environment, to find solutions to some of these problems (Parent et al., 2003). The primary objectives are : (i) to fill the radar coverage gaps by adding 6 new radars to the network, (ii) to replace 2 of the oldest radars, and (iii) to evaluate the potential of modern technologies (volumetric observation, Doppler, dual-polarization) in improving rainfall estimates.
To avoid mistakes, the project was carried out with the help of research people through specific collaborations and through a scientific committee.
In this paper, we describe the project progress in terms of : operational installations, new operational products, and research work.

2. THE OPERATIONNAL INSTALLATIONS

Before choosing the manufacturer, an external group composed of users and researchers has been assembled to define the needs and specifics. After a call for tender, the manufacturer Gematronik was chosen. The main characteristics of these radars are the following :

- C band
- 1° beam-width at 3 dB
- 250 kW peak power
- 1 to 2 µsec pulse duration
- numerical receiver which delivers I and Q to the Météo-France CASTOR2 computer
- H and V signals simultaneously transmitted and received (only the first unit is equipped with dual polarization)

The new radar locations are shown in Fig. 1 (surrounded by thick circles). Three are already installed : Trappes, North, and Aveyron (middle South). Following the schedule, all the installations will be completed by the end of 2006.

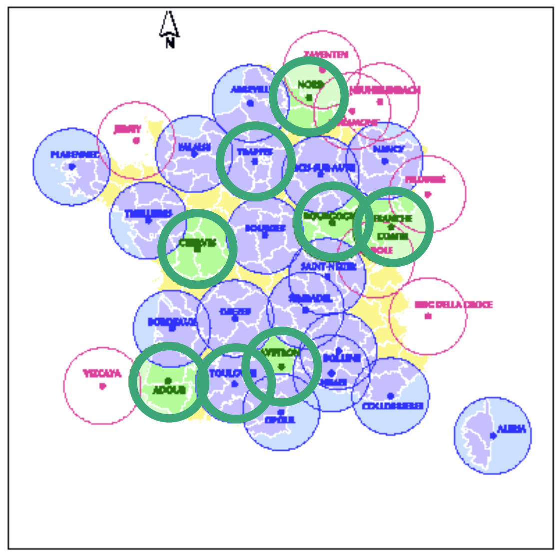

FIGURE 1. The French radar network in 2006. Each circle, 100 km radius, is centered around the position of a radar. The thick circles show the position of the 8 new PANTHERE radars.

3. DOPPLER

Measurement of radial velocity by Doppler suffers from severe ambiguitiy problems. As an example, the unambiguous interval is limited to +- 5 m/s for the prf of 300 s^{-1} used in the French network. Moreover, the operational needs for Doppler measurements were until now not so obvious for mid - latitude meteorology. For these reasons the interest for Doppler in the French operational meteorology was limited. This situation is changing now with the new generation numerical meteorological models which are able to assimilate data with very good space and time resolutions. The new French model AROME, which will be operational in 2008, will assimilate radar reflectivity and radial velocity (Caumont et al, 2005). So we

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decided to work on "dual prt techniques" (see for example Joe et al., 2003) to remove the Doppler ambiguities. We defined a mode with two pulse periods T1 and T2 alternately changed from pulse to pulse (T1=3.3 msec and T2=2.7 msec). This mode has been extensively tested with the Trappes radar and the conclusion (Tabary et al, 2004) is that good quality measurements are obtained in an interval of ±30 m/s. But a small percentage of the data are not correctly desaliased and a median filtering is necessary to avoid them.

Considering that ±30 m/s interval is not fully satisfactory for an operational application, we then investigated more complicated interlaced pulse schemes and finally chose a triple-PRT scheme (Tabary et al, 2005) leading to unambiguous measurement interval up to ±60 m/s (see example in figure 2).

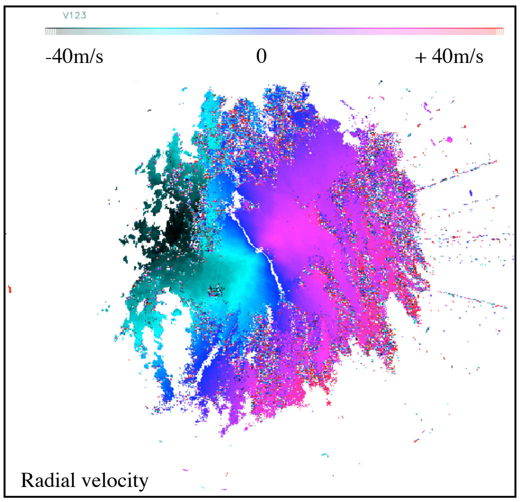

FIGURE 2. Example of radial velocity PPI map obtained with the Trappes radar using the triple PRT scheme.

In addition to these scientific evolutions, operational algorithms have been developed on the French radar computer CASTOR2 to implement the triple PRT scheme, and a hardware modification kit has been created to transform the 18 non-Panthere radars into Doppler radars. At the end of 2008, we will have a complete network of 24 Doppler radars, including the 6 new Panthere radars, and all these data will be assimilated by the new AROME numerical model.

4. VOLUMETRIC EXPLORATION FOR QUANTITATIVE PRECIPITATION ESTIMATION (QPE)

The HYDRAM quantitative precipitation estimation used at present in the operational French network uses the well known Marshall Palmer Z-R relationship (Marshall and Palmer, 1948), with a calibration method based on a radar/gage comparison on a monthly basis. A maximum of 3 elevation angles is used. Pixels with permanent ground clutter, as well as shielded pixels are eliminated, and no VPR corrections are applied. To mitigate the influence of ground clutter, the higher elevation angle is systematically used at close ranges, the lower elevation is used at large ranges, and the intermediate angle is used for intermediate ranges.

The new Panthere QPE algorithm is described in a three part paper recently submitted to Weather and Forecasting (Tabary, 2005b). A simplified flow chart is shown in Fig. 3. It still uses the Marshall Palmer Z-R relationship, but the data affected by ground clutter are dynamically detected and eliminated, and the remaining data are corrected for shielding effects and for VPR effects. During the process, a weight ω is associated to each measurement to quantify its quality : it is equal to1 for perfect data, to 0 for rejected data like ground clutter, and it decreases with the percentage of occultation by masks and with altitude above the earth. For each pixel, all the data available vertically above the pixel are averaged with their weight depending on the quality of the measurement :

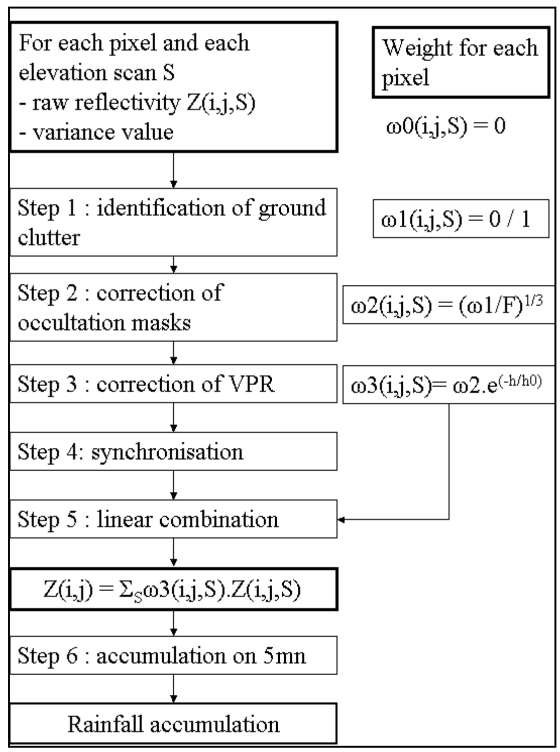

FIGURE 3. Simplified flow chart of the new Panthere quantitative precipitation estimation algorithm.

A critical part of the QPE is the VPR correction. A method has been developed and tested on a number of situations. Basically, it consists of computing the ratio between reflectivities obtained at two different elevation angles, integrated over azimuth and time. This "measured ratio versus range curve" is then compared to a number of "simulated ratio versus range curves" (one simulated curve for each candidate vertical profile). The algorithm chooses the candidate profile which gives rise to the "simulated ratio versus range curve" closest to the measured one.

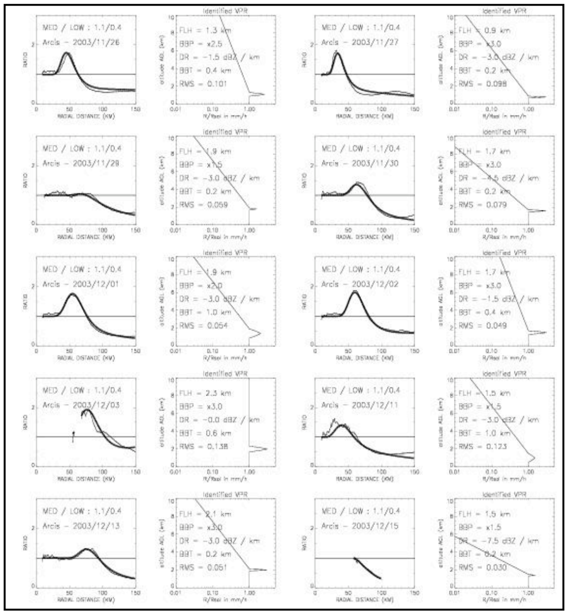

FIGURE 4. Example of VPR detection for the Arcis Sur Aube radar. The results for 10 raining days are presented here, with the "measured and simulated ratio versus range curves", from 0 to 150 km (left), associated with the corresponding VPR profiles (right, from 0 to 10 km in altitude). The agreement between simulated and measured curves is excellent, with a correlation coefficient greater than 0.96.

The Panthere QPE algorithm has been used in real time on 7 radars in the South of France, and an extensive comparison has been made with gages (Lamarque et al., 2004; Tabary, 2005b). The conclusion was that the new QPE is much better and particularly useful to mitigate bright band effects. It also gives much better results far from the radar, leading to an increase of the maximum range for hydrological measurements.

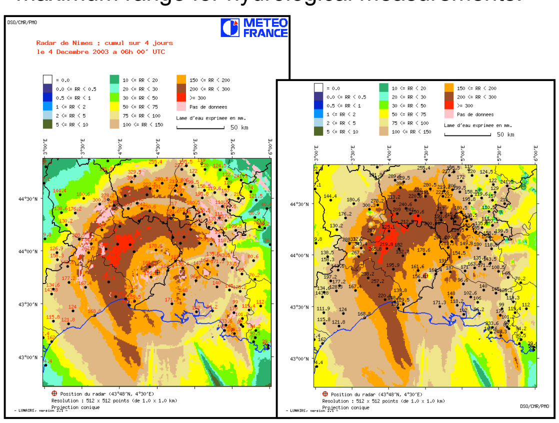

FIGURE 5. Example of Panthere QPE accumulation over 3 days (right) compared with Hydram (left), on 1, 2, 3 Dec. 2003, Bollene radar. The new product has a better spatial pattern, and a systematic comparison reveals better agreement with gages.

5. DUAL POLARIZATION

The advantages of dual polarization technique for rainfall measurements and for hydrometeors classification, are now well established for S band (see for example Ryzhkov et al., 2005). The interpretations are more challenging for attenuated C and X band wavelengths, but promising work has been done to estimate the attenuation and correct for it (Testud et al., 2000). We thus expect a useful exploitation of dual polarization with these less costly wavelengths.

All the Panthere radars are C band, and the first one, equipped with dual-polarization, has been installed in Trappes in 2004. The 7 others are single-polarized, but could be transformed in the future if the operational usefulness of the technique is proven. In the frame of the Panthere project, we have carried out an evaluation experiment with the Trappes radar since the beginning of 2005. The radar functioning has been slightly adapted for the experiment by adding one turn every 15' with a 90° elevation angle to test the calibration of Zdr, and by producing ZPHI products (Testud et al., 2000) in real time. The dual-polar observables (Zh, Zdr, ρhv, Φdp) are recorded and the Panthere QPE, as well as the ZPHI QPE, are computed at the same time. A large number of rain gages (more than 100 in a 100 km radius around the radar) are also recorded for the evaluation.

In the project, we have worked in several directions :

- (i) data quality evaluation. This basic work (Gourley et al., 2005c) is to verify that the Trappes radar are comparable to others in the world. The conclusion is quite good for this radar, with an accuracy of 1.8° on Φdp and of 0.2 dB for Zdr. This study also reveals biases in Zdr and ρhv which can be corrected. An unexpected behaviour of Zdr and Φdp with azimuth, due to the rotary joint or to structures near the radome, has been shown and must also be corrected to get good quality results.
- (ii) attenuation estimation. A semi-empirical attenuation original scheme has been developed (Gourley et al., 2005a). Basically, it consists in finding a relation between the attenuation (of Zh and Zdr) and Φdp. After application, the Zh correction is validated by comparison with the neighbouring non-attenuated radars. The method is simple and robust. It gave good results in most cases and it is a candidate for an operational application.
- (iii) calibration estimation. Absolute calibration of Zh is still a major problem for QPE and is one of the important challenges for dual polarization. The original method developed by Gourley and Illingworth (2005) on the Trappes data uses the redundancy of Zh, Zdr and Kdp to obtain an absolute calibration of Zh. As shown by Gourley and Illingworth, a critical point is to be sure that Zdr and Φdp are well calibrated and corrected for azimuthal variations. Apart from these small restrictions,

the method seems to be a very good candidate for an operational application.

- (iv) hydrometeor classification. Ground clutter, permanent or anaprop, is quite easy to detect with its Doppler or time variability signature. Other non-rain echoes are more difficult to separate from the rain (clear air, sea echoes, chaff, ..), and dual-polar technique is a hope to detect them. Gourley et al. (2005b) develops a fuzzy logic algorithm to separate precipitating and non-precipitating echoes. Initial results show successful segregation between hydrometeors and non meteors.
- (v) QPE estimation. Our general objective is to evaluate the improvement of polarimetry for rainfall estimation. Improvements are expected to correct several errors sources (attenuation by rain, shielding effects, drop-size effects, ..). The method, called "conditioning evaluation" (Szalinska et al., 2005), consists of separating the data set into several subsets, each of them concerned with only one error source. A comparison of radar data of a specific subset with ground truth (gages) would give an evaluation of the dual-polar technique to correct for the corresponding error.

We have compared the ZPHI polarimetric algorithm with a traditional Zh-based one, limiting our investigation to two error sources : (i) Attenuation by rain : up to 39 one-hour events with an averaged attenuation greater than 3 dB have been selected and examined. The normalized bias goes from –0.4 to 0.1 and the conclusion is clearly that the ZPHI attenuation correction algorithm is efficient in correcting for attenuation by rain. (ii) Drop size effects. This effect is quantified by N0*, a normalized parameter defined by ZPHI (Testud et al., 2000). Three subsets have been examined : 110 one-hour events for log(N0*)<6.2 m^{-4} (stratiform weak rain); 222 one-hour events for log(N0*) around 6.3 m^{-4}, and 240 one-hour events for log(N0*)>6.4 m^{-4} (convective rain). The comparison with gages favours dual-polar processing (in this case the ZPHI algorithm), with a lower normalized bias (from 0.3 to 0.1 for log(N0*) around 6.3), and a better correlation coefficient (from 0.7 to 0.9 for log(N0*)>6.4).

4. CONCLUSIONS

Since the beginning of The PANTHERE project, a lot of work has been done and we can conclude that :

(i) until now, the operational installations are on schedule, and it is reasonable to expect that all the Panthere radars will be in place by the end of 2008.

(ii) concerning Doppler measurements, a new method has been defined and tested. All our new operational radars are equipped with it and it will be progressively implemented on all the old radars. We expect that all the network will provide radial velocities to the future operational meteorological forecast model AROME for assimilation by the end of 2008.

(iii) A new Panthere rainfall estimate has been developed and tested. This rainfall estimate applies corrections for shielding and VPR effects, and all the data are provided to users with a quality factor. It will be implemented on all the network at the end of 2005.

(iv) Concerning dual-polarization technique, a large amount of work has been done : its usefulness to calibrate the radar, to correct for attenuation, and to separate hydrometeors and non-hydrometeors echoes has been shown. The improvement for rain estimation in attenuated areas is obvious and the improvement for errors due to DSD variability is clear, but must still be confirmed on a few more examples.

5. FUTURE WORK

Our established knowledge of dual polarization must now be applied for an operational use on the Trappes radar through a new version of the radar computer CASTOR2.

The ZPHI rainfall estimate is now being examined but other methods must also be explored. A question must particularly be addressed for an operational use : is it better to use a "profiling algorithm" like ZPHI, or to use a "local algorithm", like those based on Kdp.

The classification method, defined for hydrometeor and non-hydrometeor separation, must be extended to classify the precipitation types.

6. ACKNOWLEDGEMENTS

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