

Quantitative precipitation estimations using rain gauges and radar networks: inventory and prospects at Meteo-France

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Abstract :

This article presents the different networks operated by Meteo France to measure rainfall rates and accumulation. It also describes the different quantitative precipitation estimation (QPE) that are deduced both from real time data and from data concentrated at a lower frequency. Special emphasis is put on the description of the data quality. In the future, the rain gauge network will be re-organized taking advantage of a stronger cooperation with other existing network owners, keeping in mind the needs of all users from forecasters to climatologists. The radar network has been improved over the past years with more radars being deployed, new technologies and algorithms. A new radar QPE is elaborated dealing with most of the radar measurement limitations. Dual polarization, which is considered as the new standard for operational radars, is beginning to be introduced operationally to eliminate the main artefacts, to correct attenuation and to assess the type of hydrometeors; furthermore, some X-band radars will soon be installed in mountain regions. A new kind of QPE, ANTILOPE, take advantage of the merging of rain gauges and radar data. Hydrological models will soon benefit from the so-called QPE Reanalysis Project in order to provide the best possible hourly high resolution QPE over the 1997-2006 time period.

1. Introduction

Accurate rainfall estimates are crucial for numerous applications in hydrology, nowcasting, and mesoscale model validation. Ground-based operational weather radar networks are currently considered the only instruments capable of providing the requested high resolution (1 km²) and frequent (5 min) precipitation fields over mesoscale or even synoptic areas. The density of automated rain gauge networks is in general too scarce, especially in complex terrain, to yield the same space-time coverage of precipitation systems. On the other hand, rainfall estimation from satellite-borne instruments (radiometers or radars) is still an open field of research and does not fulfill the abovementioned users' needs. The forthcoming Global Precipitation Mission will probably open new perspectives.

Meteo-France, as part of its mission, operates different types of networks: A real-time and manual rain gauges network and a operational radar network (ARAMIS). The objectives are to develop the best possible QPE using radar information, rain gauges values or merging the both informations according to the spatial or temporal desired resolution .

The prospects in dual polarisation for the short term (2-3 years) seem particularly promising for the hydrological topic.

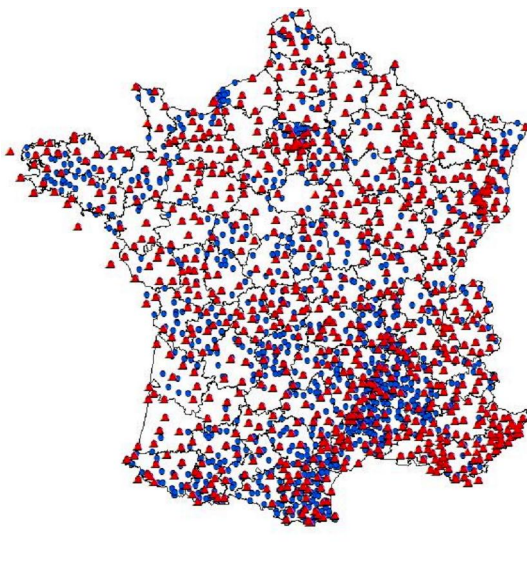
2. Rain gauges networks and associated data

2.a. Rain gauges networks

Meteo-France has several types of rainfall measurement networks that can be classified according to the mode of data concentration : the 'real time' network, addressing the needs of the forecast and the manual network, dedicated to climate studies and detailed post-event analysis. The climate database of Meteo-France contains all the data measured by these networks, the quality codes established at different stages of validation and metadata to quantify their representativeness.

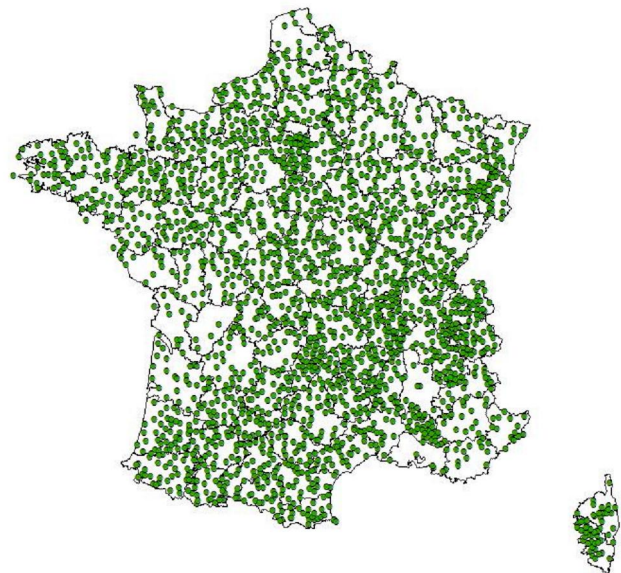
The realtime network consists of about 900 automatic stations available at $H + 10$ minutes; in addition, 900 real-time stations are concentrated between 1 hour and 3 hours (Fig. 1).

Meteo-France has also a Climate Observing Network, composed of approximately 2500 manual rainfall or rain-thermometer stations, operated run by "volunteers", for which data are available monthly (Fig.2). This network meets the needs of studies and climate modelling.



Available stations at $H+10$ mn
Partner stations

Fig.1 : Real time network



Manual stations available at the end of the month

Fig.2 : Manual network

2.b. The metadata

Thorough knowledge of the metadata of a rain gauge position (location, parameters measured,...) and control of their past evolution are essential for the correct use of data. New requirements in terms of knowledge on the environment of measurement sites and the performance of maintenance have been defined by Meteo-France in recent years and shared with other network operators.

The environment of a measurement site can generate measurement errors greater than the instrumental errors, so WMO and Meteo-France [2] described the advocated rules for the environment of sensors: five classes were defined at Meteo-France. For precipitation measurements, it is required a minimum clearance of four times the height of surrounding obstacles; a class 1 site is

considered as perfect (WMO recommendation); class 2 corresponds to a measurement error of about 5%, the error in class 3 is between 10 and 20% and, in class 4, the error varies between 20 and 50%.

From the specifications recommended by WMO [3], Meteo-France has developed a "performance classification" to quantify the intrinsic performance of measuring instruments as well as the means of maintenance and calibration implemented to keep it: 5 classes (A to E) were defined by Meteo-France. For precipitation, the class A corresponds to a measurement uncertainty of ± 0.1 mm for amounts less than 5 mm and $\pm 2\%$ above the 5 mm while the uncertainty of class B is $\pm 5\%$ with a semi-annual calibration; for class C, we move to an uncertainty of $\pm 10\%$ and a calibration every 18 months.

2.c. Control of data

The control and qualification of data can significantly contribute to the enhancement of rainfall information. Meteo-France provides these treatments in two phases:

*** 'real time' controls**

They are designed to detect hardware failures (station, transmission), the main measurement shortcomings (obstructed rain gauge, problems with solid precipitation,...) or spatial or temporal inconsistencies in the data. Supervision by regional experts can ensure the quality of products derived from these data.

*** monthly controls**

These controls are made using climatological network data, 15 days after the end of the due month, with the objective of setting up data bases for climate studies. They consist of a systematic validation of all data (daily and hourly) by the local climatologist, using automatic controls in space and time, and gradually integrating intercomparison methods with all information sources including remote sensing data (radar, satellite).

2.d. The EURO4M project

In the framework of the EURO4M project (FP 7), the DCLIM department of Meteo-France intends to provide the following contribution:

- Development and test of methods to control the rain gauges recorded rainfall using the radar data.
- Provide to other EURO4M members series of observational data with a fine network density resolution and a mastered quality.

As regard to data control system, exchanges that intend to cooperate them already exist between the different European climate services. Many countries have a control system whose general structure into 4 modules is quite similar to that proposed by the project NORDKLIM with: first lowest level controls in almost real time (range, temporal controls and of inter-parameter coherence), then spatial controls in a subsequent step with a system based on the automatic detection of suspicious values and on human expertise, and finally other time-deferred controls (slow drift of sensors, homogenization).

Meteo-France DCLIM is engaged in improving its quality system and a preliminary step was the analysis of defects that could compromise the quality of data by parameter or sensor type and in a historical perspective. Under the project EURO4M, Meteo-France DCLIM develops methods for monitoring precipitation using the radar data. In order to fulfil this task, the potential use of various radar products for control purpose was analysed while checking also to what extent those products

are independent of these controlled rainfall data. The performance of the estimation of rainfall by radar has been evaluated in different situations to have an appropriate monitoring interval.

Additional information, which may come from models, have been tested to discriminate between situations and to refine the control interval (temperatures to discriminate between solid and liquid precipitation, atmospheric vertical instability index). The radar information was also used by itself to discriminate convective and non-convective situations.

A re-analysis efforts is in progress at Meteo-France; while finished it will allow to have series as homogeneous as possible for the period 1996 to present time. Control methods developed should be applicable over that period.

To test the methods a specific database, exempt from control, was carried out. The tested control methods has been compared with the operational system of control and to human expertise.

3. The French radar network and radar QPE [1]

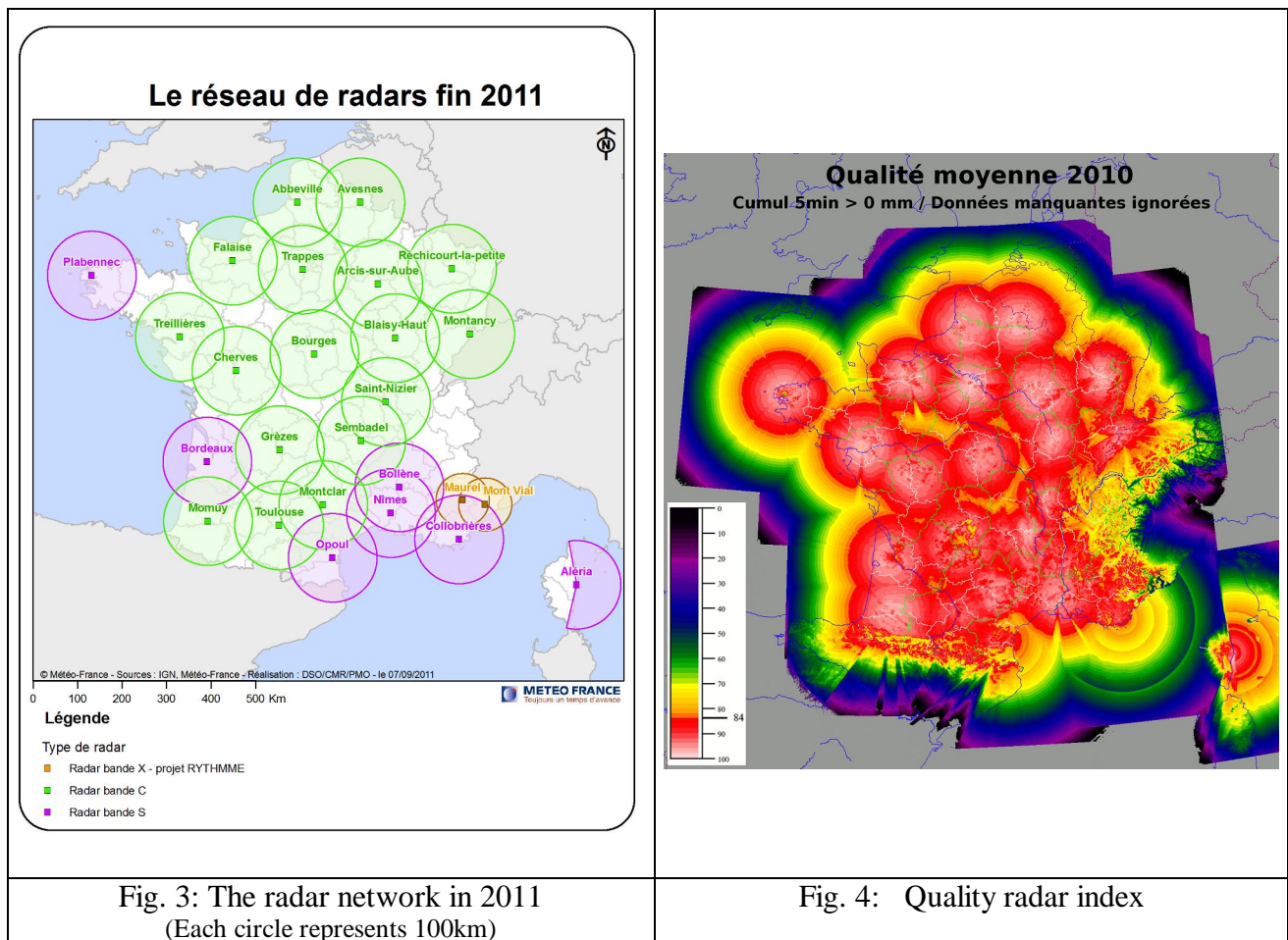
3.a. The French radar network

In 2002, at Meteo-France, there were 18 radar ARAMIS network. The project PANTHERE (Project Aramis New Technologies in Hydrometeorology Extensions and REnewals) has increased this number to 24 in 2007 (Fig 3). In 2010, the "hydrological" coverage, which can be assessed through a good quality index (Fig. 4), is satisfactory for about 80% of the metropolitan area; mountainous zones and some residual areas are still poorly covered.

The project "RHYTMME", led by Meteo-France in cooperation with the CEMAGREF, is to build a services platform that will improve hydrological risks management in the PACA region (specifically in the Southern Alps). The project will run from 2008 to 2013 and includes in particular a section "Observation" radarö which provides the implementation of 4 X-band radars.

The effort to renew radar will continue as well as the addition of X-band radars to fill areas with poor visibility. The objective of the new program "PUMA" is to renew 8 old radars and deploy 4 X-band radar over the period 2012-2016.

In parallel, new technologies such as volumic scan strategies, Doppler and polarization diversity were introduced into the radar network.



3.b. Radar QPE

While radars were recognized early on as key tools for monitoring the structure and evolution of precipitating systems, the correct understanding and assessment of the various error sources are a crucial point.

Errors affecting the measurements of rainfall by radars can be grouped into three categories:

- errors related to the radar system itself (radar hardware calibration, errors in the azimuth and elevation angles),
- errors related to the interaction between the radar wave and the environment (ground clutter or biological targets, clear-air echoes, partial beam blocking, partial beamfilling, attenuation by rain, filtering along the vertical due to beam broadening with range),
- errors occurring when converting instantaneous radar reflectivity plan position indicators (PPIs) into surface rainfall accumulations [nonuniform vertical profile of reflectivity (VPR), wave propagation fluctuations, precipitation type, Z₀R relationship, precipitation drift, advection of rain patterns].

An overview of the new radar rainfall algorithm is given in Fig. 5. The processing chain is made of seven successive modules: ground-clutter identification (GC), reflectivity-to-rain-rate conversion (ZR), partial beamblocking correction (MSK), VPR correction (VPR) [5], correction for advection (ADV), weighed linear combination (WLC), and 5-min rainfall accumulation (ACC).

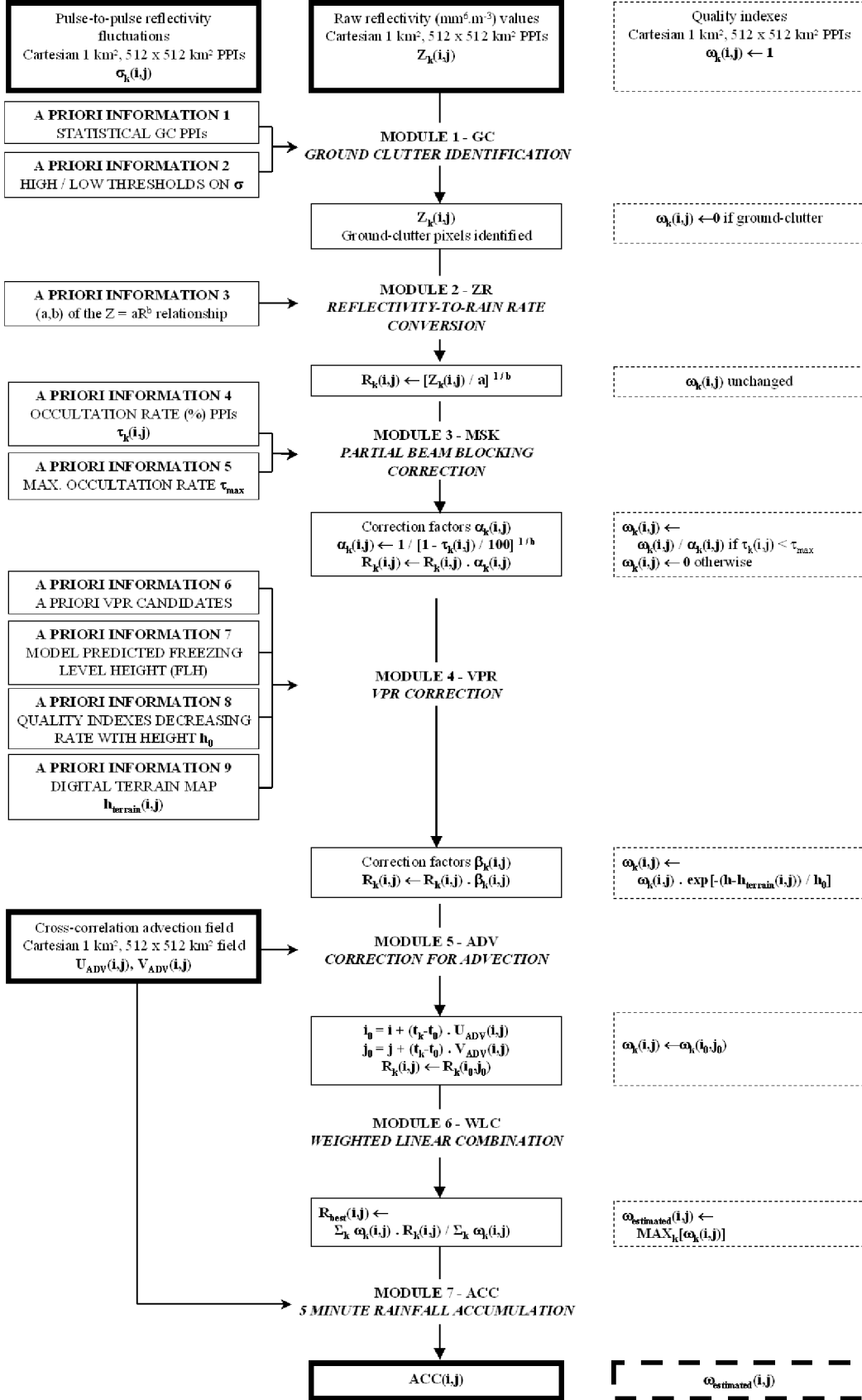


Fig. 5: Radar rainfall algorithm (from [4])

The weighing factors that are applied are the quality index PPIs. The quality of the 5-min rainfall accumulation maps can be documented by aggregating the set of quality index PPIs (Fig. 4). These quality codes are dynamic and vary from 0 to 100 (0 = very poor and 100 = excellent). Currently, these codes depend on the measurement altitude and rate of masks and can be qualitatively related to the precision of the measurement. Objective analysis have shown that these codes have a good relationship with radar rainfall scores.

A mosaic QPE over France is then calculated using the individual radar QPE (Fig. 6 and 7). The "compositing" is obtained at any point of the mosaic by weighted linear combination of the various individual radar QPE, the weights being precisely the quality codes as introduced above. The mosaic is also accompanied by a map code quality (Fig. 6).

A real-time verification of the QPE is made by using a symbolism that reflects the value of the ratio radar / rain gauge (Fig. 7).

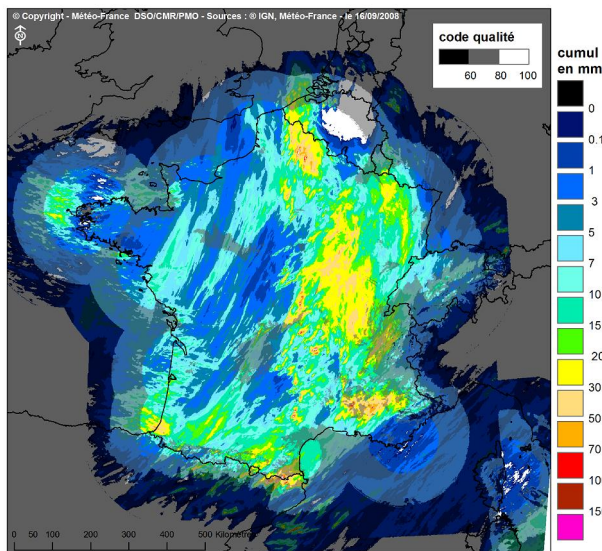


Figure 6 : Radar QPE mosaic with the quality code in transparency

(24H rainfall accumulation from
11/09/2008/06h00UTC to
12/09/2008/06H00UTC)

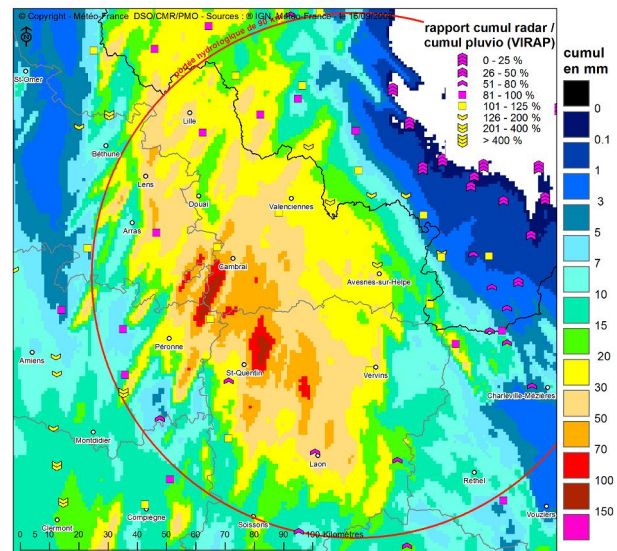


Figure 7 : 24H individual radar QPE (Avesnes radar)

Same dates than figure 6

Arrows and squares indicate the under-estimate (in red) or over-estimate (in yellow) of the QPE radar versus the rain gauges

3.c. Calibration of the radar QPE by the rain gauges

The difference between radar QPE and rain gauges values (even if rain gauges are not the ground truth) can be temporarily important, due to electronic drift or to physical reasons (change in the Z / R law for instance). In conventional radar, it is frequent to make an adjustment of radar QPE using rain gauges. At Meteo-France, this adjustment was implemented in real time with hourly rain gauges data. The basic principle is to multiply the radar QPE by a rain gauges-radar ratio applied each hour. At the end of each hour (H+120), a global adjustment factor is computed based upon the comparison of past (H, H-1, H-2, ...) radar hourly estimates with co-located rain gauges. The adjustment factor is computed using radar and rain gauges in "good visibility" areas (~ up to 80 km range distance from the radar in flat terrain).

This adjustment is working well, specially in case of heavy rain.

3.d. Evolution of radar/rain gauges values scores during several years

The monitoring of the radar QPE/Rain gauges measurements ratio for several years gives a good idea of the evolution of the improvements of the radar QPE and informs also on the areas where the radar under or over-estimates. The calculation of these scores is done by moving a box of 30 by 30km calculating, for each pixel, inside this moving box, the statistical distribution of radar/rain gauges ratio. The figure 8 shows the constant improvement of the quality of the QPE radar from 2007 to 2010.

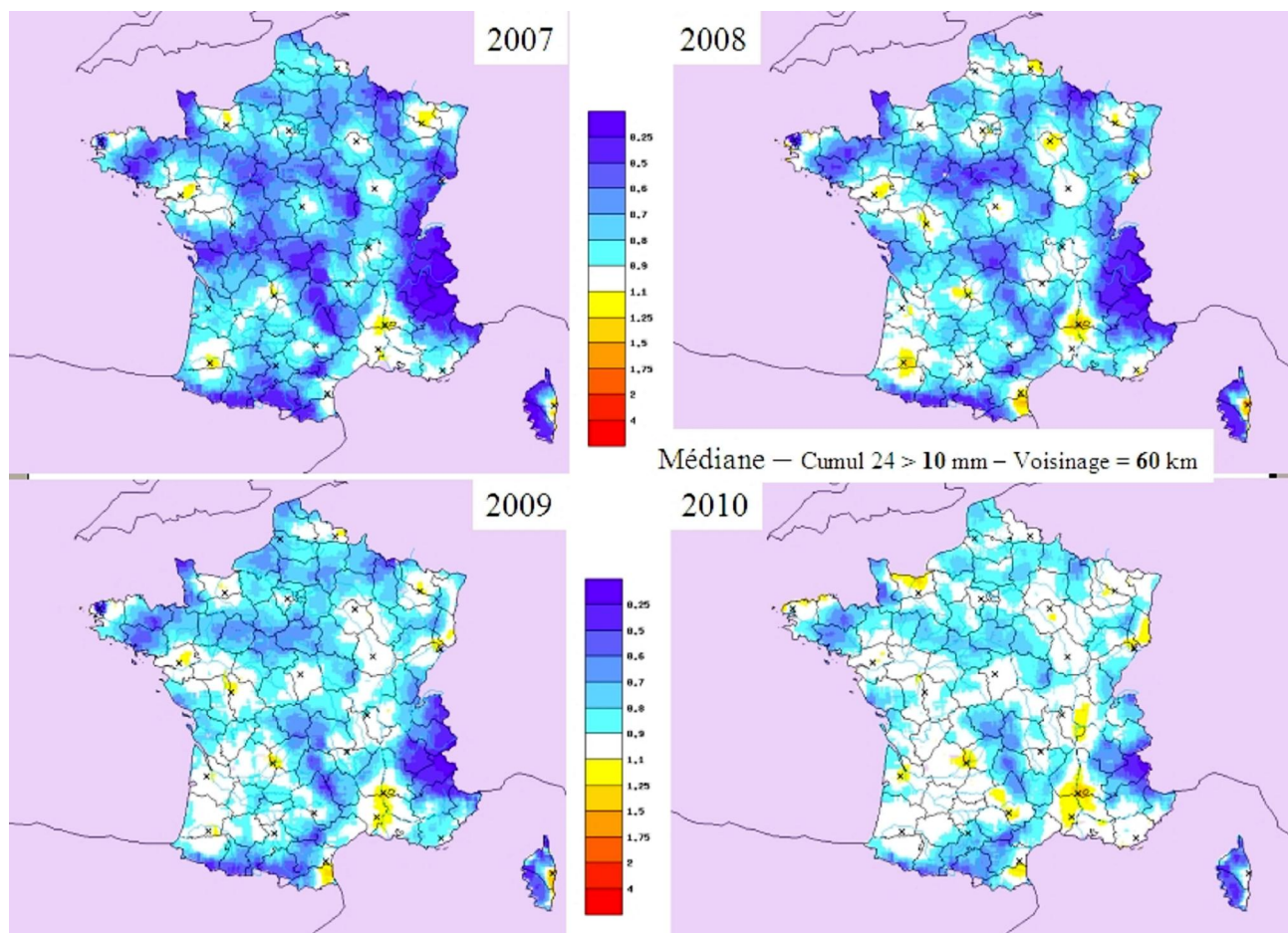


Fig. 8: The Q50 quantile of the radar/rain gauges ratio

4. Data fusion

The goal of data fusion is to integrate informations from multiple sources in order to provide a more precise estimation. Most commonly used data sources to estimate precipitations are raingauges and weather radars. The raingauge measurement is the simplest and - despite its uncertainty - the more accurate mean of estimation, but it is only representative of a very limited area around the gauge; In order to get an estimation all over a particular domain, it is necessary to use spatialization methods. At the opposite, radar gives a spatial information, but the radar QPE is not as accurate as a raingauge measurement which remains the ground reference.

ANTILOPE is a French data fusion product merging radar and raingauges data whose goal was to provide a rainfall analysis all over France on an hourly basis and available at H + 20mn. It delivers

a rainfall estimation with a spatial resolution of 1 km, about 20 mn after the considered hour and runs in an operational way since the beginning of July, 2006.

The chosen method is based upon the scale-separation principle and aims at taking advantage of those two complementary sources of data. As spatialization methods naturally give better results with large scale phenomena, precipitations field is first divided into its small and large scale parts. The large scale part (corresponding to stratiform rainfalls) is then estimated by spatializing raingauge measurements. The small scale part (corresponding to convective rains), which may not be well captured by the raingauge network is assessed through a technique of convective cells detection in radar images.

* Small-scale precipitation

We assumed that during 5 minutes, precipitation is either convective or stratiform : a detected cell does not contain any large scale part and can be considered as a convective cell. Associated precipitation is summed over the 12 images to give the small scale precipitation estimate for the considered hour. To deal with radar underestimations or overestimations, especially during convective events, a spatialization of the convective residuals has been added to improve the small scale estimate of precipitation:

- Inverse distance interpolation is used to spatialize the convective residuals (difference between the small scale parts of raingauge and radar measurements)
- This spatialized residual field is added to the small scale estimation of precipitation, only at locations where convective cells have been previously detected (to preserve radar spatial information)

* Large scale precipitation

The rain gauges used to calculate all those available in the database of Météo-France in real time (see section II.1); this represents about 900 rain gauges used by ANTILOPE.

Ordinary Kriging is used to spatialize stratiform (large scale) values. Prior to spatializing, coherency controls of raingauges values is done:

- One comparison with radar data;
- One comparison with other raingauges in the neighbourhood

Only values passing the coherency controls are spatialized by kriging. The final result is simply the sum of two contributions: the use of two data sources allows to get a better rate of available good information (Fig. 9). For example, if radar data are missing, we will have value as the large-scale component given by the raingauges.

In order to improve the quality of the stored QPE, a recalculation of the different hourly QPE of the day is done the day after, with a greater amount of rain gauges (about 1700). A development of a fusion QPE at 15mn temporal resolution is planned for the coming years.

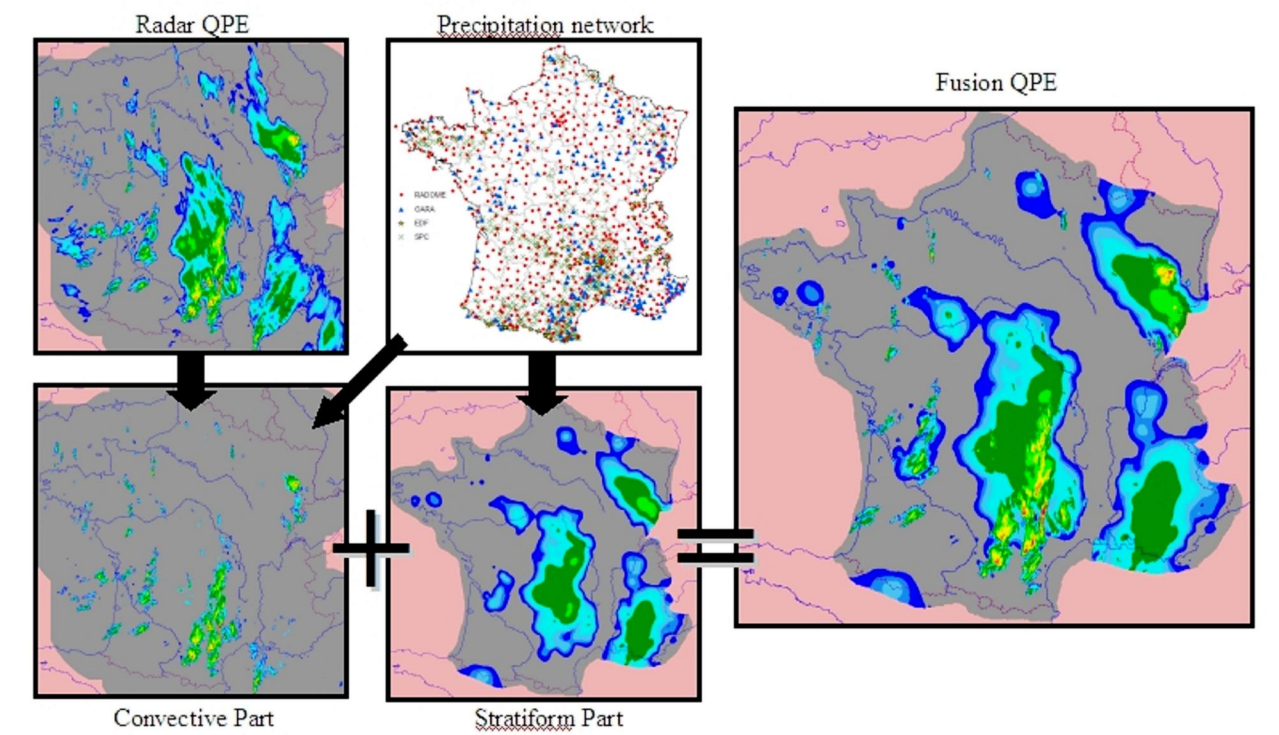


Fig. 9: Fusion methodology

5. QPE reanalysis:

Radar and merging data QPE has improved considerably step by step and these products are now widely used in the field of hydro-meteorological forecasting, particularly for monitoring the risk of flooding. However, their use for hydrological modelling applications is often hampered by the lack of high-resolution assessed and homogeneous archive.

In order to provide a common reference for hydrologists (e.g. for calibrating model parameters, assessing the value-added of inputting high space-time resolution data in hydrological models, etc), Meteo-France is currently running a national collaborative project aiming at producing a high-resolution (1 km²), 10-year reference database (1997 ó 2006) of hourly Quantitative Precipitation Estimations (QPE) covering the entire French metropolitan territory with no spatial nor temporal gaps. The input data that are used are the individual 50512x512 km² pseudo-CAPPI radar reflectivity images of the French radar network and quality-controlled hourly and daily (from 6 UTC to 6 UTC) rain gauges. A number of simple and robust algorithms have been specified, developed and verified to pre-process the radar data, which suffer from ground clutter, partial beam blocking, calibration biases, clear-air, etc.

Once pre-processed, radar data are combined with daily rain gauges and structured as a composite to yield the best 24h precipitation accumulation using kriging with external drift.

A downscaling approach is used subsequently to provide hourly rainfall accumulation maps as well as a measure of the uncertainty at the same space-time resolution (1h and 1 km²). Several validation exercises have been performed to validate the various steps of the processing chain. In particular, the final product ó 1 km² composite hourly accumulation maps - has been evaluated with independent rain gauge data over one year in southeast France.

6. Conclusion

Development projects of precipitation observation systems are particularly challenging for the coming years. For ground networks, the focus is on the systematic implementation of a strict policy of quality of observations and to pool the different partner networks. The controls will be strengthened by data intercomparison with all available information sources (rain gauges, radar, satellite).

The steps of progress are still large for the radar QPE algorithms in conventional technology: convective-stratiform separation, new Z/R laws tests, VPR and masks coupling, more local adjustment by the rain gauges.

Techniques of data fusion using the fullness of the available information available seems an inescapable way of progress. To adjust radar QPE, to validate radar QPE, to develop the fusion products, it is necessary to scale up correctly the rain gauges network (number, spatial distribution).

End users main request is that efforts should be focused on quantifying the estimation error.

Furthermore, in the next years, the radar QPE will benefit from technological advances (polarization diversity).

The development of robust QPE archive will establish the foundations for high spatial and temporal resolution hydrological modelling.

The value of satellite information will complete the prospects for further improvement and innovation.

REFERENCES

- [1] Champeaux J-L, Pascale Dupuy, Olivier Laurantin, Isabelle Soulan, Pierre Tabary et Jean-Michel Soubeyroux, 2009, Les mesures de précipitations et l'estimation des lames d'eau à Météo-France : état de l'art et perspectives, La Houille Blanche, N°5, p 28.
- [2] Leroy M., 2000. Estimation de l'incertitude de mesure des précipitations. *Note interne Meteo-France/ DSO*, 42.
- [3] Organisation Météorologique Mondiale - Guide des instruments et méthodes d'observation, sixième édition (OMM N°8)
- [4] Tabary, P., 2007 : The new French radar rainfall product. Part I : methodology, *Wea. Forecasting*, Vol. 22, No. 3, 393 - 408.
- [5] Tabary, P., J. Desplats, K. Do Khac, F. Eidelman, C. Gueguen and J.-C. Heinrich, 2007 : The new French radar rainfall product. Part II : Validation, *Wea. Forecasting*, Vol. 22, No. 3, 409 - 427.