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The quality index for radar precipitation data: a tower of Babel?

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Abstract

One of the quantitative metrics of quality of radar measurements of precipitation is the quality index (QI): a field of numbers whose values depend on the quality. Such an approach is operationally used in some national meteorological services. Difficulties in using this approach can be observed due to hardware and software differences and continuous quality control algorithm improvement. An overall review of commonly used approaches and connected difficulties is made. The challenges in hydrological applications using the QI are listed, as the technique is used to generate precipitation field ensembles. Recommendations for future common considerations are suggested. Copyright © 2010 Royal Meteorological Society

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1. Introduction

Radar ensembles are striding to getting used for flood risk assessment due to the spread of the data which may be associated to their uncertainty. In the theory of ensembles, the spread is a realisation of different simulations with a well-defined probability, in the simplest and most frequently chosen case an equal value for all realisations. These values can be interpreted as indicators for risk, e.g. for flooding. Flood risk assessment has become more important because of the EU Directive 2007/60/EC of 23 October 2007 on the Assessment and Management of Flood Risks.

Radar-derived precipitation ensembles are produced through exploitation of radar data uncertainty estimations using radar data quality indicators. Therefore, the spread of radar-derived precipitation ensembles depends mainly on radar data quality (Szturc *et al*., 2008b). Because of the operational use of ensembles the quality needs to be characterized quantitatively and in real time (Fornasiero *et al*., 2005; Friedrich *et al*., 2006; Tabary *et al*., 2007). The common way for radar data quality characterisation is to use a quality index (QI) concept, even though it is ambiguous how to define a scheme of the index calculation. The difficulties that involve the use of a QI for hydrological purposes are the subject of this article.

2. Methodology: QI for radar data

2.1. Previous work

The problem of quality of quantitative precipitation estimation (QPE) based on weather radar measurements has been a subject of many papers, and overall reviews are available, e.g. in Meischner (2004) or Michaelides (2008). Many papers are especially addressing quality related issues in weather radar measurements, for instance, a comprehensive review presented by Michelson *et al*. (2005) is available. Moreover, in the frame of COST Actions, especially 717 (Šálek *et al*., 2004; Michelson *et al*., 2005) and 731 (Zappa *et al*., 2010), have focused on radar data quality and resulting uncertainty in the data.

Advances in researcher knowledge about the radar error sources and development of correction techniques both result in a more detailed characterisation of the data quality. Such characterisation comprises an important information for the data users. One of the techniques for real-time use is to produce the so-called QI.

The QI is a quantitative metric of data quality. This means that the quality can be characterised not only by a flag indicating correct or incorrect (bad) data, but also quantitatively, e.g. using a number in the range from 0 (bad data) to 1 or alternatively to 100 or 255 (excellent data). This technique is operationally used in a few national meteorological services (NMS) (Table I). The OPERA initiative of NMS has recently made a review of these techniques and their application in Europe (Scovell *et al*., 2009).

Moreover, QI schemes have been defined for research purposes (Table II) and for use in commercial applications. The DLR scheme (Friedrich *et al*., 2006) has been developed for reflectivity, polarimetric and Doppler measurements. The Novimet scheme (Le Bouar *et al*., 2008), dedicated for polarimetric radar, differentiates between one and dual polarisation measurements. In the SCOUT software, a multiplicative

Table I. Quality index schemes operationally used in European national meteorological services for surface precipitation fields.

National meteorological service	Number of quality factors	Final QI formula	Range of QI	Used for rates	Used for accums.	Used for nowcasts	Reference
DWD (Germany)	7	Additive	Errors encoded	Yes	No	No	Helmert *et al.* (submitted)
IMGW (Poland)	Five for QPE rate + two for QPE accums. + four for nowcasts	Additive	0–1	Yes	Yes	Yes	Szturc *et al.* (2008a)
Météo France (France)	4	Multiplicative	0–100	Yes	Yes	No	Tabary *et al.* (2007)
ARPA-SIM (Italy: Emilia Romagna region)	7	Multiplicative	0–100	Yes	No	No	Fornasiero *et al.* (2005)
Met Office (UK)	1	—	0–255	Yes	No	No	Harrison (2007)
SMHI (Sweden)	1	—	0–1	No	Yes	No	Michelson (2006)
MeteoSwiss (Switzerland)	1	—	0–255	Yes	No	No	Harrison (2007)
FMI (Finland)	1	—	0–255	Yes	No	No	Peura *et al.* (2006)

Table II. Quality index schemes used in Europe for research purposes for surface precipitation fields.

National meteorological service	Number of quality factors	Final QI formula	Range of QI	Used for rates	Used for accums.	Used for nowcasts	Reference
DLR (Germany)	4	Additive	0–1	Yes	No	No	Friedrich *et al.* (2006)
Novimet (France)	4	Additive	0–1	No	Yes	No	Le Bouar *et al.* (2008)
hydro & meteo (Germany)	Six for QPE rate + one for nowcasts	Multiplicative	0–100	Yes	No	Yes	hydro & meteo (2009)

adaptation of the scheme by Friedrich *et al.* (2006) has been implemented (hydro & meteo, 2009).

2.2. Requirements for a QI

The objective of a QI is to characterise data quality regardless of source of data and their processing chain. The main factors that have an influence on radar data quality are clutter, beam blockage, attenuation, beam broadening, vertical profile of reflectivity, bright band, etc. (Michelson *et al.*, 2005). The QI value ideally should be independent from radar hardware, signal processing and technological progress.

This means that QI (radar A) = QI (radar B) implies a comparable quality of the data from the two radars. However, the practical details are more complex, because even a QI at one radar includes questions like 'should the data quality be better or worse if tests on more error sources are included?' But let us first look at the general determination of a QI.

As there is no direct measurement for areal rainfall, to approach the 'true precipitation' all available independent information have to be considered to be merged: from meteorological satellite (Meteosat), telemetric ground stations, lightning detection systems, etc. Practically, rain gauge data are considered as the best reference because only the rain gauge provides a direct measurement of rainfall although only at a point. The final estimation of data quality should reflect the differences between measured and true precipitation. However, the crucial problem is that the 'true precipitation' is unknown.

The direct comparison of radar-based estimation with rain gauge data is problematic due to the different spatial and temporal structures of the measurement techniques. There are two possibilities: a comparison at rain gauge pixels only or over a whole area (if spatially interpolated rain gauge data are generated). However, both methods are uncertain because point measurements differ from averaged pixels, and spatial interpolation uncertainties are introduced when a spatial comparison is performed.

As rain gauge values cannot be a valid benchmark for radar measurements, how can we assess the radar precipitation quality? Often it is assumed that all sources of uncertainties can be quantitatively described. However, only a small part of the factors can be exactly computed, so the results are practically insufficient.

Fabry (2004) stated that 'no radar specialist can compute with any certainty what is the expected range-dependent accuracy of a rainfall estimate in a specific weather situation'. Krajewski and Ciach (2004) even go further: 'We acknowledge the fact that in practice it is impossible to delineate and estimate these errors separately based on the available measured quantities'. Nevertheless, a measure for data quality needs to be determined, for further use in applications.

It seems that two approaches for determining a metric for quality characterization are realistic:

- to analyse individual pixels of a radar image where errors have been detected during quality check (characterisation of the measurement quality in the quality control scheme) – this is not suitable if only data after corrections are available to analyse ('measurement-based QI'),
- to analyse individual pixels of a radar image whether they were subject to modification by quality control algorithms (characterisation of level of data modification) – in this approach data having been modified are given lower quality, whereas uncorrected raw data are treated as full quality. Therefore, strictly defined quality control algorithms must be used ('correction-based QI').

The measurement-based QI approach analyses the original measurement data quality and does not take into account modifications that may have been applied to the data.

The correction-based QI approach produces a value for the finally corrected radar data, suggesting an improvement having been added to the data. A clear statement about the quality of data modification (except for the extent of data modification) is missing.

2.3. Commonly used scheme of QI calculation

The overall scheme of the QI computation can be schematically depicted as in Figure 1. The following details must be determined:

1. The number and kind of quality factors F_i to be selected: the most important ones for measurement or assessment, for instance the distance to the radar, the height of the lowest beam, the attenuation in rain, ground clutter, anaprop, etc. The total number of the parameters (n) varies from four to seven in the present operationally running schemes (Tables I and II).
2. The formulas for the transformation of each individual quality factor F_i into an individual quality index QI_i employing physically based formulas:

$$QI_i = f(F_i),\ i = 1,\ \ldots,\ n \tag{1}$$

using any benchmark (rain gauge network despite the limitations for a comparison to radar) needed for error estimation are employed as the best solution. Moreover, linear, sigmoidal or other relationships are employed as well.
3. The formula for the calculation of the averaged QI:

$$QI = f(QI_1,\ QI_2,\ \ldots,\ QI_n) \tag{2}$$

that is computed in the literature as both multiplicative (Fornasiero *et al*., 2006; Germann *et al*., 2009) and additive (Friedrich *et al*., 2006; Szturc *et al*., 2008a) schemes for the individual QI values are used to get a final combined QI operationally. The additive scheme is defined by the formula:

$$QI = \sum_{i=1}^{n} W_i QI_i \tag{3}$$

where W_i are weight coefficients assigned to each individual quality index QI_i. The multiplicative formula does not require weight coefficients, but may use weights nevertheless:

$$QI = \prod_{i=1}^{n} QI_i \tag{4}$$

or alternatively

$$QI = \prod_{i=1}^{n} W_i QI_i \tag{5}$$

4. Weights of the averaging formula: computed according to the experimentally assessed impact of each individual quality factor on final data quality determined by comparison with any benchmark.

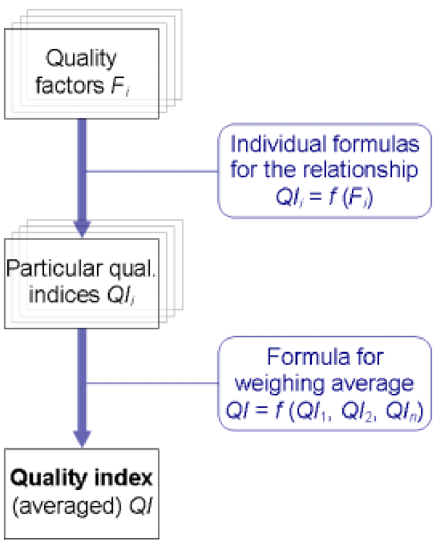

Figure 1. Overall scheme of quality index calculation.

The advantage of the additive scheme is that it can easily be assembled and average values can be determined. The advantage of the multiplicative scheme is that a quality of 0 for one factor sets the overall data quality to 0.

In Figure 2, an example of a QI field for Essen radar in Germany, generated by the SCOUT software, is presented (Einfalt *et al*., 2010). In this image, the influence of radar beam attenuation is clearly noticeable. This QI field is an example for 'measurement-based QI', so no correction has been attempted.

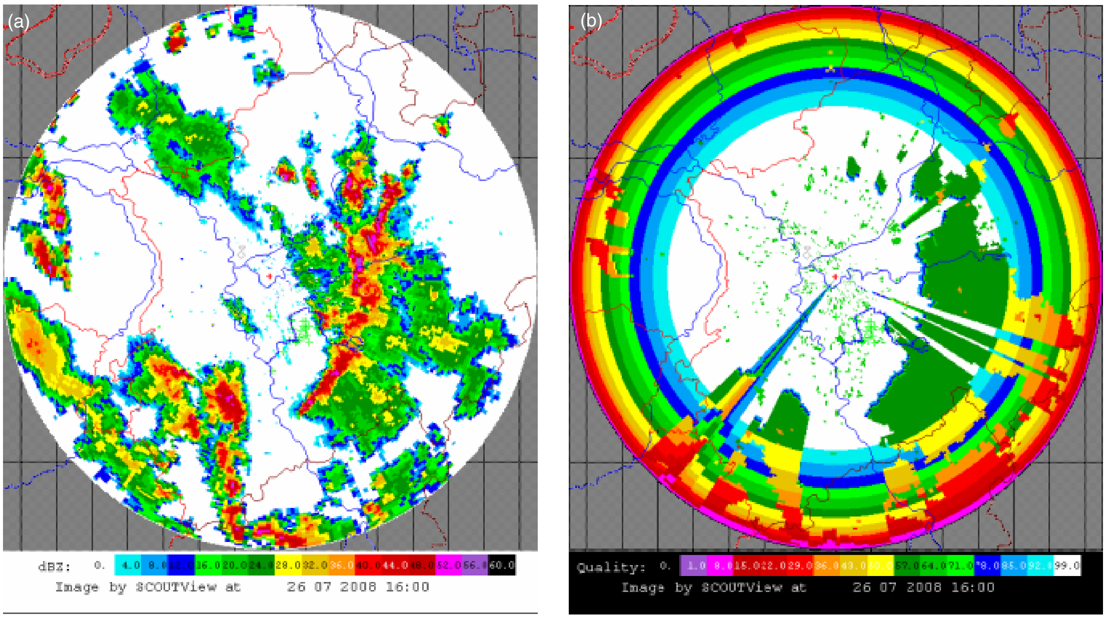

Figure 2. Example of QI field for data for Deutscher Wetterdienst (DWD) Essen radar on 26 July 2008 1600 UTC using hydro & meteo scheme (influence of attenuation is visible) (SCOUT QI product based on DX product of DWD (PPI), size: 1 × 1 km, elevation angle 0.8°).

2.4. Discussion

The current number of approaches to produce quality information leads towards many different meanings and interpretations of the same term: QI. Today, a QI computed by any NMS in Table I produces as many values as there are approaches – a true dilemma. OPERA (Scovell *et al.*, 2009) has recognised this dilemma and is working on recommendations for QI schemes. Nevertheless, the task of reducing the number of 'languages' for determining a QI is enormous.

In order to define the choice of the best methodology and to harmonize the above mentioned approaches, general reflections on quality and its assessment are required.

Assuming that all possible corrections are made so that the best QPE is produced, a comparison between QPE and (totally uncorrected) raw data illustrates how much correction was needed to produce the 'true value' for a given radar pixel. Larger corrections imply a lower quality. In this way, the level of the corrections (in dBZ or mm/h) can be a metric of the data quality.

Another solution, avoiding investigation of individual sources of uncertainties and of differences between corrected and uncorrected data, is to analyse patterns of radar precipitation fields. As some statistical properties of the field are known, especially the ones connected with spatial and temporal variability (e.g. variance), areas of precipitation fields can be recognised and existing perturbations can be separated. It is obvious that such an analysis requires climatological information about quality (for instance areas permanently suffering from radar beam blocking) and also real-time information obtained from current radar data.

How can we do such an analysis? A simple possibility is to analyse spatial and temporal variability directly by means of variance, root mean square error or standard deviation from mean value on a spatial grid or in a time window defined by consecutive radar maps. In most cases larger variabilities are related to higher uncertainty of single values in convective events, due to their small spatial and temporal scale. Extremely high variabilities can be assigned to ground echoes.

Summarizing, the most significant problems are as follows:

- weather radar data quality depends on the quality control methods employed,
- radar data quality control algorithms detect only those errors that are included in the control scheme,
- radar data errors cannot be quantified because the true precipitation values are not known,
- it is not possible to detect residual errors after correction.

3. Methodology: QI as starting point for precipitation field ensembles

The QI can be used to generate a precipitation ensemble as probabilistic input data to hydrological rainfall-runoff models (Figure 3). The ensemble can include a set of precipitation fields as members are treated as alternative scenarios or probability density function percentiles. It is assumed that the spread of the ensemble members in such probabilistic data is related to the data uncertainty (Szturc *et al.*, 2008b).

Different techniques for the ensemble generation have been proposed. One of them has been developed by Germann *et al.* (2006), who used a radar data error covariance matrix to characterise the differences in the

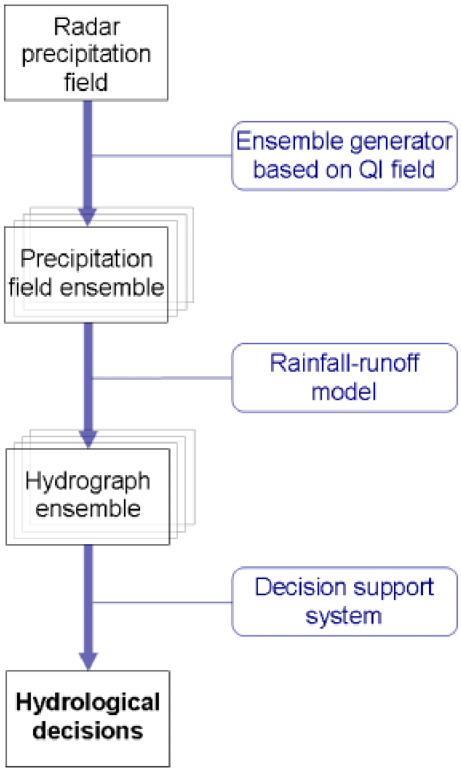

Figure 3. Overall scheme of hydrological use of precipitation ensemble.

data. Another way of determination of ensemble fields, which is based on QI, was presented by Szturc *et al.* (2008b). They generate a set of perturbation fields and add them to the initial deterministic precipitation field. The reconstruction of data errors from QI information is performed using a simple model, in which empirical relationships between QI, precipitation intensity, and quantitative error are employed.

4. Conclusions and remaining questions

Precipitation ensembles that can be generated to take into account uncertainty in radar-based QPE are destined for hydrologists mainly as probabilistic input data to hydrological rainfall-runoff models. Operational hydrologists do not want to care how such an ensemble is generated, and based on which detailed scheme of QI. They assume that the provided values are correct. They do not evaluate the spread in comparison to the 'truth'. In fact, the ensemble spread is a conventional quantity similar to the QI.

However, hydrologists have a problem when they get quality indices from different sources (e.g. different weather services close to the border) and compare the resulting runoff. Such a comparison will give results that are not comparable. Therefore, in practice the user has a problem in using different quality indices and resulting different ensembles.

In spite of this, the variety of QI schemes is a challenge for radar meteorologists rather than for hydrologists.

The following questions should be asked considering the consequences of using any QI scheme or ensemble generation concept:

- Is the relatively large number of QI methods (or other methods for characterisation of data quality) a wealth for the radar and meteorological community or does is increase confusion?
- Should recommendations, rules, guidelines be worked out to construct QI and precipitation ensembles or to use them?
- Would it be useful to start an intercomparison activity including more national weather radar networks?

OPERA has started to tackle the described problems. However, even their recommendation for a QI scheme following the basic ideas of Friedrich *et al.* (2006) and choosing a multiplicative approach leaves at least the following questions open:

- How to compare QIs based on a different number of parameters?
- How to find a common way to determine weights for the individual factors of influence (in the case of additive scheme)?
- How to define the added value of data corrections?

These points are tedious to solve, in particular with the current large number of different tongues to describe data quality. It will be a challenge to step forward, but a solution would be recognised by a large number of users of this information. Still it is an open question whether QI values from two sources will ever be comparable in the future, such as two languages spoken by two different persons. And unfortunately, the same statement holds for derived results such as QPE ensembles.

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