A quality index scheme to support the exchange of volume radar reflectivity in Europe

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1. Introduction

The quality of radar estimates of precipitation can limit the use of radar data in hydrological and meteorological applications. Radar data quality is affected by many factors, such as beam shielding, the height of the beam above the surface, interference with other transmitters, etc., each affecting the data in different ways. Quality indices are a common way of describing the quality of radar data. In France, for example, quality indices are used as a visual tool to aid interpretation of the radar images (Harrison and Boscacci (2007)). Quality indices can also be used to filter data for different applications (Peura et al (2006)). Quality control algorithms using quality indices to remove poor data can be tuned to be more or less aggressive in order to meet a given user’s requirements. For example, the assimilation of radar rainfall data into NWP models requires a high probability of detection, but for a nowcasting system issuing automated heavy rainfall or flood alerts, a low false alarm rate is a priority. Finally, the quality of radar composites could be greatly improved by using quality indices: the indices can be used to compare the quality of radar data in areas where there is coverage from more than one radar in order to decide which data to use.

Many different quality indices are generated within Europe for varying user requirements as documented by Harrison and Boscacci (2007): The aim of this work is to harmonise the quality characterisation to produce quality indices which allow a comparison of the quality of radar data across Europe, and can be used to produce a European composite on OPERA’s Operational Data Centre (ODC). The methodology presented here allows a relatively simple set of indices to be generated initially, but more complex indices can be generated as more information becomes available. To achieve this, the quality indices will be split into three levels of complexity: the first (level 1) being the simplest, relies only on reflectivity data and some global quality factors. The second (level 2) incorporates “climatological” data such as frequency of detection or clutter maps and the third (level 3) uses additional dynamic information such as the height of the freezing level from NWP models.

In addition to the three levels of complexity, three quality indices address the different aspects of quality. The indices are similar in nature to those outlined by Szurc et al (2008) and Friedrich et al (2006); information about the radar measurement is scaled linearly between 0 and 1, (poor and good quality respectively). The framework for producing the indices is described in Section 2, Section 3 given an overview of the three indices, which are described in more detail in Sections 4 and 5. Some examples of compositing the radar data using the quality indices are given in Section 6.

2. Quality Framework

Holleman et al (2006) presented a framework for producing a quality index, which aims to facilitate the exchange of quality information tailored to the end users needs by generating various quality indices for different users within the same framework. The framework is shown schematically in Fig. 1. Quality indicators are an intermediate stage, which can be combined in different ways to create the quality indices, tailored to user’s requirements.

Quality factors refer to a wide range of information relating to the estimate of surface precipitation rate. Quality input methods translate the quality factors into quality indicators. As suggested by Holleman et al (2006), the quality indicators could be harmonised by scaling the values linearly (or logarithmically as appropriate) between 0 and 1. For each quality factor, $h$, values of minimum and maximum quality, $h_{min}$ and $h_{max}$, must be defined. Values in between can be assigned values of quality indicator (Q) between 0 and 1 as in Equation 1. In this report, a quality indicator is generated for each variable associated with a radar error. For example a quality indicator derived from the height of the radar beam could be used to show the quality of the surface precipitation rate estimate.
Many NMSs use quality information to generate data flags, to indicate where and what data quality issues are manifest in the radar data. Here $h_{\text{min}}$ is set to the same value as the threshold used in the processing of radar data to generate these data flags at the Met Office. For example, where an attenuation correction is capped (because the correction factor is unacceptably large) data are given a quality indicator value of 0. 0 is reserved for errors in radar data where the data cannot be used, which must be reflected in the choice of value for $h_{\text{min}}$. $h_{\text{max}}$ is chosen to represent no error in the data, or the maximum quality. For example, an attenuation correction factor of 1 (no correction) shows the data is very unlikely to be suffering from attenuation, and therefore is an obvious choice for $h_{\text{max}}$.

The final quality indices can be a multiplicative or additive combination of the relevant quality indicators. Additive combination may result in the misrepresentation of very bad quality data. Unusable radar data are represented by zeros in the quality indicators and these should propagate through to the final quality indices. Therefore, multiplicative combination (geometric mean) seems more appropriate.

### 3. Three Quality indices

The quality of radar data can be divided in to three components, which correspond to the different types of quality information users may wish to receive:

1. **Information related to the likelihood of an echo being from a hydrometeor.**
   Although radar data processing identifies the majority of non-meteorological echoes in the reflectivity data, occasionally some will remain. This causes problems for advection-based nowcasting and automated severe weather warning systems, especially when spurious echoes persist in time. A quality index related to the probability of an echo being a particular type of target (Peura et al (2006)), in this case a hydrometeor, will enable further filtering of the data to meet this data quality requirement.

2. **The quality of the radar measurement of reflectivity.**
   Errors in radar data can result from the inability to accurately measure reflectivity in certain locations due to beam shielding or attenuation. Although these errors are corrected for, there are still likely to be large errors in the corrected estimate, which propagate through to the surface precipitation rate estimate.

3. **The quality of the conversion of reflectivity at a height above the earth’s surface to an estimate of the rainfall rate at the surface.**
   This aspect of quality is affected by the synoptic conditions, which in turn affect the vertical profile of reflectivity (VPR), orographic enhancement, wind drift etc.

4. **Final combined quality index**
   It is envisaged that the two volume quality indices $(1)$ and $(2)$ and the surface quality index $(3)$ could be combined into a final quality index $(4)$ so that it is only necessary to exchange one quality index field for each

$$Q_h = \frac{h - h_{\text{min}}}{h_{\text{max}} - h_{\text{min}}}$$

*Equation 1*
The final quality index will represent the overall quality of the radar derived surface precipitation rate estimate, on a two-dimensional Cartesian grid akin to the precipitation rate data.

This quality index scheme is not a good representation of the error or uncertainty in the precipitation estimate, but a relative indicator of the quality of the radar data at any given time.

4. Reflectivity volume quality indices

In this section, the quality indices associated with volume reflectivity measurements will be presented. (The index associated with surface precipitation rate estimates is given in the next section). There are two quality indices proposed to accompany volume data: the quality of the reflectivity measurement and the likelihood of an echo being from a hydrometeor.

4.1. Quality of reflectivity measurement.

The quality of the reflectivity measurement is dependent on several factors including the extent of signal attenuation, whether the beam has been shielded and whether the signal can be measured above the noise level. Firstly, the reflectivity itself can be used to estimate how attenuated the signal is, and therefore the quality of the radar measurement at long range or beyond heavy precipitation. Measurements at long ranges from the radar are also of poorer quality because the minimum detectable signal increases as a function of range, allowing lower reflectivities to be measured close to the radar.

Beam shielding occurs where some or all of the radar beam is blocked by surrounding topography or man-made structures, causing only a fraction of the transmitted power to interact with the atmosphere further along the ray. This causes a reduction in the power returned from hydrometeors at longer range.

**Attenuation quality indicator**

An attenuation correction factor can be derived from reflectivity data using the empirical relationship given by Gunn and East (1954) in Equation 2, for C-band in rain. $A$ is an estimate of the two way attenuation of the signal in dB/km. At the Met Office, this is used to produce a correction factor, $F_n$ in order to correct radar reflectivity data (in Z units) as in Equation 3, where $r_b$ is the bin length (in this case 600 m) and $n$ is the number of bins along each ray. In order to create a quality indicator from this factor, we propose, that $h_{F,max} = 1$ (no attenuation, maximum quality) and $h_{F,min} = 2$ (100% estimated error in Z due to attenuation).

$$A_i = 0.0044R_i^{1.17} \text{dB/km}$$

Equation 2

$$F_n = \prod_{i=0}^{n} \left(10^{\frac{A_i}{10}}\right)$$

Equation 3

**Radar sensitivity quality indicator**

The sensitivity quality indicator gives an indication on the detectability of radar echoes. In bins where the signal is above the noise threshold, Q is set to 1, since an echo is detected. In areas where the signal is identified as noise, the sensitivity quality indicator must give a measure of the level of confidence that the absence of an echo corresponds to clear air. The minimum detectable reflectivity ($Z_{min}$) increases with range and can be used for measuring this level of confidence: The value of $Z_{min}$ at 1 km is very low and therefore defines the maximum quality. The minimum quality is set at $h_{Z,min} = 20$ dBZ, a value close to the climatological average Z for detectable precipitation.

**Beam shielding quality indicator**

A simple quality indicator can be derived using the percentage of the beam that is shielded (S), where $h_{S,max} = 100\%$ and $h_{S,min} = 0\%$. Here, the calculation is done simply in terms of the illuminated area, though ideally this should be calculated in terms of Power assuming a Gaussian distribution (Friedrich et al (2006)). The radar horizon elevation (from a site survey) for each azimuth has been used in this calculation.
An example of the attenuation quality indicator outlined above, corresponding to the reflectivity field in FIG. 2 is given in FIG. 3. Initially, for the level 1 quality index, the attenuation and sensitivity indicators could be combined to generate the index representing the quality of the reflectivity measurement.

![Image of Refractivity](image1)

**FIG. 2.** Un-corrected lowest elevation reflectivity data from Preddanack radar (South West England).

![Image of Attenuation](image2)

**FIG. 3.** Quality indicator relating to the estimated attenuation along each ray.

### 4.2. Likelihood of measuring a hydrometeor

The second aspect of the quality of volume data for precipitation rate estimation is whether or not the right type of target is being measured. This can vary between scan elevations and neighbouring bins. Echo identification is a relatively complex problem and solutions vary greatly from one NMS to another. Some of the quality factors used by the Met Office to identify non-hydrometeors are detailed below with corresponding quality indicators. This quality index only applies where the signal is greater than the noise, so the remainder of the data has a quality of one.

*Frequency of detection quality indicator*

Many algorithms for echo identification make use of relatively static or climatological data, such as frequency of detection or clutter maps. Often this is used in conjunction with other algorithms for clutter removal, this needs to be taken into account when designing the quality indicator and will not described in detail here.

*Satellite probability of precipitation quality indicator*

Satellite data can be used for identifying areas likely to have no precipitation, where any echoes are likely to be a result of anomalous propagation. Satellite data ‘alpha’ values (See Pamment and Conway (1998) for details) are used to remove anaprop from UK radar data. Here alpha is defined as the ratio of the conditional probability of precipitation divided by the conditional probability of no precipitation, for the observed visible and/or infrared channel data. Because alphas are ratios, a logarithmic scale was found to be most suitable for scaling of alpha values to quality indicator values.

*Clutter indicator quality indicator*

Clutter indicator is a measure of the pulse-to-pulse signal variability (Sugier et al (2002)) and is used operationally for spurious echo detection at the Met Office and Meteo France. FIG. 4 shows an example of how the clutter indicator can be represented as a quality indicator.
Combining the quality indicators described above (frequency of detection, satellite data and CI) gives a quality index relating to the likelihood of an echo being from a hydrometeor as shown in FIG. 5.

5. Surface quality index

The conversion of a reflectivity measurement to a precipitation rate estimate at the surface is prone to many errors, such as variations in the VPR, orographic enhancement or wind drift. The quality of the final precipitation rate estimate depends on the correction made to the data.

A simple quality indicator based on the height of the beam can be used as a measure of the quality of surface precipitation estimates, since it has been shown that the quality of precipitation estimates is highly correlated with the sampling height. FIG. 6 gives an example of the quality indicator where the heights of the highest and lowest quality are 0 and 10000 m above mean sea level respectively. An example of the final quality index when combined with the lowest elevation volume scan quality indices is shown in FIG. 7. This quality indicator could be improved fairly easily by using the height relative to the height of the ground instead of 0 m and incorporating information on the height of the freezing level.

Information from satellite data can also be used to improve the quality indicators shown previously: For example the quality associated with the height of the radar beam should be set to zero at the cloud top instead of 10 km as used previously. Diagnostics from processing algorithms could also be used as quality information; for example the size of the correction made for VPR could be used as a quality factor. The measured VPR, or a profile used for the purposes of correction could also be used as quality factors.

For the initial level 1 surface rainfall rate quality index, \( h_{\text{min}} \) and \( h_{\text{max}} \) have been set to 10000 m and 0 m respectively. As more data is available to the ODC, such as topography, satellite or NWP model data, \( h_{\text{min}} \) and \( h_{\text{max}} \) can vary both spatially and temporally as described above.
6. Compositing using the quality indices.

The quality indices described in the previous sections were used to choose the scan elevation in each bin and to produce the UK composite. The scan elevation used to produce the surface precipitation rate was chosen based on a weighted comparison of the combined volume quality indices at each scan elevation. The weights used were the reciprocal of the beam height in kilometres. The surface rainfall quality index was then generated using the reflectivity data in the bins chosen in the previous step. Four composites were produced, one using the quality indices from each level of complexity, and the fourth using the current algorithm for producing the UK composite. The compositing using the new quality indices was achieved by choosing the data with the highest final quality index. The current UK composite is generated using data from the sample volume closest to the surface and the scan elevation used in each bin is chosen based on flags for clutter, anaprop, speckle etc. The level 3 final quality index used the attenuation, sensitivity, frequency of detection, beam shielding, clutter, anaprop and beam height quality indicators.

The principal improvement seen by using the quality index compositing technique compared to the one used by Met Office currently, is the elimination of the discontinuities associated with the lines of equal beam height between radars. This is shown in FIG. 8.

Unfortunately, the choice of scan elevation using the quality index had some detrimental affects. The quality index took very low values for large areas around the radar site at all scan elevations, resulting in other radars (sometimes at far range) being used instead in these areas. At these long ranges, other radars detect no rain, which leads to gaps in the composite in areas where there is a low density of radar coverage. This indicates that the quality index is not a suitable method for choosing the scan elevation without considerable tuning.

7. Discussion

Qualitatively, the example of the level 1 quality indicator (which excludes any target identification information) given in FIG. 7 looks to be a good representation of radar data quality. However, due to the sensitivity quality indicator, data containing a signal above the noise is given a greater quality than data with no signal above the noise, which means that all echoes will appear in the composite. This could have a negative impact if spurious echoes or evaporating precipitation are present. Other quality indices or flags will have to be relied upon to remove these echoes.

The example composites generated showed that the attenuation quality indicator made the most improvement to the composite in this case, due to the elimination of the discontinuities where data from two different radars meet. However, the target identification quality indicators were detrimental to the composite, causing large areas close to the radar to be in-filled with data from another radar instead of higher elevation scans. This is mainly due to the values of $h_{min}$, $h_{max}$ and the weights used for choosing the scan elevation, which could be tuned for better performance. Alternatively, the QI could not be used to choose the scan elevation, instead relying on the existing quality control and correction procedures, and only using the QI descriptively and for compositing.

As the quality index is developed and new quality indicators are added, testing of the individual quality indicators will be needed to decide whether $h_{min}$ and $h_{max}$ are defined correctly and whether they show overall skill. Different evaluation methods could be used for the 3 quality indices: The quality of the reflectivity measurement and quality of the surface rainfall rate estimates could be tested by calculating the RMS error and bias compared to rain gauge accumulations or disdrometer data or using the correlation coefficient between the radar and gauge measurements (Tabary et al (2007)). Whereas the likelihood of measuring a hydrometeor quality index could be tested using the false alarm rate.
8. Conclusions

Three quality indices have been proposed that represent three aspects of radar data quality: the quality of the reflectivity measurement, the likelihood that an echo is from a hydrometeor and the quality of the surface precipitation rate estimate. These three indices allow quality information to be used in different ways, by different users. Information on the extent of radar signal attenuation has improved the quality of the composite more than other quality indicators, though tuning is now required to take advantage of the scheme for compositing.

References


