

# Getting more value from the UK weather radar network

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**Abstract.** Although there is a record of continuous improvements in UK weather radar rainfall in recent years, it is still recognized that recurring spatial problems such as occultation and spurious clutter limit the application of radar data in flow forecasting models and in numerical weather prediction.

This paper explains how the processing of UK radar data, which is about to move onto a new platform, will dynamically correct for these problems. As it is now economical to transfer high resolution polar data to a central processor, such problems can be tracked and corrected, and these data can then be combined with the best meteorological data available.

The overall design philosophy of the new system is described in detail, but as well as delivering improvements in data quality, the system aims to concentrate all quality control and correction procedures on one central system, thus reducing the processing performed at radar sites, and allowing quality control decisions to be informed by the best meteorological information. Other design aims are to maintain data resolution at the highest level until the generation of products for customers, and to establish a common processing chain for UK and other radar data from Europe.

gauge networks, further improvement in radar accuracy is essential.

To respond to this challenge in the UK, the Met Office and the Environment Agency are investing in a project to re-engineer the radar data processing chain. The objective is not only to bring about an incremental improvement in the accuracy, availability and timeliness of radar rainfall products, but also to design a system that should improve the benefit to cost ratio from future development work. The design fundamentals are:-

- Concentration of all quality control and correction procedures on a central system, with minimal processing at radar sites (Fig. 2),
- Deferment of categorical quality control decisions to the point in the processing chain where the decisions can be made in the light of all available meteorological evidence.
- Retention of maximum data resolution as close as possible to the point where products for end-users are generated.
- Use of best-practice correction algorithms and collaborative development to minimise costs.
- Common processing of UK and other radar data from Europe.

## 1 Introduction

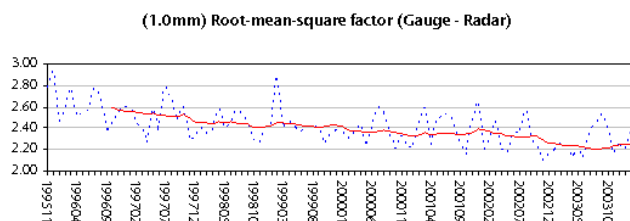
In the UK, it is perceived that the benefit to operational hydrology derived from the radar network is limited by the quantitative accuracy of the rainfall estimates. Steady improvement in radar data quality over recent years (see Fig. 1) has resulted in the data being used as input into flow forecasting models in a limited number of catchments. If flood warning service delivery targets are to be met in a larger number of catchments whilst avoiding heavy investment in new

## 2 Algorithm design philosophy

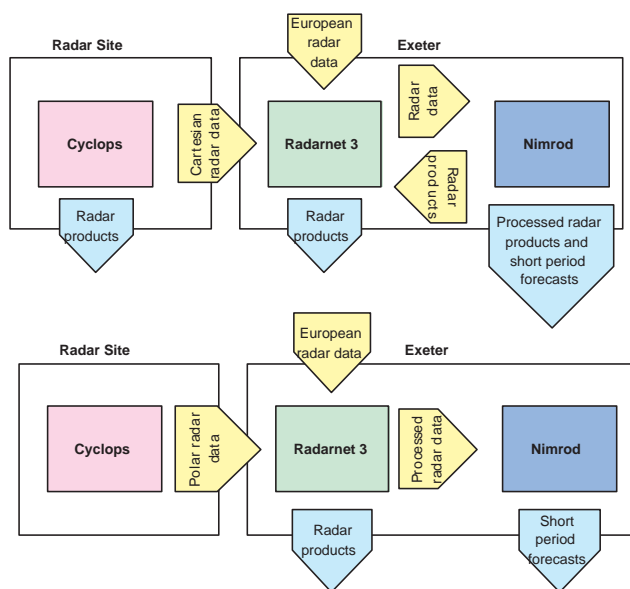
At present Radarnet III system receives partially processed data and performs initial corrections. Data are then passed through to the Nimrod forecasting system where further corrections are applied and forecasts made. An advantage of the increased processing power gained with the new hardware is that all the data processing can be done on one machine. This reduces the load on the Nimrod system and increases timeliness of products to customers.

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**Fig. 1.** Long term trends in the differences between gauge and radar estimates of rainfall over the UK. The dashed line joins monthly values of the RMS fractional difference between hourly gauge accumulations and collocated integrated radar data. The solid line is a running annual mean of the monthly values weighted by the number of comparisons within each month.



**Fig. 2.** The current system (above) compared with the new streamlined (below). This shows the increased efficiency of the new Radarnet system with a reduced load in the Nimrod machine.

The installation of Radarnet IV will also coincide with an increase in the resolution of the input data from Cartesian 1 km, 2 km and 5 km resolution to polar data of  $1^\circ \times 750$  m resolution. Although it isn't yet possible to process data from individual pulses, it is now feasible to receive data which represent averages over approximately 100 samples. The current starting point is Cartesian rainrate data which has been processed at the radar site. This is a situation which is ideal for combination with other gridded data such as satellite cloud top heights and raingauge totals (Kitchen et al., 1994) but leaves no possibility of revisiting potential problems in the radar reflectivities (i.e. the radar measurements) themselves. When radar data have been degraded in resolution, effects such as clutter and occultation (beam blocking) will contaminate the average. As will be discussed later, these effects can be detected by monitoring data over periods of up to three months, but if data are degraded in resolution at an early stage in the processing such information is lost.

The processing chain will now be discussed in more detail so that other enhancements can be highlighted. As mentioned previously, the new system will handle UK and European data, but for the sake of simplicity only the UK processing chain is discussed at the moment. This chain can be considered to consist of three sections, namely:

- radar error identification
- polar surface rainfall field production
- products

### 3 Radar Error Identification

This stage involves identification of various fault conditions in the radar data. The current methods are to be expanded to include three techniques which have recently been developed.

The clutter handling is a two stage dynamic procedure. This two stage approach uses the local spatial and temporal variability to make a judgement on whether or not a cell is cluttered (Sugier et al., 2002). It does this by comparing a long term frequency of detection map with the current radar data. This enables rain to be detected where clutter is present. Secondly, the same frequency of detection map is used to define where occultation occurs for each radar. If the blockage is two degrees or less in azimuth, the data are interpolated across the blockage. Anything larger than this is marked as invalid and higher scan data should be used where available. The third technique is to correct radar pointing errors. These errors are derived by observation of sunrise and sunset (Darlington et al., 2003). The offset is then applied at a later stage in the processing.

The errors are identified by a flagging method which allows the original data to be preserved until the last possible stage. Flags will be set to either valid, invalid or corrected.

### 4 Polar Surface Field Production

Once errors in radar data have been flagged for each scan elevation (up to eight scans) the polar data have to be combined to form a best estimate surface rainfall field. As the most accurate rainfall measurements are made from scans below the brightband, the lowest elevation possible should be used for the surface rainfall field. To optimise the data received, each polar cell is scrutinised for each scan elevation and the lowest elevation containing a valid flag, and therefore valid data, is recorded. This constitutes the “lowest usable scan”, and is used to estimate the surface rainfall. This technique enables the extraction of best quality data while leaving behind data contaminated by clutter, anaprop or occlusion. If there are no valid scan elevations for a cell it is marked as invalid and is dealt with in a later process, either the polar to Cartesian conversion or the compositing stage.

Following on from this step, a parameterised vertical profile of reflectivity is defined for each cell, using the satellite measurements of cloud top height along with numerical model freezing levels to define the initial profile. The best fit profile is derived by a process of iteration to minimise the differences between the observed surface rainfall rates and those predicted by the profile (Kitchen et al., 1994). During this stage, it is possible to obtain an estimate of the radar uncertainty expressed in terms of the beam height of the lowest usable elevation. This product can be distributed to customers along with the rainfall data and is used at a later stage in the compositing to assist in the selection of the best radar site data for a particular point.

## 5 Cartesian Products

Before radar data are delivered to customers they are mapped onto an appropriate Cartesian grid (initially at 1, 2, and 5 km resolution in UK National Grid coordinates). At this stage the same flags indicating whether data are valid or invalid are passed along with the rainfall rates, so that invalid data (i.e. data for which all elevations were cluttered) are not included in the Cartesian averages. Fewer polar cells are present in higher resolution pixels and it is sometimes necessary to use lower resolution data to cover missing pixels (pixels which contain no valid data). As the corrections are applied to the data at a much earlier stage than was previously possible, more valid data are extracted and this technique will be less prominent. The last adjustment to single site data is a raingauge adjustment factor which is applied across the whole radar field. Although radar hardware is calibrated on a monthly basis, this adjustment can compensate for long term drifts in the calibration.

The last task in the Cartesian Products stage is the production of a UK composite. This is an attempt to combine the best data from all radar sites into one field covering the whole of the UK. From the earlier discussion it will be recognised that some single site data will have been produced using very high scan elevation data to avoid clutter and/or occultation. In this situation it is preferable that data from another site which was able to collect valid data from a lower elevation is used. These decisions will be based on the uncertainty product, which contains information about the beam height. The uncertainty product can also be produced to correspond with the UK composite.

Another addition to the Cartesian part of the processing is the generation of a composite that contains 1, 2 and 5 km data. Again the uncertainty product is used to determine the best quality data and, as a default, 1 km data are used in preference to 2 km data and 2 km data in preference to 5 km data. This means that for customers receiving a composite, the best quality and highest resolution data are provided for each Cartesian pixel.

## 6 Processing of Data from European Radars

The chain that has been presented here is for processing of UK data only. European data are not received as frequently as UK data (e.g. composites are produced every 15 min, as opposed to every 5 min for UK data). These data are presently received in Cartesian format, and for the purpose of producing a composite, software developed by the University of Graz as part of the collaborative OPERA project can be used (Randeu, 2001). In the longer term, the processing chain should be sufficiently adaptable that European data can be fed through the same processing chain as UK data, although this may involve performing a Cartesian to polar conversion on the initial data, until such a time when polar data can be distributed around Europe. Another proposed development is to produce composite data at 1 km, 2 km and 4 km resolution, rather than the current 1 km, 2 km and 5 km. This is line with a perceived trend in Europe which will allow data of different resolutions to be combined more easily.

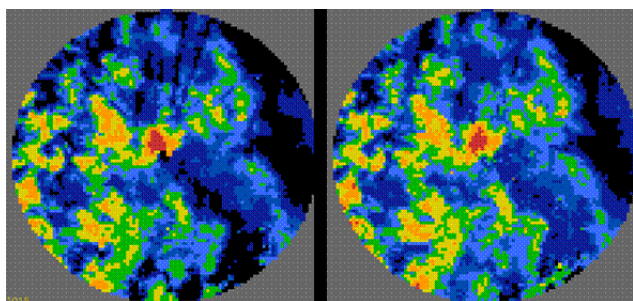
## 7 Results

The processing chain is now complete and due to start testing shortly; however, there are optimizations to be made before it is deemed to be a fully operational system. The following images are in pairs, the left hand image is the current Nimrod system and the right hand image is from the new Radarnet 4 system.

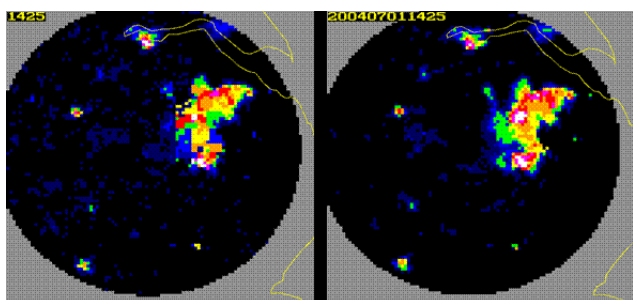
The developments in occultation corrections described above allow better quality data to the north of Chenies radar (shown in Fig. 3). This has been a long standing problem, previously of some concern. Ingham radar, in Lincolnshire, had a history of clutter breakthrough close to the radar site. This is due to its situation in a relatively flat area. Figure 4 shows this has been significantly improved with the new clutter removal scheme. The blockiness seen here and, more prominently, in Fig. 5 has been reduced due to the reception of polar data. Previously it was necessary to supplement the higher resolution data with the occasional pixel of lower resolution data to prevent missing data pixels but now this will be a less common feature in radar data. Also in Fig. 5 it is possible to see the retrieval of rain from cluttered pixels and the removal of invalid data from the polar to Cartesian averaging. The pointing error correction of order 1 degree, also applied in the polar to Cartesian averaging, can be seen here as the data have been rotated slightly in a clockwise direction.

## 8 Conclusion

It is anticipated that the new Radarnet IV system will have a lifetime of 5 years, and consequently it has been designed to provide the flexibility to deal with increased volumes of radar data from within the UK and beyond. Concentration of radar quality control on one central processor will allow quality



**Fig. 3.** Chenies, NW London, 10:15, 8 January 2004, showed improvements in rainfall retrieved over areas suffering occultation.



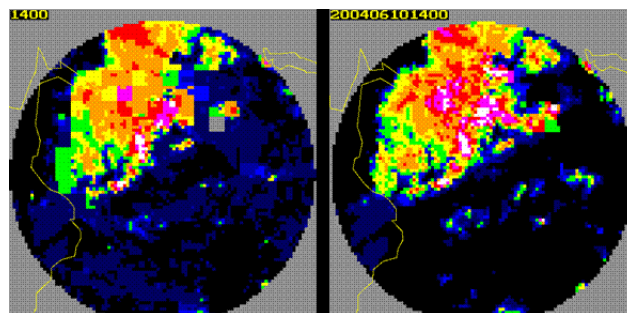
**Fig. 4.** Ingham, Lincolnshire, 14:25, 1 July 2004, has reduced clutter and more detailed rain within a storm close to the radar.

control algorithms to be developed, tested and implemented in the future more quickly and at lower cost.

Although the results shown here demonstrate that the new scheme can provide improvements to weather radar data, whenever a new site is added to the scheme there will have to be a trial period to collect enough data to provide clutter and anaprop climatology, and to allow the identification of these parameters to be tuned so that the amount of rain retrieved in cluttered areas can be optimised.

Improvements in availability and timeliness should be readily measured initially, but in the long term it is hoped that the improvements demonstrated in this paper in single site data will feed through to long term composite statistics to provide a continual gain in the accuracy of rainfall measurements (in Fig. 1), accompanied by a reduction in the false alarm rates.

**Acknowledgement.** The project is jointly funded by the Met Office and the Environment Agency of England and Wales. This work represents the efforts of the project team and not just the authors.



**Fig. 5.** Corse Hill, SW Scotland, 14:00, 10 June 2004, shows reduced clutter and better resolution over the storm area with higher retention of rain over cluttered areas.

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