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Acquisition and management of meteorological precipitation data from a raingauge network

Part 4: Guide for the estimation of areal rainfall

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Contents

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 14, an inside back cover and a back cover.

Foreword

Publishing information

This part of BS 7843 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 29 February 2012. It was prepared by Technical Committee CPI/113, *Hydrometry*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

BS 7843-4:2012 supersedes BS 7843-2.4:1996, which is withdrawn. Together with BS 7843-1:2012, it supersedes BS 7843-1.1:1996 and BS 7843-1.2:1996, which are withdrawn.

Relationship with other publications

BS 7843, *Acquisition and management of meteorological precipitation data from a raingauge network*, comprises four parts.

- *Part 1: Guide for design, development and review of a raingauge network.*
- *Part 2: Code of practice for operating raingauges and managing precipitation data.*
- *Part 3: Code of practice for the design and manufacture of storage and automatic collecting raingauges.*
- *Part 4: Guide for the estimation of areal rainfall.*

Taken together the four parts of BS 7843 provide guidance on the acquisition and management of meteorological precipitation data from a raingauge network. This part of the standard is not directly applicable to the design, development and review of a raingauge network; such guidance is given in BS 7843-1. The operation of a raingauge network is detailed in BS 7843-2, while a code of practice for the design and manufacture of storage and automatic collecting raingauges is given by BS 7843-3.

Information about this document

This is a full revision of the standard.

Use of this document

As a guide, this part of BS 7843 takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this part of BS 7843 is expected to be able to justify any course of action that deviates from its recommendations.

Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

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1 Scope

This Part of BS 7843 gives guidance on the methods commonly used in the UK for the estimation of areal rainfall. It is applicable to the use of meteorological precipitation data from a raingauge network.

This Part of BS 7843 highlights factors to be considered during the estimation of areal rainfall and presents an outline of methods (full technical details of the methodologies are not provided).

It does not cover methods using precipitation data collected by weather radars. However, discussion of their relevance is included.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 7843-1:2012, *Guide for design, development and review of a raingauge network*

BS EN ISO 772:2001, *Hydrometric determinations – Vocabulary and symbols*

3 Terms and definitions

For the purposes of this part of BS 7843, the terms and definitions given in BS EN ISO 772:2001 and the following apply.

3.1 areal precipitation
value of precipitation within a specified time interval averaged over a specified area

3.2 areal rainfall
value of rainfall within a specified time interval averaged over a specified area

*NOTE UK convention is for calculations of areal rainfall to be based on total measured precipitation, where measured precipitation includes both rainfall (as measured in a raingauge; see **3.11**) and the water equivalent of new snow (see BS 7843-2).*

3.3 average annual rainfall (AAR)
arithmetic mean of the water equivalent of the annual sums of daily amounts of measured precipitation at a point over a period of time, usually 30 years

3.4 daily precipitation
total precipitation that accumulates over 24 h ending at 0900 UTC

NOTE For general use this total is credited against the previous day's date.

3.5 domain
geographical area with specific and common characteristics of precipitation

3.6 exposure
extent of shelter or protection from the weather

3.7 monthly precipitation
total precipitation from 0900 UTC on the first day of the month to 0900 UTC on the first day of the following month

3.8 normalization
mathematical procedure for adjusting rainfall data according to the average annual rainfall for the locality

3.9 precipitation
water or ice derived from the atmosphere and deposited at ground level

NOTE Measured in terms of the depth in mm of its liquid equivalent.

3.10 precipitation metadata
records relating to the site, the equipment and the operating practices that specify the circumstances under which precipitation measurements are made

3.11 rainfall
total liquid component of precipitation, including condensation from the atmosphere, collected and measured by a raingauge

3.12 site
area of ground where a raingauge is deployed for measurement or has been deployed in the past

NOTE Other instruments for measuring the environment may also be deployed at the site.

3.13 UTC
Coordinated Universal Time

4 General comments on the estimation of areal rainfall

4.1 Estimates of areal rainfall are required for a range of applications, each with differing requirements (e.g. temporal and spatial scales). A range of techniques exist for the calculation of areal rainfall estimates.

NOTE Example application areas and aspects of precipitation data requirements are given in BS 7843-1.

4.2 Because of the spatial variability of rainfall, the uneven distribution of raingauges and factors which influence the uncertainty associated with individual raingauge catches (see **4.6**), areal values calculated from a set of point observations should be treated as estimates, not as measurements. To be capable of making a good estimate of areal rainfall, the raingauge network needs to be capable of capturing the normal spatial variability in rainfall, and a method has to be available to estimate the profile between raingauges. Many such methods are capable of estimating the distribution of rainfall over an area (e.g. a catchment) via a grid of rainfall estimates (termed a surface) in addition to estimating the areal average.

4.3 Spatial variability in rainfall tends to diminish or become more systematic over longer time periods. Therefore, the choice of method used for areal estimation is most critical for short time periods. This is particularly true when a substantial proportion of the rainfall is convective. Generally, frontal rainfall exhibits considerable spatial coherence, whereas rainfall of convective origin often exhibits very discontinuous behaviour with extreme rainfall gradients. Under such circumstances any interpolation technique will be of limited accuracy. Radar-based estimators, where possible incorporating adjustments based on contemporaneous raingauge catches, can be particularly helpful in such circumstances.

4.4 BS 7843-1 provides guidance for the design of a raingauge network, including an outline of the data requirements that influence its development. Where estimates of areal rainfall are of principal interest the following requirements are or particular importance.

a) *Spatial density.* The data requirement for the calculation of areal rainfall is dependent on the type of application and varies according to the spatial and temporal scale of interest. In some cases this may be expressed in terms of the spatial density of raingauges.

b) *Spatial representativeness.* The degree to which measurements are representative of the local area should be taken into account during the design of the network and subsequent use of raingauge data for areal rainfall estimation. A raingauge network should capture the spatial and temporal variability of the precipitation of the region of interest.

4.5 Generally, areal assessments incorporate all available raingauge data including, on occasions, non-standard raingauges (e.g. to help assess extreme rainfall events). However, changes in network density over time are inevitable and where homogeneity is a primary requirement (e.g. in the detection and quantification of rainfall trends) areal time series may rely on a representative subset of long-term, well-sited raingauges with time series subjected to rigorous quality control. Where a robust association has been established between the areal rainfall estimates thought to be most accurate (usually based upon a period for which a more detailed network was available) and the long-term homogeneous subset of the raingauge networks, this may be used as a correction factor for the long-term dataset.

4.6 The calculation and use of areal rainfall estimates should consider the uncertainty in the raingauge measurements used. BS 7843-1 provides information on the systematic and random errors in precipitation measurement by raingauge networks. In particular, areal rainfall is normally assessed using UK standard raingauges (as recommended in BS 7843-3). These systematically underestimate the rainfall reaching the ground (due largely to wind effects). Typically, the underestimation is in the range of 3-6%. Where snow forms a significant component of total precipitation the underestimation is likely to be substantially greater. To ensure consistency across the area of interest, when using areal rainfall estimates it is important to consider whether any corrections have been applied to raingauge measurements (BS 7843-2 recommends that values of both measured and estimated precipitation should be recorded in the source data). For some applications (e.g. water resources assessments and catchment water balances) where corrections have not been applied to data from individual raingauges, there might be justification for applying correction factors to the derived estimates of areal rainfall.

NOTE When storing estimates of areal rainfall for future use it is important that details of contributing raingauges (or raingauge selection criteria), calculation methods and, where appropriate, any correction factors applied are recorded in the metadata/data flags to aid future interpretation (see BS 7843-1).

5 Approaches to the estimation of areal rainfall

5.1 Grid-based approaches

A common approach to the estimation of areal rainfall over a particular geographical area is to use an interpolation procedure to derive a regular square grid of rainfall estimates from the raingauge observations. Grids may consist of rainfall estimates at each discrete grid point location or estimates of the average rainfall over each particular grid square. Areal rainfall estimates are then derived by overlaying the boundary of the area of interest on the grid and computing the average of all those grid points/squares that fall within the boundary. Compared with other approaches, this brings a number of benefits:

a) the gridded values may be reused;

b) the gridded values may be readily combined or compared with other gridded datasets, particularly where the grid intervals are the same (e.g. to show rainfall for a period as a percentage of the long term average);

c) the grid may be displayed in two or three dimensions using standard software;

d) grids produced using different interpolation procedures can be compared;

e) grids can be exported in standard formats;

f) quality control procedures can be applied at the gridding stage.

In applying a grid-based approach, the user should select a suitable grid interval. This is normally one that is capable of adequately representing the information that has been recorded by the raingauges.

Care should be taken when estimating an areal average for an area that contains a low number of grid points (in the order of <50) or where the width of the area in question spans only a few grid cells (in the order of <5). In such cases, where it is not appropriate/practical to recalculate a smaller spatial interval grid, it is recommended that the existing grid is first subdivided, using bilinear interpolation, to a suitable finer interval in the vicinity of the area.

5.2 Non-grid-based approaches

A number of approaches to the estimation of areal rainfall do not make use of a grid. These include the following.

a) Manual graphical methods.

b) Methods where, for a given area, a weight is allocated to each of a set of raingauges.

c) Methods where the rainfall surface is represented by an equation that can be integrated over the area of interest.

6 Normalization and the average annual rainfall (AAR)

6.1 General

Prior to implementing techniques for the estimation of areal rainfall (Clause **7**), it is necessary to consider whether or not the raingauge data should first be normalized with respect to the long-term average annual rainfall (AAR), using one of the methods outlined in **6.2**.

6.2 Methods of normalization

Normalization involves expressing the rainfall at the gauges as a percentage of raingauge AAR. The calculation process may then proceed in one of two ways.

a) An areal average percentage value is derived from the raingauge percentages (using any of the techniques in Clause **7**). This areal value is an estimate of the areal rainfall amount as a percentage of the AAR for the area. The AAR for the area is obtained from a map of AAR and is used to convert the calculated areal percentage value to millimetres.

b) The raingauge percentages are interpolated to a regular grid (using a suitable technique from Clause **7**). Each grid point value is converted to millimetres by multiplying by the AAR at that location (obtained from a map of AAR). The areal rainfall value is then obtained by taking the average of all the grid points that fall within the required area.

The normalization procedure is intended to allow for the uneven distribution of raingauges between higher, wetter locations and lower, drier locations, with more raingauges being situated in the latter due to proximity to population centres and ease of regular access. In general the methods described in Clause **7** will not extrapolate beyond the range of the recorded data, so without normalization the areal values will tend to be biased.

The aim of normalization is to produce raingauge values that are less related to topography and which vary smoothly from one region to another, thus making them easier to interpolate. However, for this approach to be valid, the areal distribution of rainfall in the time period in question has to be similar to that on the AAR map, and this is not always so, particularly for short time durations (e.g. of a day or less). Each case should be examined (manually or by computer) to consider whether normalizing by AAR improves the estimate of areal rainfall. If not, the calculation should proceed directly in millimetres (using any of the techniques in Clause **7**).

6.3 Standard-period average annual rainfall (SAAR)

Any suitable AAR could be used for normalization. However, it is conventional to use averages for standard 30-year periods, i.e. 1961-1990, 1971-2000, 1981-2010, etc. [known as standard-period average annual rainfall (SAAR)]. The choice of 30 years for the averaging period is based on guidance from the World Meteorological Organization [1] and aims to balance the need for a sufficiently large sample size with the need to capture variations in the climate.

If the intention is to estimate an areal rainfall amount in millimetres then it does not matter greatly which standard period is used. The role of the SAAR in normalization is to improve the analysis of the raingauge data by incorporating spatial variations that are not sampled by the observations. It is the spatial pattern in the SAAR that is important rather than the absolute values. The use of multiple SAAR periods might introduce unwanted variations in the resulting areal rainfall estimates. For long-term analysis over a period of time, it is preferable to use a single SAAR period.

SAAR values based on the national archive of precipitation data managed by the Met Office are available, both for individual registered raingauges and as a grid of values covering the UK at 1 km intervals.

6.4 Methods of calculating SAAR

SAAR values for individual raingauges are calculated readily from the observed rainfall amounts. Missing data should be allowed for by making estimates for any periods without observations, for example by scaling the values from a nearby raingauge with an overlapping record [2].

Maps of SAAR values may be produced by manually drawing rainfall contour lines (isohyets) on a map of raingauge values or by interpolating the raingauge values to a regular grid. Normalization is not possible so some other method for allowing for the uneven distribution of the raingauges should be used. For the manual approach the solution is to plot the values on a topographic background and use this to guide the analysis. For the gridded approach one possibility [currently (2012) employed by the Met Office] is to use regression analysis to construct a model of the variation of SAAR with topographic factors such as altitude, aspect and terrain shape [3]. This model can be evaluated at each grid point and, separately, the regression residuals at the raingauge locations can be interpolated at the grid points (using any suitable technique from Clause **7**). The final SAAR grid is obtained by summing the estimates from the regression model and the smoothly interpolated regression residuals.

7 Specific techniques for the estimation of areal rainfall

7.1 General

A range of techniques are in common use for the estimation of areal rainfall. The most appropriate method for calculating areal rainfall estimates depends on the area of application and should be selected with reference to the statement of data requirements (see BS 7843-1), the quality and spatial cover of the raingauge data available and the expertise, time and tools available for the task.

Details of techniques are presented in **7.2** to **7.11**. Of these methods, three (**7.3**, **7.4** and **7.7**) are suitable for both gridded and non-gridded implementation, two (**7.2** and **7.10**) are only suitable for non-gridded implementation and five (**7.5**, **7.6**, **7.8**, **7.9** and **7.11**) are only suitable for gridded implementation.

7.2 Arithmetic mean

The arithmetic mean is simply the average value for the raingauges in an area. The method makes no attempt to model spatial distribution, so for short, highly variable events it is likely to give unreliable estimates which are strongly influenced by raingauge distribution. For periods of a year or longer, using normalized data and a fairly uniform raingauge distribution, it can give acceptable results for little computational effort. (This method does not provide a rainfall surface; all it produces is a single value for a specific geographical area.)

7.3 Thiessen weighting

A major disadvantage of the arithmetic mean is its sensitivity to raingauge distribution; if the density of raingauges is greatest in one locality it will be biased towards the rainfall in that locality. The Thiessen method [4] overcomes this by stating that each raingauge represents the region for which it is the closest raingauge. The areas of these regions (excluding any parts which are outside the area of interest) are then used to weight the raingauge observations before averaging them. Thiessen weights have traditionally been obtained by drawing Thiessen polygons (see Figure 1) constructed from the perpendicular bisectors of lines joining neighbouring raingauges.

On a computer, the method is readily implemented by sampling a regular square grid which covers the area of interest and allocating each grid point to its nearest raingauge, while ignoring any grid points outside the area of interest.

NOTE This approach is often termed the "nearest neighbour" method.

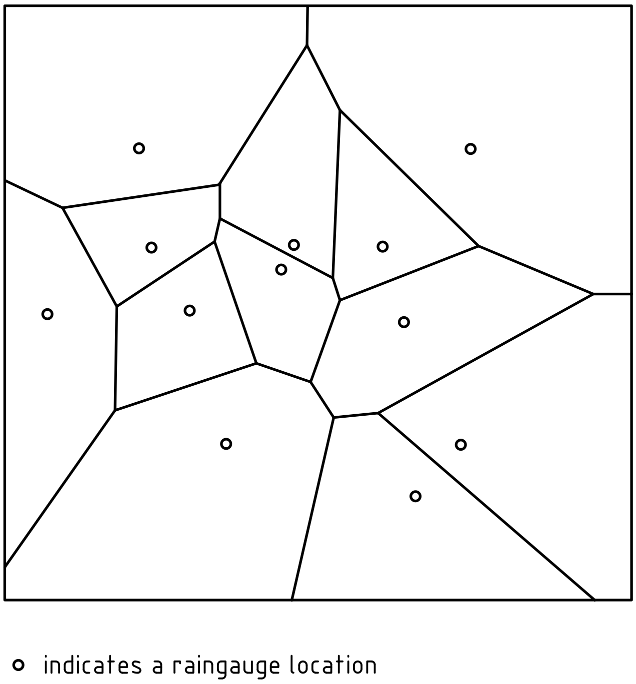
The Thiessen weight for a raingauge is then the number of grid points allocated to the raingauge divided by the total number of grid points in the area of interest. Provided that a suitably fine grid interval is used (a ratio of at least 20 grid points per raingauge is suggested) acceptably accurate Thiessen weights can be obtained.

This method always give superior results to the arithmetic mean. The need laboriously to reconstruct the polygon network whenever the set of operational raingauges changes was often cited as a disadvantage, but this is of little practical concern when using the computerized method. Perhaps its main weakness is its unrealistic spatial representation of rainfall on two counts:

a) the sudden step across the boundary between two polygons (though this might not be so obvious if the data have been normalized); and

b) the lack of any physical factor such as aspect or elevation relating polygons to raingauges.

Figure 1 **An example of Thiessen polygons**



7.4 Domain weighting

The domain weighting method overcomes the weaknesses of the Thiessen method by allocating a region (domain) to each raingauge on the basis of physical homogeneity, i.e. the rainfall at the raingauge is likely to be typical of that in its domain. In practice this method tends to be used only for small research areas because of the time required to define the domains and the impracticality of automation.

7.5 Triangular planes

The triangular planes method is only practical for computer operation. For each point on a regular square grid covering the area of interest, the three closest raingauges capable of forming an enclosing triangle are identified. A plane is fitted through the three rainfall observations to obtain a value at the grid point. If a triangle cannot be formed, the value at the nearest raingauge is used. This method gives a better representation of spatial distribution than those described in **7.2**, **7.3** or **7.4**. It is relatively easy to program and is computationally efficient. In common with the methods described in **7.2**, **7.3** and **7.4** it does not extrapolate beyond the range of the recorded rainfall (other than within the normalization procedure).

7.6 Inverse distance weighted mean

The inverse distance weighted mean method also estimates rainfall at points on a regular square grid. Typically, at each grid point a search is made for a well-distributed selection of neighbouring raingauges (for example, the closest two raingauges in each octant). A weighted average is then calculated, with the weight applied to each raingauge being proportional to $1/d^n$ where d is the distance to the raingauge and n is usually between 1 and 2. The selection of n depends on the nature of the intensity and patterns of rainfall. Traditionally the value was set at 2, but analytical methods can be used to establish the most suitable value.

7.7 Mathematical surface

The multiquadric method [5,6] is well suited to the interpolation of short duration rainfall [7]. This defines the rainfall surface as the weighted sum of a set of quadric functions (commonly cones) each centred on a raingauge location. The method may be used to generate a regular square grid of estimates, or, by a process of integration, it can be used to estimate areal averages directly.

An alternative surface-fitting method involves the local fitting of a curved surface. At each grid point, as in **7.6**, a selection of neighbouring raingauges is made, then a surface (e.g. $\text{rain} = a + bx + cy + dx^2 + ey^2 + fxy$, where x is the easting and y is the northing on a geographical grid) is fitted by the least squares method to the rainfall values at these raingauges. At grid points where the number or distribution of raingauges is poor, the method might default to fitting a plane or taking a weighted mean. This method should be used with caution as it can give unrealistic extrapolations and large unwarranted differences between neighbouring grid points.

7.8 Kriging

Kriging is a widely-implemented spatial interpolation procedure. It may be applied to any set of observations that are spatially correlated, i.e. where the difference between pairs of observations tends to decrease with increasing proximity. It is therefore suitable for the interpolation of raingauge observations.

In "ordinary kriging", an initial analysis of the data is used to determine the relationship between the variance between observations at raingauges and their separation; this may take direction into account if necessary. Then, at each grid point, this information is used to determine the weights to be applied to each raingauge.

In "universal kriging" (also known as "kriging with a trend"), a trend surface is fitted to the observations, and the differences between the observations and the trend surface (the residuals) are interpolated as for ordinary kriging.

Kriging has also been used to interpolate the residuals from georegression models that relate rainfall statistics to positional and topographic predictor variables (for example, [8,9]).

An important benefit of kriging is its ability to generate a map of the standard error statistic of the gridded rainfall estimates. This shows localities which require additional raingauges to provide an acceptably reliable estimate, making it a useful aid to network design.

NOTE For more details see Webster and Oliver [10], Cressie [11] and Delhomme [12].

7.9 Natural neighbour Interpolation

Natural neighbour interpolation [13], less commonly termed Voronoi interpolation [14], is a development of the Thiessen polygon approach: indeed, "Voronoi polygon" and "Thiessen polygon" are just different terms for the same object. However, where the surface produced from Thiessen polygons is a series of plateaus with sharp steps between them, the natural neighbour method provides a gradually varying surface. It achieves this by first constructing the network of polygons for the raingauge network. Next, to calculate the rainfall at a grid point, the point is introduced into the raingauge network and the polygons in its vicinity are reconstructed, treating the point as if it were a raingauge. The point will then possess its own polygon, which will have been obtained at the expense of the surrounding raingauges. All raingauges whose polygons were diminished by this process are used to estimate the rainfall at the point. A weighted mean is taken with the weight for a raingauge being proportional to the area that it lost. This produces a gradually varying surface, unlike many other methods that fit to a selection of neighbouring raingauges, because the weight for a raingauge always diminishes gradually from one or close to one (grid point coincident or close to the raingauge) to zero (grid point not influenced by the raingauge).

Computer implementation is straightforward. Each grid point is allocated to its closest raingauge, and for each individual grid point those other grid points that are closer to it than to any raingauge are identified. From this, those raingauges that have lost points are determined, weighting is allocated to the raingauges proportionately, and the rainfall for the grid point is computed.

As described, the method does not extrapolate beyond the raingauge observations (other than via the normalization process), and although it gives a gradually varying surface, it contains discontinuities in gradient at raingauge locations. Sibson [13] described a more elaborate method designed to overcome these limitations, in which a local surface is fitted at each observation location and then the method described earlier is applied to the surfaces rather than the point observations. However, this method does not appear to have been adopted for the interpolation of raingauge data, and the use the multiquadric method **7.7** is recommended if these limitations are of concern.

7.10 Isohyetal method

This traditional manual method involves drawing isohyets on a map of raingauge observations. The effect of altitude and aspect is allowed for either by working in units of rainfall as a percentage of long-term average or by working in millimetres against a backdrop of a ground elevation contour map and letting the shape of the isohyets be governed by a combination of raingauge observations and relief.

Areal averages can be calculated manually by tracing the area of interest onto the isohyetal map, and measuring the areas between isohyets by planimetering or counting squares.

In the hands of a skilled operator with knowledge of the region and of the reliability and representativeness of individual raingauges, it can be used to good effect.

7.11 Interpolation in space and time

In flood event analysis using a catchment rainfall-runoff model, the required rainfall data are a time series of catchment totals, usually at hourly or sub-hourly intervals. These often have to be derived from a set of sub-daily raingauges in combination with a set of daily raingauges (from other locations). Historically, in the UK, the vast majority of raingauges have been daily, though in recent years there has been a very substantial increase in the number of sub-daily raingauges.

One method of deriving hourly rainfall grids that makes full use of both daily and sub-daily raingauges is to first produce provisional observed grids for each of the hours in a rainfall day (ending at 0900 UTC) using the available sub-daily raingauge data. Secondly, at each of the daily raingauges an adjustment factor (observed daily rainfall divided by the sum, at the raingauge location, of the 24 provisional hourly grids) is computed. Thirdly, an adjustment factor grid for the day is derived by interpolating these daily raingauge adjustment factors in combination with factors of 1.0 at each hourly raingauge location. The final hourly grids are the product of the provisional grids and the adjustment factor grid.

Another approach, particularly suitable where the sub-daily raingauge network is sparse, is described by Jones [15]. Here, daily catchment rainfall totals are obtained from the daily raingauges using a grid-based method. The hourly raingauge profiles are then aligned and averaged, using Thiessen weighting, to give a catchment average point profile. (Alignment is necessary because different raingauges tend to record the same storm at different times as a result of storm movement. Averaging observations from several raingauges without first aligning them would therefore tend to smooth and attenuate the storm profile and make it dependent on the number and distribution of raingauges.) This profile is then scaled in accordance with the previously calculated daily totals.

8 Use of radar data

8.1 General

Weather radars can give good qualitative estimates of rainfall across extensive areas at fine spatial and temporal resolutions. Radar rainfall data can complement the more quantitatively accurate point raingauge observations and thus have an increasingly important role in areal rainfall estimation. For example, in flood forecasting radar can detect the location, extent and evolution of convective storms that raingauge networks rarely sample well, if at all.

Across the UK mainland, the radar network provides frequent (15 min to 5 min) and high-resolution (5 km to 1 km) gridded estimates of rainfall rate that are available in real time. This readily-available source of national rainfall information is used widely in real-time weather forecasting, flood forecasting and water management applications.

NOTE More details of the radar processing are given in BS 7843-1:2012, Annex C.

For a given region of interest, the finest spatial (e.g. 1 km) and temporal (e.g. 5 min) radar rainfall products that have been processed or "quality controlled" by the Met Office should be used. The use of composite radar data that combine data from across the network and/or different resolution data products from individual radar sites should be considered.

The quantitative accuracy and error characteristics of radar rainfall products vary with space (e.g. distance from radar, local topography effects, beam blockages, clutter) and time (e.g. meteorological situation, radar network and processing algorithm changes). Even the processed radar rainfall data can differ significantly from collocated raingauge observations with a factor of 2 typical between the radar and raingauge estimates (see BS 7843-1:2012, **C.5**).

As a consequence, combination of the fine spatio-temporal radar rainfall estimates with the more quantitatively accurate point estimates of rainfall from raingauge networks should be considered when using radar data.

8.2 Forming radar rainfall accumulations

The use of radar rainfall accumulation products, rather than radar rainfall rate, should be considered (if available and at an appropriate time interval) as these typically allow for advection of the rainfall field between the instantaneous radar rainfall rate estimates.

However, if only radar rainfall rate products are available care is needed when forming rainfall accumulations over a given period, particularly for the short hourly or sub-hourly periods that are typically required by real-time flood forecasting or water management applications.

For forming hourly or sub-hourly accumulations from radar rainfall rates, a simple "trapezoidal" weighting scheme can be used. For example, a 15 min radar rainfall accumulation (mm) at time *t* from 5 min radar rainfall rate data (mm/hr) is formed by applying the trapezoidal weights 1/6, 1/3, 1/3 and 1/6 to the *t*-15, *t*-10, *t*-5 and *t* rainfall rate data and then dividing by 4 to convert from mm/hr to mm over the 15 min time interval. The trapezoidal method makes some allowance for the non-constant rainfall rates over time but does not explicitly account for advection.

For certain applications, or if the temporal resolution of the radar rainfall rate product is coarse (e.g. 15 min), more complicated accumulation schemes are available that explicitly account for advection of the rainfall field (e.g. [16]).

8.3 Disaggregating raingauge totals

One simple use of radar data is to utilize its fine temporal resolution to disaggregate daily raingauge totals into hourly or sub-hourly interval profiles (a procedure which is otherwise constrained by a lack of recording raingauges), and then apply standard raingauge methods for areal estimation (see Clause **7**).

8.4 Combination of radar and raingauge data

Merged radar and raingauge rainfall products aim to combine the benefits of the fine spatio-temporal detail of the radar data with the point accuracy of the raingauge observations.

Typically, a small number of raingauges from a dedicated network is used for each radar within the Met Office radar processing scheme (see BS 7843-1:2012, **C.2.10**) to derive a mean field bias adjustment, i.e. a single adjustment factor that is applied to the entire domain of the radar. This mean field bias adjustment factor can potentially change every hour, but often changes less frequently due to raingauge availability and the need to exceed thresholds within the scheme on the number of raingauge to radar comparisons.

More dynamic methods exist that apply frequent (sub-hourly) and spatially varying adjustment factors, and can be used with mean field bias adjusted radar products. An example is the "dynamic gauge-adjustment of radar" method [7] where a multiquadric surface (see **7.7**) of adjustment factors is fitted to the modified ratio between the raingauge and collocated radar rainfall accumulation estimates.

NOTE The "dynamic gauge-adjustment of radar" method is used within the national flood forecasting procedures of the Flood Forecasting Centre for England and Wales and the Scottish Flood Forecasting Service.

Bibliography

Standards publications

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 7843-2, *Code of practice for operating raingauges and managing precipitation data*

BS 7843-3, *Code of practice for the design and manufacture of storage and automatic collecting raingauges*

Non-standards publications

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