Proceedings of ERAD (2004): 7–11 © Copernicus GmbH 2004

ERAD 2004

Gauge adjustment of radar-based precipitation estimates in Europe

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Abstract. There is an increasing demand for quantitative precipitation information from weather radar data. For the user, it is important to be aware of the steps involved in the conversion between the reflectivity measurement and the precipitation estimate. One of the most widely used methods for increasing the radar estimate's quantitative accuracy is the adjustment to precipitation gauge measurements. Gauge adjustment is applied either in combination with other quality control methods or alone. A successful gauge adjustment can correct for much of the errors caused by the choice of an incorrect Z-R relationship, the VPR, partial beam blockages etc., but combining radar data with gauge measurements is a challenge. The review presented here has been carried out for the COST Action 717. Information about the gauge adjustment methods applied at 21 European institutes has been collected. It is shown that the choice of method depends on factors like the radar network density, the radar data processing, the topography, and the spatial and temporal availability of gauge measurements.

1 Introduction

This paper gives a short overview over the gauge adjustment methods applied at European Meteorological Services, research institutes and private companies, both operationally and experimentally. The focus is on the operational methods. The paper is a summary of a review (Gjertsen et al., 2003) carried out for COST 717 dealing with "Use of Radar Observations in Hydrological and NWP models". The COST review is based on the replies to a questionnaire sent out during spring 2003.

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2 Background

Gauge adjustment is a widely used approach for improving the quantitative accuracy of radar precipitation estimates. It may be defined as being a term used to describe any procedure whereby the characteristics of radar data are modified such that they correspond as well as possible with the quantity given by gauge measurements (Michelson, 2003). The main idea of gauge adjustment is to combine the individual strengths of the two measurement systems. The radar provides information on the spatial distribution while the gauge provides a point measurement of relatively high quantitative accuracy. Combining radar and gauge data is a challenge, and the literature on this topic is abundant. A short overview of the error sources is given by Steiner et al. (1999). Nevertheless, a successful gauge adjustment can partly correct the errors induced not only by the incorrect Z-R relationship but also by many other radar specific error sources (beam blockages, attenuation, improper radar calibration, the VPR-related error, etc.). The initial choice of the Z-R relationship is not critical when a gauge adjustment is applied. The b-exponent in the Z-R relationship shows no clear dependency on precipitation type (Amitai et al., 2002) and can be regarded as constant over longer time periods without causing large errors (Steiner and Smith, 2000). The gauge adjustment changes the multiplicative A-factor in the Z-R relationship. Unless the gauge adjustment is preceded by a VPR correction, the A-factor should be adjusted continuously to reflect the short term variations of the VPR as well as can be expected. This is a challenge in an operational environment where the density of synoptic gauges is low and the reliability of the individual measurements is variable.

The adjustment of radar precipitation estimates is sometimes considered as a synonym for radar calibration. However, the main goal of radar calibration is to ensure the long-term stability (and reproducibility) of the radar measurement. It is an electronic procedure and is usually being made by the radar system itself, whilst the gauge adjustment is a statistical procedure that aims at the more accurate radar-based precipitation estimate by comparison of radar estimates with collocated gauge measurements. The adjustment can also reflect changing meteorological conditions (precipitation type, DSD/VPR variation, attenuation etc.).

3 The basis for gauge adjustment

Following Koistinen and Puhakka (1981), there are a number of assumptions which must be made when conducting a gauge adjustment of radar data. These are:

- *Gauge measurements are accurate for the gauges' locations.*

  It is crucial for the success of the adjustment that the gauge data used as reference is of good quality. The quality of gauge observations can be considered high provided that a quality control has been performed. Even better is a systematic correction of the gauge measurement. Quality controlled gauge data is usually available with a certain delay; real time gauge adjustment may therefore be problematic.

- *Radar successfully measures relative spatial and temporal variabilities of precipitation.*

  This topic encompasses quality-related issues of identifying and removing spurious echoes like clutter, insects, birds, the sun, etc., and correcting for missing echoes where the beam is blocked or overshooting the precipitation. For the identification and removal of noise, a combination of different detection and removal algorithms should be applied since no noise filter works perfectly. It depends also on the application of the precipitation data how much remaining noise can be tolerated or how much precipitation can be removed.

- *Gauge and radar measurements are valid for the same locations in time and space.*

  This is not true. Gauges provide point values and radars provide volumetric integrations often at significant heights above the earth's surface. This assumption must nevertheless be made. The issue of sampling and representativeness errors when comparing gauge and radar measurements is well-known (Zawadzki 1975; Kitchen and Blackall 1992; Seed et al. 1996). On average, however, the gauge/radar ratio expresses the degree of radar underestimation (or overestimation) relative to the gauge that can be expected at a certain location. The influence of the temporal and spatial sampling errors described above can be minimised by selecting the appropriate spatial and temporal scale for the adjustment.

- *Relationships based on comparisons between gauges and radar(s) are valid for other locations in space and/or time.*

  Little is known of this issue. The reflectivity profile is highly variable in time and space. It may vary on the scale of single radar measurements, especially in convective situations (Germann and Joss in Meischner et al. 2003). In mountainous regions, the spatial representativeness of a gauge may be low due to the dominating influence of topography on the precipitation distribution. However, the assumption must be made that gauge-to-radar (G/R) relationships can be interpolated between gauges and extrapolated in time.

4 Gauge adjustment methods - results from COST 717

Gauge adjustment schemes are applied routinely at the following meteorological services or institutions: CHMI (which is utilizing/testing also procedures of the national Institute of Atmospheric Physics), Météo France, KNMI, met.no, SMHI, UK MetOffice, and MeteoSwiss. This is also being conducted for hydrological purposes at CEH (UK), and Einfalt and hydrotec (Germany). Experimental methods are running at the Technical University of Graz (Austria), the Meteorological Service of Cyprus, DWD, Politecnico di Torino (Italy), the Institute of Meteorology in Portugal, and at GRAHI (Group of Applied Research on Hydrometeorology, Barcelona, Spain). Thus, almost a half of the services/institutions utilize some type of gauge adjustment routinely. If combined with the experimental systems, the ratio reaches 80%. A summary is given in Table 1 (Exp. stands for experimental systems).

4.1 Integration time for G/R factors

The choice of integration period (time window for obtaining the G/R factor) is strongly related to the analysis domain size and the number of available gauges found in it. The G/R factor becomes naturally more stable for longer integration periods and more gauge data available, provided that the sampling difference errors are stochastic. On the other hand, long integration periods do not reflect the short-term variations due to changing meteorological conditions. It is therefore a challenge to find the best balance between the two rather contradictory requirements. This situation is also reflected in Table 1. The integration periods are in the order of days, varying from 10 minutes to several years.

4.2 Spatial interpolation of G/R factor

Mean field bias adjustment (or bulk adjustment) is the simplest method and therefore its use is widespread. It is applied at the Technical University of Graz, CHMI, Météo-France, Einfalt and hydrotec, Politecnico di Torino, SMHI, MeteoSwiss, CEH, and the UK MetOffice. The UK MetOffice system applies a correction using the mean field bias computed according to Seo et al. (1999) and Fulton et al. (1998). At short ranges close to the radar, this is a reasonable approach since the G/R factors are relatively low and constant.

Table 1. Results from the COST-717 questionnaire (the reports are mainly from spring 2003).

Institute	**Gage radar adjustment scheme**	**Mean/local bias**	**What time period is used for the bias computation**	**Use**
Institute of Communications and Wave Propagation, TU Graz, Austria	Exp.	Exp. mean bias	Typically 2 hours	Hydrology, still in evaluation, method is steadily improved
Institute of Hydraulics and Hydrology, TU Graz	Exp.	Exp. local bias	10 minutes	Hydrology, no operational use
Royal Meteorological Institute of Belgium	No			Nowcasting, hydrological applications under development
Meteorological Service of Cyprus	Exp.			Quantitative precipitation estimation, NWP model comparison
Czech Hydrometeorological Institute (CHMI)	Yes	Mean bias, local bias is planned	Flex. time moving window of at least 1 day	Instantaneous (areal) quantitative precipitation estimate, input to hydrological models, NWP model verification
Institute of Atmospheric Physics (ASCR), Czech Republic	Yes	Mean bias as the first step	The current data	(i) estimate of area precipitation, (ii) estimate of precipitation fields to verify a precipitation forecast of a high resolution NWP model
Finnish Environment Institute	No			Interpolation and calculation of areal daily precipitation in the Watershed Simulation and Forecasting System of Finnish Environment Institute (in progress)
Finnish Meteorological Insitute (FMI)	Yes, for snow accumulation	Mean bias	1 year	QPE, nowcasting, snow clearance, aviation, TV
Météo-France	Yes, for hydrological products	Mean bias	1 month	
Einfalt&hydrotec GbR, Germany	Yes	Mean, and WPMM (experimental)	Event	Event analyses, flood forecasting/real-time warning, input to hydrological models
Deutscher Wetterdienst (DWD)	Exp.			Instantaneous quantitative precipitation estimate, input to hydrological models
Politecnico di Torino, Italy	Exp. WMR	Both experimental	24 hours	To verify whether the radar can be use quantitatively in mountainous terrain. What circumstances? What uncertainties
KNMI, Netherlands	Yes	Range dependent	24 hours	Climatological information, delivery to waterboards for input to hydrological models
met.no, Norway	Yes	Local bias	1 month	Monitoring precipitation, hydrology, water power, road maintenance
Inst. of Meteorology and Water Management, Poland	No			NWP model verification. NIMROD system (of Met Office of UK) is to be implemented
Inst. of Meteorology, Portugal	Exp.	Experimental local bias	One hour	Quantitative precipitation estimates
Slovenian Environmental Agency	No			
GRAHI	Exp.	no		Quantitative precipitation estimates Input to hydrological models
Swedish Meteorological and Hydrological Institute, SMHI	Exp., yet routinely running	Both experimental (yet routinely running)	Moving 10-day window	QPE, input to hydrological models (experimental), NWP model validation Activitities conducted within the framework of the Baltic Sea Experiment
Meteo Swiss	Yes	Local bias, WMR technique used	Case studies: a few tenths of hours for operational products: a couple of years	Monitoring and nowcasting precipitation, hydrology, near future (hopefully): assimilation into NWP models
CEH Wallingford	Yes	both		
Met Office, UK	Yes	Mean bias	Variable period (down to 1 hour) according to availability of data	Instantaneous quantitative precipitation estimate, input to hydrological models, assimilation in NWP model

Range dependent G/R factor

Range dependent gauge adjustment techniques classify the G/R pairs into range bins and derive the adjustment factor as a function of distance from the radar. The underlying assumption is that the differences between radar and gauge precipitation totals contain an inherently strong range dependency. Issues like the bright band, water phase of precipitation and the VPR are implicitly treated with this type of method. Examples for range dependent adjustment methods are the TRMM GV (Amitai et al 2002), and the BALTEX adjustment method that is mainly range dependent, although containing a spatial component (Michelson et al., 2000). The performance of a range dependent adjustment method depends, like the performance of a VPR correction, on the maximum height of the precipitation and the scan elevations/radar locations. In cold climates such as in the Nordic countries, the limiting factor is the shallowness of precipitation in winter, in the majority of cases below 4000 m (Pohjola and Koistinen, 2002).

Weighted Multiple Regression

In complex orography, where the G/R factors are influenced by beam blockages and orographic influences on the precipitation process, the radar-gauge distance is not sufficient as predictor. To cope with this kind of problem, Gabella et al. (2000) proposed an adjustment based on a non-linear Weighted Multiple Regression (WMR). The WMR technique is used at MeteoSwiss, experimentally at the Meteorological Service of Cyprus, and at Politecnico di Torino.

Spatial adjustment

Alternatively, the G/R factors may be interpolated by applying a 3-dimensional curve fit. This approach requires longer integration periods for the G/R factors. Spatial adjustment is applied operationally at met.no, for the BALTEX radar precipitation product, and in HYRAD (Wood et. al., 2000). For such a spatial technique to work successfully, a dense network of precipitation gauges is required. Spatial adjustment is used experimentally at the technical University of Graz, by Einfalt&hydrotec, SMHI, MeteoSwiss and CEH.

Combination of radar and gauges

CHMI runs a procedure combining radar estimate (adjusted by mean field bias) with available gauge observationss using a modified procedure called double optimum interpolation of Seo (1998). A combination of radar and gauge data utilizing kriging with external drift is used for the final precipitation estimate at the UK MetOffice.

5 Verification

Verification of the adjustment procedures encounters the same problem of representativeness as the determination of G/R factors. However, the problem can be tackled in a relative sense: the performance of the adjustment (or combination) procedure can be expressed in terms of change of the difference between the adjusted radar estimates and the independent (i.e. not used in G/R computations) gauge measurements. The measure of the difference can be the e.g. the Root Mean Square Error:

$$RMSE = \sqrt{\sum_{i=1}^{n} (G_i - R_i)^2}, \tag{1}$$

G_i, R_i being the gauge measurement and collocated radar estimate, or explained variance (square of correlation coefficient) applied for sufficiently large number of cases, although usually there are problems with not-gaussian distribution of the data. Since the RMSE quantity overemphasizes the big difference that may be caused by erroneous data, another quantity called Root Mean Square Factor can be used:

$$RMSf[dB] = \sqrt{\frac{1}{N}\sum_{i=1}^{n}\left[10\log\left(\frac{G_i}{R_i}\right)\right]^2}. \tag{2}$$

However, there is usually not enough independent gauge data for verification for time intervals less than 24 hours. Nevertheless, the daily precipitation estimates can be usually verified against the climatological gauge network whose readings are reported off-line, often with a significant delay. Leaving aside the role of the longer integration time, the daily accumulations can serve as reasonably good indicator of the accuracy of the precipitation estimate algorithms.

6 Conclusion

There is little doubt that a gauge adjustment and/or some kind of combination of radar and gauge data improves the accuracy of radar-based precipitation estimates. Gauge adjustment is generally recommended but the methodologies to use depend on:

1. The purpose of the precipitation estimates.
2. Accessibility and quality of gauge data.
3. Quality of radar data (including network density, quality control, pre-processing).
4. Scale of the areas for which the (areal) precipitation estimates are made.
5. Time and space resolution of the radar precipitation estimates.
6. Geographical region of interest (orography, climatology).

Gauge adjustment approaches vary throughout Europe. Even the most simple and feasible mean-field-bias correction can be applied in a number of variations depending on the accumulation time and/or time window used for the computation of the G/R factor.

However, the mean field bias correction is suitable mostly in situations of non-significant range degradation, or in dense network of overlapping radar domains. Where the change of the G/R factor with range is substantial, some compensating procedures like a VPR correction should be applied before the mean field bias calculations; otherwise the locally variable (or at least range-dependent) G/R factor is recommended. It is a good option to correct the short-term and/or local variations of bias by a VPR-based algorithm and (where necessary) a beam blockage correction before performing a gauge adjustment which would remove the residual bias. This is the methodology adopted in the Swiss radar network and in Finland. It is certainly the best approach for challenging environments such as the Alps or high latitudes. The balance between relative weights of both corrections is affected by the quality and quantity of the available gauge data along with their representativeness; especially influence of orography plays an important role in the considerations.

An adjustment procedure, which improves the original radar estimates on average, cannot guarantee acceptable performance for every place/time in the radar domain. This is true especially in mountainous regions where the radar information is heavily influenced both by limited visibility (and ground clutter) and by special meteorological conditions of precipitation processes such as lifting, channelling, heating etc. (Germann and Joss in Meischner et al, 2003, p. 52-77). It is recommended to use additional information about the precipitation processes in the given areas. The nature of the precipitation processes can be estimated not only by the radar itself but also using additional information sources, namely observations and NWP models, which are able to assess the magnitude of the precipitation enhancement. One example of this ”multisource” (or ”multiprocess”, ”multisensor”) approach can be system NIMROD (Golding 1998) which combines observation, NWP models, remote sensing data and even climatology (for the orographic enhancement) for the best analysis and very short range prediction.

References

Amitai, E., Wolff, D. B., Marks, D. A., and Silberstein, D. S.: Radar rainfall estimation: lessons learned from the NASA/TRMM validation program, Proceedings of ERAD 2002, ERAD publication series, 1, 255–260, 2002.

Fulton, R., Breidenbach, J., Seo., D.-J., Miller., D., and O'Bannon., T.: The WSR-88D rainfall algorithm. Wea. Forecasting, 13, 377–395, 1998.

Gabella, M., Joss, J., and Perona, G.,: Optimizing quantitative precipitation estimates using a non-coherent and a coherent radar operating on the same area, J. Geophys. Res., 105, 2237–2245, 2000.

Gjertsen, U., Salek, M., and Michelson, D. B.: Gauge-adjustment of radar-based precipitation estimates – a review, COST-717 working document No. WDD_02_200310_1, 33 p. (http://www.smhi.se/cost717/), 2003.

Golding, B. W.: Nimrod: A system for generating automated very short range forecasts, Meteorol. Appl., 5(1), 1–16, 1998.

Kitchen, M. and Blackall, R. B.: Representiveness errors in comparisons between radar and gauge measurements of rainfall, J. Hydrolog, 134, 13–33, 1992.

Koistinen, J. and Puhakka, T.: An improved spatial gauge-radar adjustment technique, Proc. 20th Conference on Radar Meteorology, AMS, 179–186, 1981.

Meischner, P. (Ed.): Weather Radar, Principles and Advanced Applications, Springer-Verlag, 337 p, 2003.

Michelson, D. B.: Quality control of weather radar data for quantitative application, PhD thesis, Telford Institute of Environmental Systems, University of Salford, Salford, UK, 281 pp, 2003.

Pohjola, H. and Koistinen, J.: Diagnostics of vertical reflectivity profiles at the radar sites, Proceedings of ERAD 2002, ERAD publication series, 1, 233–237, 2002.

Seed, A. W., Nicol, J., Austin, G. L., Stow, C. D., and Bradley, S. G.: The impact of radar and raingauge sampling errors when calibrating a weather radar, Meteorol. Appl., 3, 43–52, 1996.

Seo, D.-J., Breindenbach, J. P., and Johnson, E. R.: Real-time estimation of mean field bias in radar rainfall data, J. Hydrol., 223, 131–147, 1999.

Seo, D.-J.: Real-time estimation of rainfall fields using radar rainfall and rain gage data, J. Hydrol., 208, 37–52, 1998.

Steiner, M., Smith, J. A., Burges, S., Alonso, C. V., and Darden, R. W.: Effect of bias adjustment and rain gauge data quality control on radar rainfall estimates, Water Resources Research, 35, 2487–2503, 1999.

Steiner, M. and Smith, J. A.: Reflectivity, Rain Rate, and Kinetic Energy Flux Relationships Based on Raindrop Spectra, J. Appl. Meteorol., 39, 1923–1940, 2000.

Wood, S. J., Jones, D. A., and Moore, R. J.: Static and dynamic calibration of radar data for hydrological use, Hydrology and Earth System Sciences, 4, 545–554, 2000.

Zawadzki, I.: On Radar-Raingage comparison, J. Appl. Met., 14, 1430–1436, 1975.