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Radar and rain gauge estimates of daily and hourly sums of precipitation for river basins in the Czech Republic

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Abstract. Procedures adjusting pixel precipitation by merging radar data and rain gauge measurements and estimating area precipitation are presented. They determine daily and hourly precipitation for warm part of the year (April–September). The procedures use radar products (the estimate of radar-derived precipitation based on column maximum reflectivity) together with the data from on-line rain gauges routinely provided by the Czech Hydrometeorological Institute.

The adjusting procedure combines radar and gauge values in one variable that is interpolated into all radar pixels. The adjusted pixel precipitation is calculated from radar precipitation and from the value of the combined variable. Two procedures estimating daily area precipitation for seven river basins in the Czech Republic are evaluated. The first one uses the adjusting procedure to estimate pixel precipitation and the area estimates are determined by summing the corresponding pixel values. The second one applies regression technique to describe the relationship between area precipitation and individual precipitation estimates obtained by various methods. The regression model is developed separately for each river basin. The pixel adjusting procedure decreases the RMSE by 10–15% in comparison with the estimates based only on rain gauge data. The application of the regression technique decreases the error by additional 15%.

1 Introduction

Estimating area precipitation it is suitable to utilise high-resolution rainfall fields derived from weather radar measurements. However, direct application of radar-based precipitation determined from measured radar reflectivity is restricted by errors and uncertainty in the derived estimates (e.g. Austin, 1987; Joss and Waldvogel, 1990; Collier, 1996). The correction of radar precipitation fields by adjusting radar precipitation to rain gauge measurements is one of the frequently used methods (e.g. Fulton at al. 1998; Gabella and Amitai, 2000; Gibson, 2000; Michelson and Koistinen, 2000; Šálek, 2000). Its aim is to obtain the agreement between rain gauge precipitation and adjusted radar-derived rainfalls in corresponding pixels and thus to reduce systematic errors while the structure of radar fields is maintained. The disadvantage of this method is the limited representativeness of the gauge measurements (Collier, 1996; Germann and Joss, 2001).

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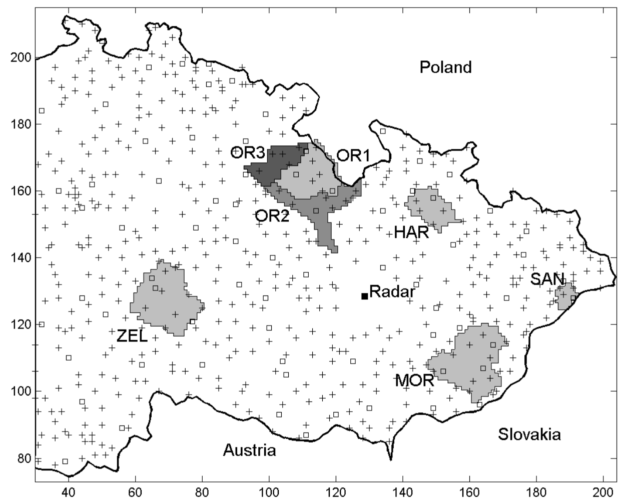

Fig. 1. The positions of rain gauges providing daily precipitation sums. The on-line gauges are marked by squares and the filled square shows the position of the radar Skalky. The river basins are shaded and marked by the abbreviations. The coordinates are given in pixels.

In this contribution, a method adjusting pixel precipitation by merging radar and gauge data is presented. The method is applied to daily and hourly precipitation sums. For daily sums two procedures calculating mean area precipitation are compared and their accuracy is evaluated for selected river basins in the Czech Republic (CR).

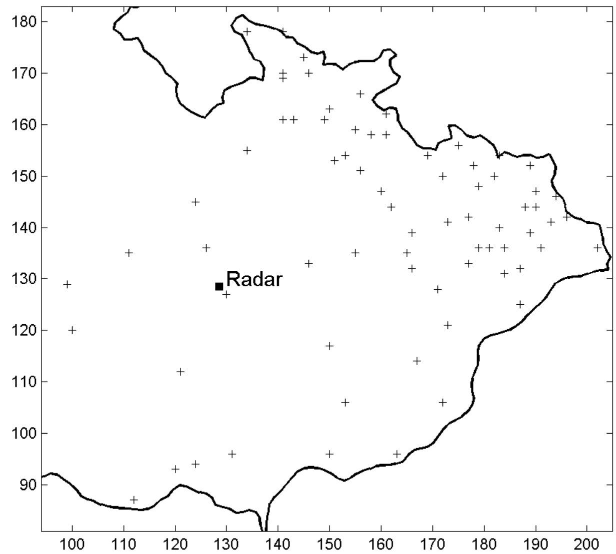

Fig. 2. The positions of rain gauges providing hourly precipitation sums. The filled square shows the position of the radar Skalky.

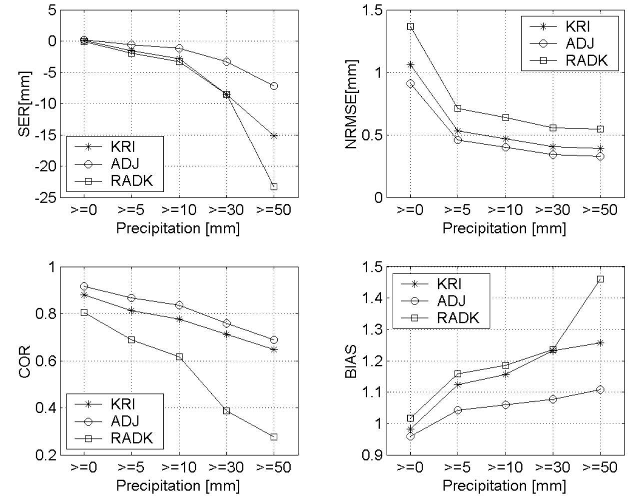

Fig. 3. Comparison of the pixel values of daily precipitation estimated by the ADJ, RADK and KRI methods. The SER, NRMSE, COR and BIAS are evaluated for precipitation categories $\geq$0, $\geq$5, $\geq$10, $\geq$30 and $\geq$50 mm.

2 Data

Data from radar Skalky (Doppler C band Gematronik METEOR 360 AC), and gauge measurements from the territory of the CR related to warm seasons (April to September) were used. The hourly and daily sums of radar rainfalls (RADX) were calculated by the procedure routinely applied in the Czech Hydrometeorological Institute (Havránek and Krácmar, 1996). The RADX values were available in 256×256 pixels of the radar domain where each pixel represented the area of 2 km $\times$ 2 km. Each rain gauge was assigned to the corresponding pixel of the radar domain. Both radar and gauge data were checked to remove data of unsatisfactory quality. Daily precipitation sums from 653 rain gauges from years 1996-98 were utilised (Fig. 1). While the measurements of 81 on-line gauges were used in the adjusting procedure the remaining gauge measurements served as independent data for verification. Area precipitation estimates were tested at seven river basins, which differed by the size, mean elevation above the sea level and distance from the radar (Fig. 1). In contrast to daily precipitation, the hourly precipitation sums are measured by a relatively small number of gauges. Data from 71 on-line gauges from 2001 were used in this study (Fig. 2).

3 Methods

3.1 Estimation of daily area precipitation

In the first step, the daily RADX values were corrected to adapt the radar precipitation level to the gauge values. In each pixel the RADX values were multiplied by a factor s,

$$s = \frac{\Sigma G_k}{\Sigma \mathrm{RADX}_k} \tag{1}$$

where G_k is the gauge precipitation and RADX_k is the value of RADX from the corresponding pixel. The sum is over all pairs with $G_k \geq 3$ mm and $\mathrm{RADX}_k \geq 3$ mm. The factor s was set to 1 when the number of the pairs was less than 10% of the total number of gauge data. The corrected radar field (RADK) was used instead of the RADX in the following calculations.

Two methods estimating area precipitation were compared. The first one (PADJ), adjusted radar precipitation in each pixel and the area estimates were determined by adding the pixel values covering the basin. The adjusting procedure (ADJ) combined radar value, RADK_k, and gauge value, G_k, at each k-th gauge position in one variable q_k

$$q_k = \frac{G_k + \lambda}{\mathrm{RADK}_k + \lambda}, k = 1, \ldots, n \tag{2}$$

where λ is a positive constant and n is the number of G_k, RADK_k pairs. Then the values q_k were interpolated (extrapolated) by the kriging method (Gandin, 1963; Seo et al., 1990) into all pixels (i, j) within the radar domain. The precipitation estimate $\mathrm{ADJ}(i, j)$ can be derived from (2) by using the interpolated value $q(i, j)$ and corresponding radar precipitation $\mathrm{RADK}(i, j)$:

$$\mathrm{ADJ}(i, j) = \max\big(q(i, j)(\mathrm{RADK}(i, j) + \lambda) - \lambda, 0\big) \tag{3}$$

The maximum assures that the adjusted precipitation is not negative. The kriging method applied the correlation function

$$C(r) = \exp(-\alpha r^{1/2}), \tag{4}$$

where r is the eucledian distance. The values of parameters $\lambda = 10$, $\alpha = 0.1$ were determined by tests comparing ADJ values with independent gauge measurements. Several values of λ and α were applied and the selected ones yielded the lowest root-mean-square-error.

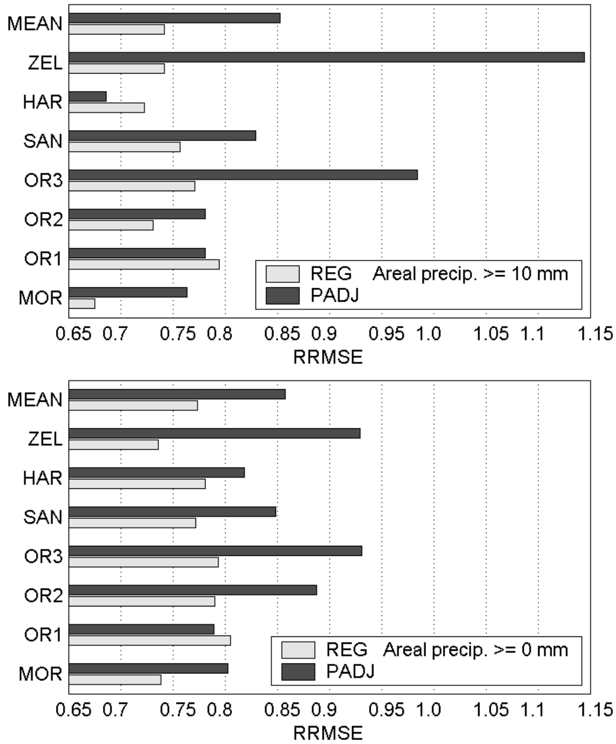

Fig. 4. Comparison of the PADJ and REG methods, estimating area precipitation, by the RRMSE. The acronyms of river basins correspond to Fig. 1 and MEAN shows the mean value over the basins. The methods are compared separately for all terms (bottom) and for terms with mean area precipitation ≥10 mm (upper).

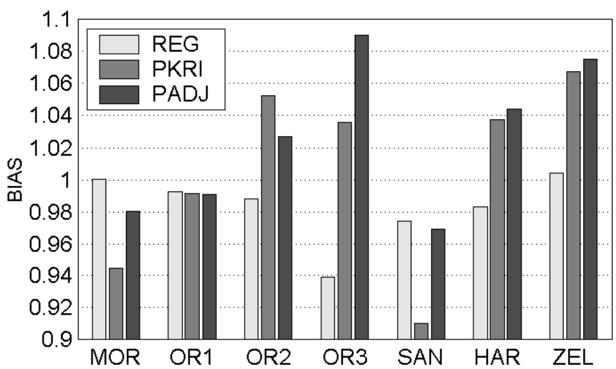

Fig. 5. The BIAS of the REG, PKRI and PADJ methods for the individual river basins. The acronyms from Fig. 1 are used.

The second method (REG) consisted in a statistical post-processing of the PADJ results. A regression model was developed to describe the relationship between the area precipitation (dependent variable) and three estimates of area precipitation (independent variables) based on pixel values: (i) RADK; (ii) on-line rain gauge measurements interpolated (extrapolated) by the kriging method into pixels (KRI) and (iii) ADJ. In order to take into account local characteristics

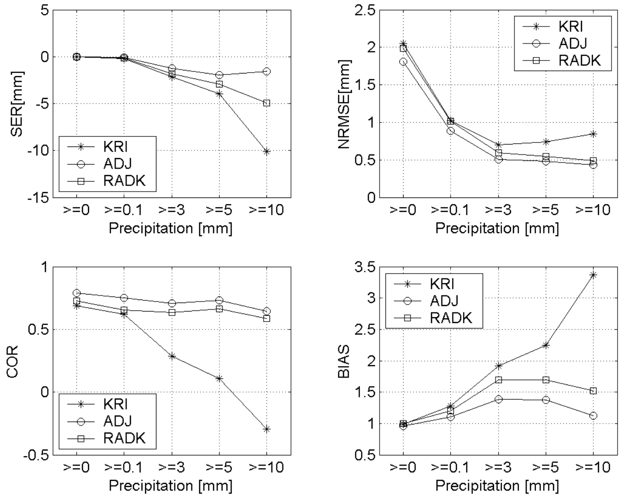

Fig. 6. Comparison of the pixel values of hourly precipitation estimated by the ADJ, RADK and KRI methods. The SER, NRMSE, COR and BIAS are evaluated for precipitation categories ≥0, ≥0.1, ≥3, ≥5 and ≥10 mm.

of the radar and gauge measurements the regression models are developed separately for each river basin. In addition to the multiple linear regression also ridge and robust regressions were applied (Dodge and Jurečková, 2000). In contrast to the multiple linear regression, the ridge and robust regressions are less sensitive to outliers. It is useful when there is not close relationship between predictors and predictands or when predictors and predictands can contain large errors. The applied methods are summarised in Table 1.

3.2 Adjusting procedure for hourly precipitation sums

For hourly sums the RADX was also corrected by the factor s (see Eq. 1). The sums were over all pairs with $G_k \geq 0.1$ mm and $\mathrm{RADX}_k \geq 0.1$ mm. When the number of the pairs was less than 10% of the total number of gauge data then s value was set to 1. The same adjustment procedure as for daily precipitation was applied (Eqs. 2–4). The parameters $\lambda = 10$ and $\alpha = 0.1$ were determined by the tests. The cross-validation was applied to perform independent verification. The measurements from one gauge were excluded from the data set and the corresponding adjusted pixel estimate was compared with the gauge measurements. In this way, all gauges were gradually excluded and the results were evaluated.

4 Results

The aim of the adjusting procedures was to estimate precipitation amount in a given location that would be measured by a rain gauge if one existed in this place. Therefore, the accuracy of the adjusting methods was compared with independent gauge measurements. The estimates of area precipitation were compared with area precipitation calculated by

Table 1. Abbreviations of the applied methods and their brief description

Abbreviation	Description
RADX	Radar-derived precipitation
RADK	Corrected radar-derived precipitation
KRI	Pixel precipitation estimate by using gauge data
ADJ	Pixel precipitation estimate by merging radar and gauge data
PKRI	Area precipitation by using KRI
PADJ	Area precipitation by using ADJ
REG	Area precipitation by using regression models

using all gauge data (653 gauges). In order to obtain area precipitation the gauge measurements were first interpolated by the kriging method into the radar network and then corresponding pixel values were summed.

The comparison was performed by using root-mean-square-error (RMSE), bias (BIAS), additive bias (SER) and Spearman correlation coefficient (COR):

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(p_i - g_i)^2}\,, \tag{5}$$

$$\mathrm{SER} = \frac{1}{n}\sum_{i=1}^{n}(p_i - g_i)\,, \tag{6}$$

$$\mathrm{BIAS} = \sum_{i=1}^{n} g_i \Big/ \sum_{i=1}^{n} p_i\,, \tag{7}$$

$$\mathrm{COR} = \sum_{i=1}^{n}\left(p_i - \frac{1}{n}\sum_{j=1}^{n} p_j\right)\left(g_i - \frac{1}{n}\sum_{j=1}^{n} g_j\right) \Big/ \sqrt{\sum_{i=1}^{n}\left(p_i - \frac{1}{n}\sum_{j=1}^{n} p_j\right)^2 \sum_{i=1}^{n}\left(q_i - \frac{1}{n}\sum_{j=1}^{n} q_j\right)^2} \tag{8}$$

where p_i and g_i are estimated and measured values, respectively, and n is the number of data pairs. While the RMSE and COR compare single values, the SER and BIAS compare mean of estimated and measured values over the studied period. The evaluated characteristics are calculated for various values of actual precipitation. The aim is to compare the performance of the methods for various precipitation categories.

4.1 Daily precipitation

In Fig. 3 the accuracy of the ADJ procedure is compared with both RADK and KRI. The normalised RMSE (NRMSE), which is the RMSE divided by the mean precipitation amount for the given precipitation category, is used. For the categories $\geq$0, $\geq$5, $\geq$10, $\geq$30 and $\geq$50 mm the corresponding means are 3.5, 14.4, 21.2, 45.5 and 74.7 mm. All the characteristics compared in Fig. 3 confirm apparently better results of the ADJ for all precipitation categories.

The REG models were developed separately for each river basin. The data from 1996-98 were divided into the calibration (two seasons) and verification (one season) data sets in all three possible ways. The model coefficients were derived from the calibration data and applied to the corresponding verification data. The type of the model, which yielded lowest mean RMSE over the three verification data sets, was selected. The accuracy of the estimates of mean area precipitation was evaluated separately for all cases and for the mean area precipitation greater than 10 mm. The threshold 10 mm represents heavy precipitation and its frequency is less than 10%. The accuracy of the PADJ and REG methods was compared with the PKRI. The relative RMSE (RRMSE), which is the ratio of RMSE of the considered method and PKRI is displayed in Fig. 4. It shows that the PADJ improves the estimate of the PKRI in all basins except one. On average, the improvement is 10–15%. The REG significantly improves the PADJ estimates. The REG decreases the RMSE of the PKRI by more than 20% for all terms and by more than 25% for terms with heavy precipitation. Apparently the best performance of the REG is also confirmed by the BIAS (Fig. 5), which is close to one for most basins. As the relationships between the predictors and predictands differed from year to year, the robust regression model provided the lowest RMSE for most basins.

4.2 Hourly precipitation

The accuracy of the ADJ is compared with the RADK and KRI in Fig. 6. The NRMSE is used for precipitation categories $\geq$0, $\geq$0.1, $\geq$3, $\geq$5 and $\geq$10 mm with the corresponding means 0.3, 0.9, 4.5, 7.1 and 14.4 mm. In contrast to the daily sums, the KRI yields significantly the worst results and confirms the importance of radar data for short accumulation intervals. The ADJ shows the best performance in all compared characteristics and for all categories.

5 Conclusion

The proposed adjusting method, merging radar and rain gauge data, yielded more accurate pixel estimate of precipitation comparing to the corrected radar as well as to the method that uses only rain gauge data. Although hourly precipitation is estimated by the corrected radar quite well the adjusting procedure improves the estimates.

The adjusting method applied to mean area estimates of daily precipitation decreases the RMSE by 10%–15% in comparison with estimates based on rain gauge data only. The application of the regression postprocessing technique decreases the error by additional 10%. On one hand, this method requires careful development of the regression models for each river basin to avoid overfitting; on the other hand, it considerably improves the accuracy of the area estimates.

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References

Austin, P. M., 1987: Relation between measured radar reflectivity and surface rainfall. Mon. Wea. Rev., 115, 1053-1070.

Collier, Ch.C., 1996: Applications of weather radar systems. Praxis Publishing Ltd.

Dodge Y., and J. Jurecková, 2000: Adaptive linear regression. Springer-Verlag, New York.

Fulton, R. A., J. R. Breidenbach, D. J. Seo, and D. A. Miller, 1998: The WSR-88D rainfall algorithm. Wea. Forecasting, 13, 377-395.

Joss, J., and A., Waldvogel, 1990: Precipitation measurements and hydrology. D. Atlas (Ed.), Radar in Meteorology, Amer. Meteor. Society, 577-606.

Gabella, M., and E. Amitai, 2000: Radar rainfall estimates in an alpine environment using different gauge adjustment techniques. Phys. Chem. Earth (B), 25, 927-931.

Gandin, L., S., 1963: Objective analysis of meteorological fields. Gidrometeorologicheskoe izdatelstvo, Leningrad.

Germann, U., and J., Joss, 2001: Variograms of radar reflectivity to describe the spatial continuity of Alpine precipitation. J. Appl. Meteorol., 40, 1042-1059.

Gibson M., 2000: Comparative study of several gauge adjustment schemes. Phys. Chem. Earth (B), 25, 921-926.

Havránek, P., and J., Krácmar, 1996: New weather radar station in central Moravia. Czech Meteorological Bulletin 49, 81-84.

Michelson, D. B., and J. Koistinen, 2000: Gauge-radar network adjustment for the Baltic sea experiment. Phys. Chem. Earth (B), 25, 915-920.

Seo, D. J., W. F., Krajewski, A. Azimi-Zonooz and D. S., Bowles, 1990: Stochastic interpolation of rainfall data from rain gauge and radar using cokriging. 1. design of experiments. Water Resour. Res., 26, 915-924.

Šálek, M., 2000: The radar and rain gauge merged precipitation estimate of daily rainfall First results in the Czech Republic. Phys. Chem. Earth (B), 25, 977-979.