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Operational application of combined radar and raingauges precipitation estimation at the CHMI

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Abstract. The Czech Hydrometeorological Institute (CHMI) runs two C-band Doppler weather radars which provide good coverage of precipitation over the area of the Czech Republic. For the quantitative precipitation estimation (QPE), reflectivity from pseudoCAPPI level of 2 km above sea level is used and the rainfall rate is then obtained by a constant Z-R relationship. Since the radar-only-based QPE is not considered satisfactory, some corrections have been introduced in order to achieve better accuracy of the instant precipitation estimates. The corrections include the algorithm using vertical profile of reflectivity which reduces the range-dependent underestimation of single radar estimates, raingauge-based adjustment and combination with available raingauge measurements. The adjustment using single coefficient over the radar domains is based on collocated radar and raingauge measurements in a time-moving window whose length is an adaptable parameter. The combination of the adjusted radar QPE with available raingauge measurements is achieved by a simplified method of double optimal estimation. The system is in routine operation for precipitation accumulation of 1, 6 and 24 h and the results are available in HTML format. It serves for warning purposes, for NWP model verification and hydrological applications at the CHMI. The visualization allows for quick comparison of radar, radar-adjusted, raingauge-only and combined estimates along with mean areal QPE for predefined catchments using all mentioned estimates. The instant comparisons and some additional diagnostic information allows to see better the deficiencies and errors of the two complementary estimation systems.

1 Background

The Czech Hydrometeorological Institute modernized its weather radar network in late nineties and now runs two single polarization C-band Doppler radars used for qualitative analyses and extrapolative nowcasting of weather phenomena (connected with precipitation), VAD-based wind measurement and quantitative precipitation estimations (QPE). As the radar-based QPE is error prone for known reasons (see, e.g. Joss and Waldvogel, 1990 or Collier, 1996), two correction methods have been proposed at the Czech Hydrometeorological Institute (Kráčmar et al., 1999), which could partially compensate for the radar measurement deficiencies. The former correction method was based on the statistical relationship between the raingauge measurements and collocated radar estimates, the latter used vertical profile of reflectivity (VPR). Since the VPR-based method, although performed slightly worse than the statistical correction, offers more physically sounded algorithm, it resulted to be the preferred method for later development.

Since the 1999 the effort at the CHMI was oriented towards multisensor approach, inspired mainly by the procedure of the NOAA/NWS (Fulton et al., 1998; Seo, 1998b), which combines the measurement of the radar with the operationally available raingauge readings. This method is based on following ideas and assumptions:

1. The radar-based QPE and raingauges are complementary sensors and the estimates should be used in similar visualization environment for instant comparisons.

2. The intercomparison between the radar-based QPE and corresponding raingauge measurements can indicate errors of the particular measurement or nature of the precipitation processes.

3. Mean field bias (MFB) adjustment generally decreases the error of radar-based QPE.

4. Combination of ”semicontinuous” radar estimate and the “point” measurement of raingauges, using some of geostatistical concepts, can result in the most accurate QPE.

The multisensor method was built in at the CHMI in 1999–2003, starting from experimental calculation of daily precipitation estimates in 1999–2000 (Šálek, 2000). Since 2003 the

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Table 1. Parameters of the weather radar of the Czech Hydrometeorological Institute

Radar station	Skalky	Brdy – Praha
WMO Indicative	11718	11480
Location	Central Moravia	Central Bohemia
Latitude	49,501 N	49,658 N
Longitude	16,790 E	13,818 E
Altitude of the antenna.	767 m	916 m
Measurement cycle	10 min.	10 min
In operation since	1995	2000
Made by	Gematronik	EEC
Type	Meteor 360AC	DWSR-2501C
Frequency band	C	C
Doppler mode	yes	yes

multisensor (radar-raingauge combined) QPE system, providing hourly-and-longer accumulation estimates, has been serving as a standard application for general precipitation overview, warning purposes, hydrological application and NWP verification at the CHMI. The work in 2002–2004 concentrated more on tuning adaptable parameters, improvement of the HTML-based graphical user interface (GUI) and utilization of the areal estimates in hydrological models. In the same time, similar procedure of the Institution of Atmospheric Physics (Sokol et al., 2002) has been put into semioperational use on daily sums as an alternative to the algorithm that is presented in this paper.

2 Algorithm of the original radar-based QPE

The parameters of radar data are listed at the Table 1. The radar-based QPE is based on the Z-R formula

$$Z = 200R^{1.6} \tag{1}$$

For $Z < 7$ dBZ R=0 mm/h and for $Z > 55$ dBZ R=R(55dBZ)=99.85 mm/h. These limits suppress the influence of non-precipitating clouds and hail on the radar estimation.

The reflectivity used in the conversion into the precipitation rate is taken from the altitude 2 km above seal level (pseudoCAPPI 2 km). It is calculated from the volume reflectivity data using vertical interpolation between two closest elevations measured by the radar (PPI levels) or taken from the lowest available PPI (if the lowest available PPI is above 2 km level). The ten-minutes precipitation rates are then integrated for following time periods: 1, 3, 6, 12 and 24 h. VPR corrections (Novák and Kráčmar, 2001) are applied routinely but since there is substantial overlap of both radars, the potential benefit of the VPR correction is not so significant. The VPR corrections are much more important when one of the radar is out of operation for a long time. Therefore the VPR-corrected radar data are not yet operationally used in further processing and hydrological simulations except some experiments.

3 Combined (multisensor) precipitation estimate

3.1 Mean field bias adjustment

The original radar precipitation estimate is routinely adjusted using the mean field bias adjustment. The key issue is to estimate the bias factor (assessment factor) optimally. If one uses the assessment factor only for the given time period (e.g. one hour), usually only a few raingauge measurements (and small precipitation accumulation) are available and the bias tends to be unrepresentative for the whole radar domain. Therefore the adjustment algorithm accumulates the radar data and the corresponding raingauge measurements (for the raingauge up to 150 km from the radar site) for time-moving window of typical size of several days.

The time moving window (adaptable parameter) is also dependent on the mean areal accumulation of precipitation and in some extreme dry spell it could reach even several weeks until predefined accumulation threshold is reached. However, as it is assumed that the 'old' precipitation regime is not representative for the beginning of 'new' precipitation process and long-time assessment factor should not be far from one, during "dry" weather when no precipitation is recorded, the bias slowly drifts to value of 1. The contribution of the daily accumulations used for the bias calculation is also weighted by negative exponential function which is designed so that the "oldest" day used for the bias computation has the weight of 0.1. This parameter is rather arbitrary but it reflects the assumption that the bias should be representative especially for the nearest periods of precipitation accumulation. The bias (adjustment factor) is then computed by following formula:

$$BIAS = \frac{\sum_{i=1}^{n} w_i G_i}{\sum_{i=1}^{n} w_i R_i} \tag{2}$$

where G_i and R_i are the raingauge measurement and collocated radar estimate (for element 1×1 km) and w_i are weights exponentially decreasing with the time of accumulation (the farer daily accumulation, the less the weight).

3.2 Gauge-only and radar-raingauge combination estimate

The combination (called "merge") is computed as a simplified version of double optimum estimation (Seo, 1998b). It is a linear combination of adjusted radar estimate and raingauge data. The weights of the radar and raingauge(s) contribution are estimated using the distance from the raingauge site(s) and the average variability of the radar and raingauge precipitation fields. Generally, the weight(s) of raingauge measurement(s) is (are) inversely proportional to the distance from the nearest raingauge(s) and the course of the weights is modelled by negative exponential function with a parameter dependent on the variability of the precipitation field.

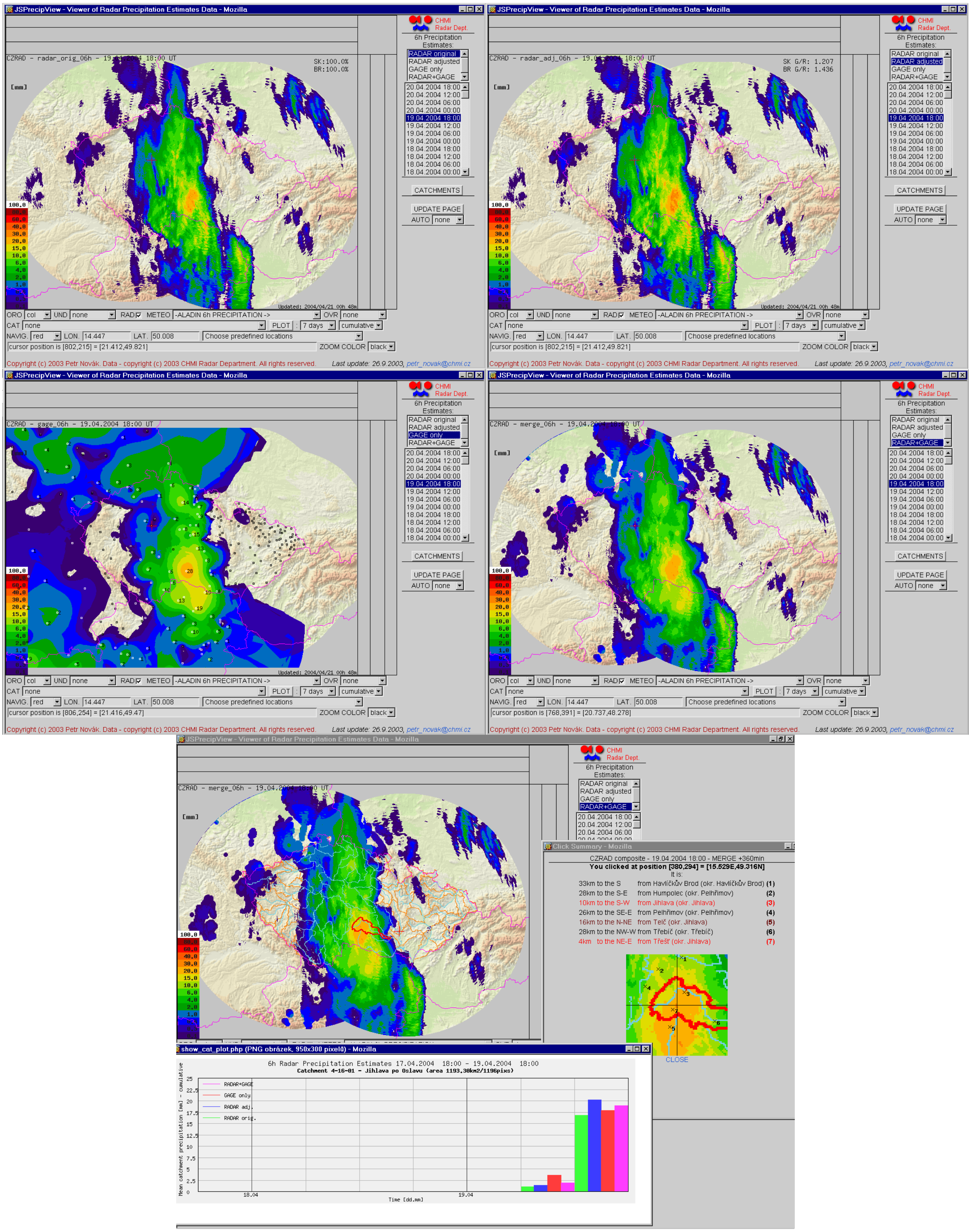

Fig. 1. An example of original radar, adjusted radar, gauge-only and combined 6-h estimate (from left to right, from top to bottom) for 19 April 2004, 18 UTC, as presented in the system JSPrecipView. At the bottom you can find an example of the areal precipitation estimate displayed in a form of accumulation of the different types of estimate for the catchment highlighted in the map and in the zoom.

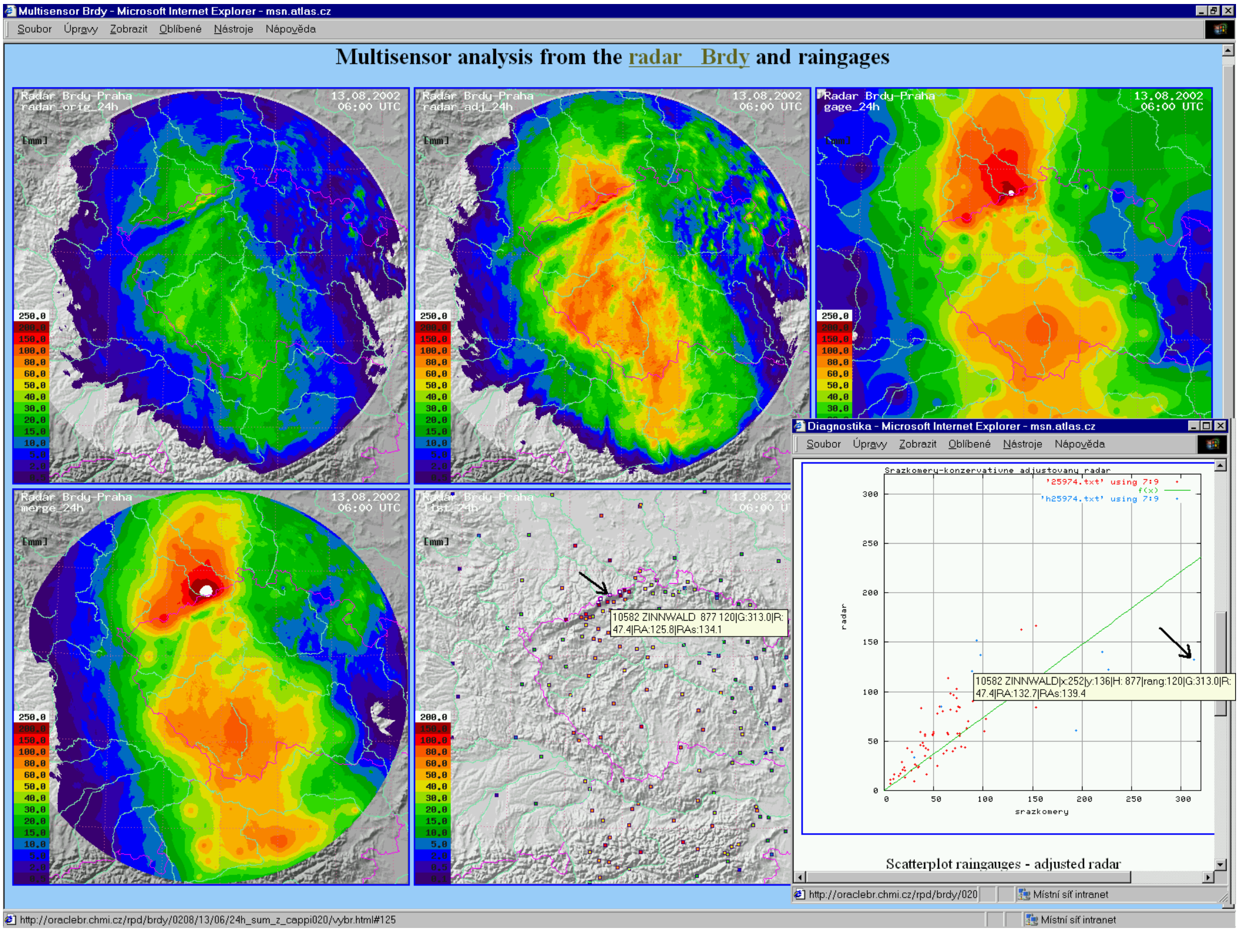

Fig. 2. An example of the original radar, adjusted radar, gauge-only, combined 24-h estimate, raingauge locations and scatterplot of gauge measurements and collocated adjusted radar estimates (from left to right, from top to bottom) for 13 August 2002, 06 UTC, as presented in diagnostic mode for radar Brdy domain. The black arrows point at the mountainous station Zinnwald (877 m above sea level, 120 km from the radar site) which recorded 312 mm/24 h and where orographic enhancement caused significant underestimation of the radar QPE due to strong north-west winds.

In addition, the multisensor procedure routinely provides also a raingauge-only estimation estimate that is computed by an adapted version of the Seo (1998a) algorithm.

The original radar estimate, adjusted radar estimate, raingauge-only field and combined radar-raingauge estimate ("merge") are available operationally for visual inspection for 1-h accumulations, for 6-h accumulations (calculated at 00, 06, 12, 18 UTC) and 24-h accumulations (calculated at 06 UTC).

All the precipitation estimate for given time period can be displayed using WWW browser. The user has an option to choose between two type of visualization: "JSPrecipView" and "Diagnostic". The JSPrecipView is a JavaScript-based system which uses PHP scripts at the server side and provides the user with the option to switch between original radar, adjusted radar, raingauge-only and merged estimate (see Fig. 1). The application is equipped by advanced features of geographical information systems (GIS): It can provide the user with geographical coordinates at any point at the map(s), distance from predefined locations (mostly towns), layers of main roads, railways, districts, rivers and catchments. The system is able to compute areal precipitation accumulations within predefined catchments in a user-adaptable time-moving window spanning from 1 to 21 days (see Fig. 1).

The "Diagnostic" presentation provides the user with more information about the radar-raingauge relationship for both radars and with more statistical characteristics of the radar and raingauge data. It also displays raingauge data that were rejected from the further processing due to obvious malfunctioning of raingauge and the raingauge data that are "suspicious" because their values are outlying too far from the radar estimates. An example of the "Diagnostic" presentation of an 24-h precipitation estimate is at Fig. 2. The purpose of the diagnostic version is to allow the user or supervisor for deeper insight into the radar and raingauge precipitation estimates, radar-raingauge relationships (by scatterplots), MFB adjustment performance etc. This presentation can better explain possible deficiencies of the sensors than the JSPrecipView images and is useful mainly for application development and for analyzing of problematic/suspicious cases by well-experienced users. On the contrary, the JSPrecipView is designed for advanced presentation of all precipitation estimates to wide user-base.

4 Verification

The verification is being made especially for 24-h accumulation on those raingauge measurements that are not operationally used as an input for the multisensor analysis. These data, recorded manually by cooperative non-professionals, are available "off-line", usually several weeks afterwards. Although the radar-raingauge relationship for these readings also suffers from the known sampling problem, the difference between the (independent) raingauge measurement and the particular estimate (measured usually by the root mean square error, RMSE) can indicate the quality of the estimates.

One of the first attempt to verificate the quality of daily estimates was made in Šálek (2000), stating that the combined estimate yields the best results (least RMSE). The second best estimate was obtained by gauge-only field, followed by adjusted radar and original radar estimate.

Concerning the hourly estimates, verification concentrated only for period of 6–16 August 2002 when special effort was taken to obtain the hourly precipitation accumulation from the manual pluviometers (old version of recording raingauge) in the framework of the evaluation of the flood that occurred in the Czech territory that time. The pluviometer measurements were considered as an alternative independent data set which was compared with the types of the hourly QPE estimate. The differences between the estimates and the collocated pluviometer readings measured by RMSE are shown at Fig. 3. Although the mean RMSE for the whole period is not very informative regarding the absolute accuracy, it can be seen that the unadjusted radar provides similar accuracy as telemetric raingauges, but adjustment reduces the RMSE by 16% and the combination with the telemetric raingauges by 20% of the original radar RMSE.

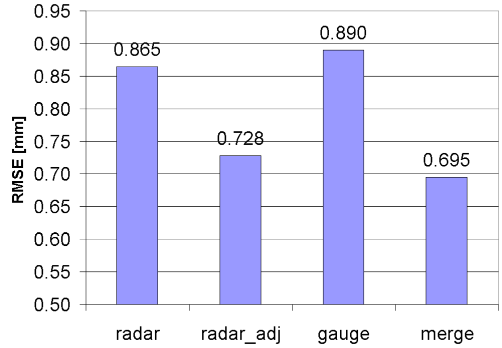

Fig. 3. RMSE between the hourly pluviometric measurement of 74 stations within 150km range from the radar Brdy and the collocated QPE of Brdy radar, adjusted radar estimate, optimum estimation from telemetric raingauges and merged estimates from 6 August 2002, 06 UTC to 16 August 2002, 06 UTC. The estimates are on 1×1 km grid. The number of telemetric raingauges merged with the adjusted radar estimate is 74, from which 40 are located within 150 km from the radar site.

5 Conclusions and outlook

The combined radar-raingauge (or multisensor) estimate proves to be a useful concept which is being used not only for qualitative warning system of the CHMI, but also by the hydrological community at the CHMI for hydrological modelling (see Šálek and Březková, 2004) and also by specialists responsible for the monitoring of the quality of the raingauge measurements. The analyses are being used more also in elaborating export opinions dealing with heavy precipitation.

However, the multisensor system does not guarantee that there is not a substantial estimate error stemming from the deficiency of the radar-based QPE and from the insufficient raingauge density in the particular area. This system rather attempts to exhaust the information potential of all the sensors in a way which is easy to use and which allows further training of the hydrometeorologists.

Future work will concentrate mostly on application of the QPE in the hydrological modelling and further tuning of the adaptable parameters concerning mainly the adjustment scheme.

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