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# The use of radar and gauge accumulation datasets for the derivation of daily tuned Z-R relationship

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**Abstract.** In the report, the application of the daily-tuned ***Z-R*** relationships for the rain radar calculation is discussed. For the comparison the operational radar and ground-based data about daily rainfall precipitation in summer season 2000 in Moscow are used.

## 1 Introduction

The main purpose of this paper is to investigate the effect of application of daily-tuned ***Z-R*** relations to operational radar data in terms of daily rainfall accumulations. This idea about of influence of dominant physical process on formation of microphysical precipitation structure has been stated about 40 years ago (Borovikov et al., 1967) and Lee and Zawadzki (2001, 2004) actively popularize it now. This process could determine mainstream ***Z-R*** relationship during a days or duration of storms.

In this report, we will attempt to answer the following questions:

- What errors do the radar measurements of the daily rainfall accumulations by the use of the single ***Z-R*** relation in rain calculations have?
- How to obtain a daily-tuned ***Z-R*** relation?
- What residual radar-gauge (R-G) discrepancy in daily accumulations remains at use of daily-tuned ***Z-R*** relations?

It is also discussed how well the gauge-based rain rate agrees with radar ***R*(t)** estimates that was calculated with daily-tuned ***Z-R*** relations.

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## 2 Experimental Data

### Radar

Our data were collected with the dual-wavelength (S- and X-band) operational radar MRL-5 in Moscow on summer rain seasons 2000 and 2003. For the analysis, we use non-attenuated S-band data with beam width 1.5°. The volume coverage pattern (VCP) includes 21 elevation tilts: from 0.7° to 41°. The resolution of radar volume file is 1° in azimuth and 1-km in radial direction. Next, the clutter echoes were removed from raw radar data and VPR correction is implemented. Finally, from pseudoCAPPIs generated at height 0.8 km, rain rate and daily accumulation maps are computed in Cartesian coordinates with 4×4 km space resolution taking into account horizontal propagation of precipitation systems between successive scans. Radar rain estimates are available every 10 min.

For our analysis we select the summer rainy season 2000 (June–September) in Moscow region. Case study for 18 days with considerable mean daily accumulations >4 mm is presented. Most of them are mesoscale stratiform frontal storm with separate local embedded convection zones. The selected days provide about 85% of total precipitations for this period in Moscow.

### Gauge

Ground validations of radar estimates are provided by comparison with daily rain accumulations obtained from 18 operational gauges of Russian Meteorological Service located at the distances up to 100 km from the radar site in Moscow region.

### Pluviograph

We also compare our radar rainfall rate ***R*** (mm $h^{-1}$) estimates with pluviograph measurements. The automatic tipping-bucked rain gauge (pluviograph) has accuracy

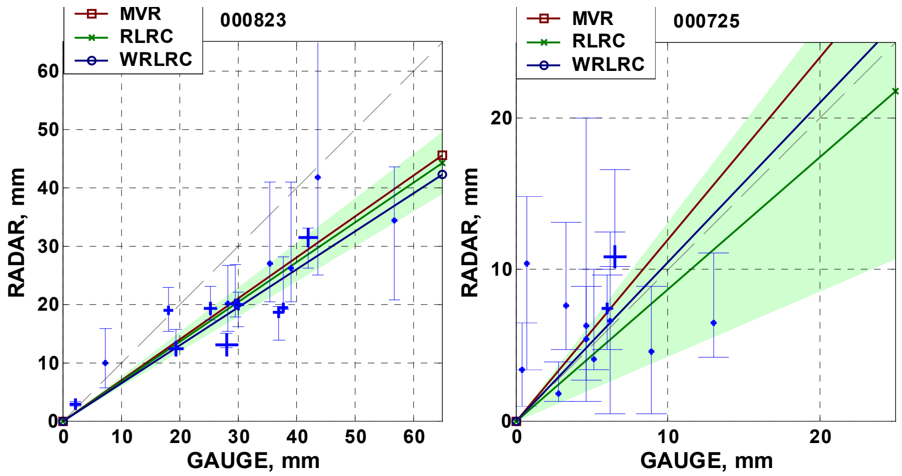


**Fig. 1.** Scatterplot of Radar-Gauge daily accumulations (mm) in Moscow for 08/23/2000 (left) and 07/25/2000 (right). The vertical bars represent precipitation field heterogeneity (min/max accumulation values around of gauges pixel vicinity). Size of marker represents the gauges weight in WRLR corresponding to degree of precipitation heterogeneity. Shaded area denotes 95%-probability region of MVR line slope.

≤0.16 mm for one tip. The pluviograph is located on distance 21 km from the radar site.

## 3 Data analysis procedure

The radar rain rate $\boldsymbol{R}$ estimations we calculate by single $\boldsymbol{Z}$-$\boldsymbol{R}$ relation

$$Z = AR^b, \qquad R = \exp\left\{\frac{\ln 10}{10\,b}(dbZ - dbA)\right\}, \qquad dbZ \equiv 10\,lgZ, \quad dbA \equiv 10\,lgA, \tag{1}$$

with climatological coefficient values (for our conditions): $\boldsymbol{A}_*$=200, $\boldsymbol{b}_*$=1,6 . The radar was adequately calibrated in an absolute sense taking into account the requirement of total bias absence in seasonal time scale for parameter $\boldsymbol{A}$ value. In that case, scatter of radar rain estimations around gauge data can be due to different reasons: time-space DSD (and $\boldsymbol{Z}$-$\boldsymbol{R}$ relation) variations, a volume-point difference in nature of R-G rain measurements, and instrumental errors. It is very difficult to estimate their relative contributions to total discrepancy. Two examples with good and poor R-G agreement in daily accumulations are presented in Fig. 1.

The small R-G discrepancy case is shown in Fig. 1 (left), and the day with large scattering and low data correlation is presented in Fig. 1 (right). In first case, we probably deal with dominant physical process in the entire day. The corresponding coefficients $\boldsymbol{A}_0$ and $\boldsymbol{b}_0$ can differ from accepted in our calculations values $\boldsymbol{A}_*$ and $\boldsymbol{b}_*$, and R-G difference can be evaluated by the following way

$$R_* = \alpha\,(R_0)^\beta, \quad \alpha = \left(\frac{A_0}{A_*}\right)^{1/b_*}, \quad \beta = b_0/b_*, \tag{2}$$

where $\boldsymbol{R}_*$ – radar estimation and $\boldsymbol{R}_0$ – real rain rate, and $\alpha$ represent the slope of regression line in Fig. 1 under condition of $\beta \sim 1$. To the quality evaluation of radar rain estimates by comparison with gauge network, we use some criteria: absolute bias (in *mm*), normalized bias (NB in %) and NB-related "mean value ratio" (MVR), as well as reduced linear regression coefficient (RLRC):

$$bias \equiv \frac{1}{N}\sum_{i=1}^{N}(R_i - G_i) = \langle R\rangle - \langle G\rangle, \quad rmse = \left[\frac{1}{N}\sum_{i=1}^{N}(R_i - G_i)^2\right]^{1/2},$$

$$NB \equiv \frac{bias}{\langle G\rangle}, \qquad NSE \equiv \frac{rmse}{\langle G\rangle}$$

$$MVR \equiv \frac{\langle R\rangle}{\langle G\rangle} = NB + 1, \qquad RLRC \equiv \frac{\sum_{i=1}^{N} R_i G_i}{\sum_{i=1}^{N} G_i^2} \tag{3}$$

where $\boldsymbol{R}_i$ and $\boldsymbol{G}_i$ – radar and gauge rain accumulations (expressed in mm), which corresponds $\boldsymbol{i}$-th gauge site, and brackets mean averaging over all ($\boldsymbol{N}$) such sites. The line with MVR slope is minimize of distance from measurement points to line, while the RLRC line is minimize of their square. In analysis we use RMS error (in mm) and normalized standard error NSE (in %) also. In the Fig. 1 we can see MVR and RLRC regression lines as well as weighted regression line (WRLRC) with weights $\boldsymbol{w}_i$, which are proportional to the precipitation heterogeneity degree by estimation on associate pixels around of gauges site pixel. It is interesting that for radar estimates with large bars (high heterogeneity of precipitation field degree at this point) the relatively larger contribution of high rate to total accumulation in comparison with the gauges with small bars is usually observed. Thus, the use of the weighed regression coefficients permits to reduce the influence of the strong heterogeneity of the field of the rain accumulation in the cases of storms with the substantial contribution of high rate to the rain accumulation.

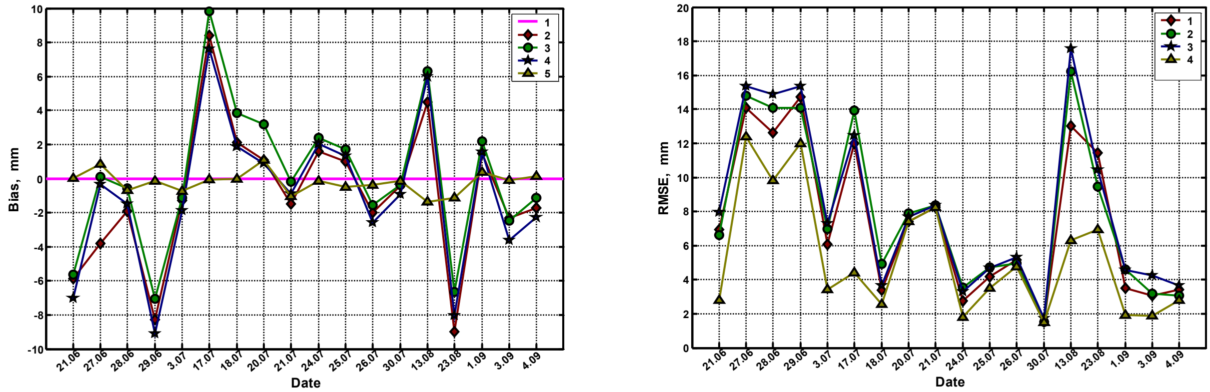


**Fig. 2.** The R–G bias (left) and R-G rms error (right). The abscissa is the date of the analyzable period. Table of symbols for bias: 1 – line without bias, 2 – Z=200 $R^{1.6}$, 3 – Z=215 $R^{1.5}$, 4 – Z=300$R^{1.4}$, 5 – min RMSE. Table of symbols for RMSE: 1 – Z=200 $R^{1.6}$, 2 – Z=215 $R^{1.5}$, 3 – Z=300$R^{1.4}$, 4 – daily-tuned by min(RMSE).

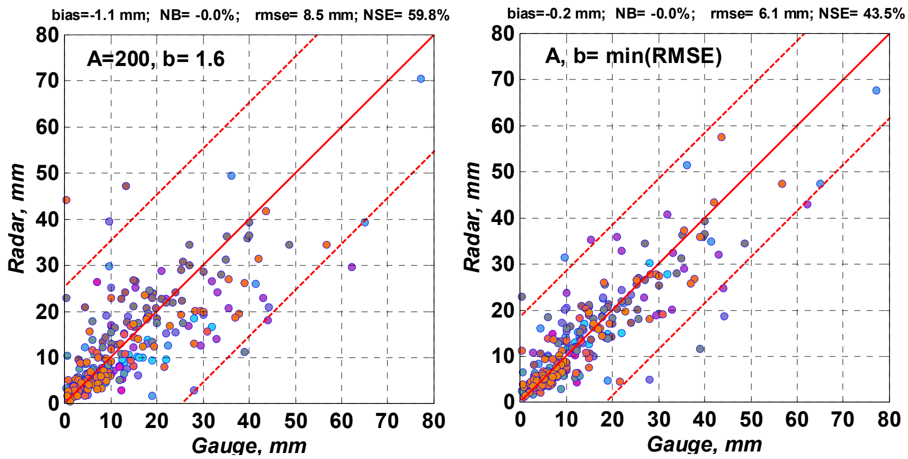


**Fig. 3.** Daily rain accumulation R–G scatterplot for single ***Z-R*** relation (Z=200$R^{1.6}$) (left) and for daily-tuned ***Z-R*** relation (right). The triple SD lines are shown also. The different color of separate measurements corresponds to the separate days of the analyzed period.

## 4 Daily tuned *Z-R* relation

As usual the day-to-day variability can be investigated by considering daily averaged DSDs (or daily averaged ***R*** and ***Z***). Next, information about daily average DSD and connected the dominant physical process can be used in the radar rain calculations (Lee and Zawadzki, 2001, 2004). However, this approach is local and his results are difficult for applying to the analysis of results for scales of the total radar range and long time intervals.

As opposed to that, we search of daily ***Z-R*** relationship, carrying out the criterion function (3) investigation in space of factors ***A*** and ***b***. Usually the retrieval domain extended by coefficient ***A*** in the range 50–500, and by coefficient ***b*** in the range 1.0–2.75. This method, hereinafter called Ab-diagram method, allows retrieval parameters values, which provide the conceivable agreement of the R-G measurements. Examples of the using this method can be seen in (Melnichuk and Pavlyukov, 2001). Here we only shall note the interesting features, which have been revealed by means of this method:

1) in range space of ***A*** and ***b*** parameters in ***Z-R*** relation radar data are in full agreement by any criterion with gauge measurements on optimal curve instead of unique value of ***A*** and ***b***, as it would be possible to expect. The optimal curve has significant change location in (***A***, ***b***)-space depending on variations of the averaged event characteristics, e.g. DSD,

2) the maximum of correlation coefficient and the minimum RMS error for radar-gauge rainfall datasets are reached at ***b***:1,4÷2,0 for most of examined event.

## 5 Results

Let us consider the day-to-day variability of radar-gauge consistency on an example of *absolute bias* and *RMSE* if fixed coefficients in ***Z-R*** relation are used. In our radar rain calculations we used several pairs of the fixed ***A,b*** coefficients for all analyzed days ($\boldsymbol{Z}$=200 $\boldsymbol{R}^{1.6}$,$\boldsymbol{Z}$=215 $\boldsymbol{R}^{1.5}$, $\boldsymbol{Z}$=300 $\boldsymbol{R}^{1.4}$), and

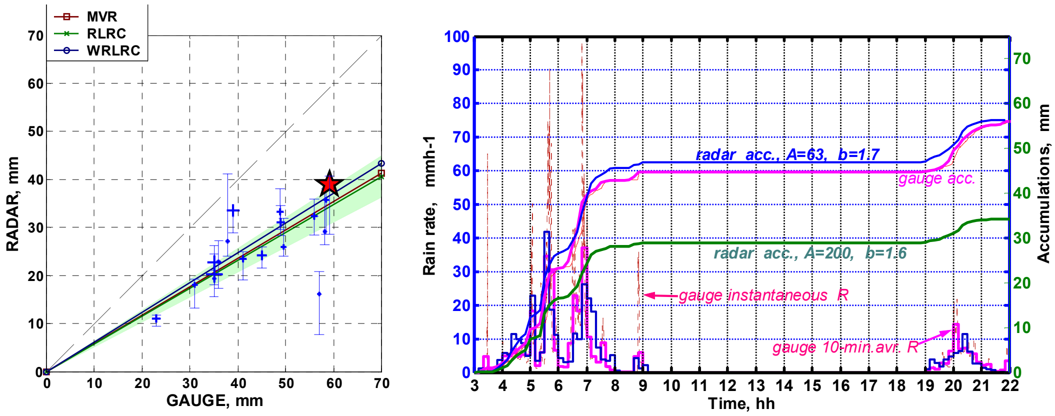


**Fig. 4.** Radar measurements of heavy rain over Moscow region on August 13, 2003. The scattergram of daily accumulation for radar versus gauge is presented at the left graph. Variations of radar and pluviograph rain rate ***R*(t)** (mmh$^{-1}$) and total accumulation ***Q*(t)** (mm) as a function of LST are shown at the right graph. The instantaneous and 10-min average ***R*(t)** and ***Q*(t)** values are shown for the gauge measurements. The radar ***R*** and ***Q*** are calculated for two ***Z-R*** relations: ***A***=200,***b***=1.6 and daily-tuned ***A***=63, ***b***=1.7. The accumulation value corresponding to pluviograph measurements is pointed by "starlet".

daily-tuned ***A,b*** values for each day separately, which minimize RMSE.

As we can see from the left graph in Fig. 2, the radar estimations of total precipitation with the use of any fixed coefficients ***A*** and ***b*** show the appreciable day-to-day bias. Use in radar calculations of optimal daily coefficients significantly decreases bias for all days. However, the right graph in Fig. 2 shows that to remove mean-square R-G discrepancy by the use of optimal values of ***Z-R*** coefficients in radar rain calculations is impossible. It is possible to descend the RMS error only in the half of the cases: this error is lower than 4 mm for 9 days. In the remaining cases, RMSE is from 4 mm up to 12 mm for daily accumulations. The absence of one dominant physical process in daily scale can be the possible reason for high residual of the R-G data comparison. Further reduction RMS error is possible only by the use of ***Z-R*** relation corresponding to the current precipitation microstructure in the radar rain calculations.

Situation for the analyzed period as a whole is shown in Fig. 3. The cases of the radar rain calculations with the use single relation are presented: (1) $\boldsymbol{Z}=200\boldsymbol{R}^{1.6}$ (left), and (2) daily-tuned ***Z-R*** relation for each day separately from the requirement of RMSE minimum (right). The use of optimal relations for each day permits to decrease RMS error for all season long from 8.5 to 6.1 mm or from 60% to 44% for NSE. For the separate days the average absolute bias was reduced from 3.3 to 0.5 mm.

Comparing the errors level of 44% FSE obtained in the present work for daily-tuned ***Z-R*** relations with the results for the polarimetrically-tuned ***Z-R*** relations (Chandrasekar and Bringi, 2004; Ryzhkov and Giangrande, 2004) with 15–20% FSE, it is possible to conclude that the difference in 25–30% FSE can be explained by time-spatial variations ***Z-R*** relation relative to mean diurnal values. Our value RMS error 6.1 mm well agree with the Ryzhkov (2004) information about RMSE level in their radar measurements of hourly accumulations in point by conventional ***R(Z)*** algorithm – 5.51 mm.

### 5.1 Use of the daily tuned *Z-R* relations for the calculations of radar rain rate

It is interesting how does radar rain rate ***R***(t) behave if the daily-tuned ***Z-R*** relation is used. For the period 03:00–22:00 LST, August 13, 2003 the comparative analysis of the radar and gauge accumulations shows the high value of the determination coefficient (∼96%), therefore there are the foundations for assuming about the influence of the dominant physical process. Furthermore, the essential radar underestimation of total accumulation for all gauges occurs. We determined the daily tuned coefficients ***A*** (63) and ***b*** (1.7), then ***R***(t) were calculated and compared with the pluviograph measurements. The radar and gauge rain intensity ***R*(t)** and accumulation ***Q*(t)** profiles are represented in Fig. 4.

In this case the use of the fixed daily tuned coefficients for radar calculations has provided a good agreement between ground-based and radar rain measurements. Notice that revealed Chandrasekar and Bringi (2004) significant time variations of factor ***A*** in rain polarization measurements are realized probably not always.

## 6 Conclusions

The use of the weighed regression coefficients permits to reduce influence of the strong heterogeneity of the rainfall field in the cases of storms with the significant contribution of heavy rain intensities to the storm total accumulation.

The comparative analysis of R-G measurements of daily rainfall accumulation permits to determine the daily ***Z-R*** relationship, which provides their best of possible agreement.

For summer rain season 2000 in Moscow approximately in the half of the cases of 18, the influence of the dominant physical process is noticeable and the use of the daily-tuned ***Z-R*** relation permits to decrease RMS error to 1.5–7 mm.

But, it is evidently that the precipitation nature not always is defined by the dominant physical process, though such cases take place also.

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