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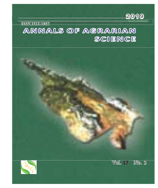

Relationship of rainfall rate and radar reflective in east georgia

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A B S T R A C T

Because the Country territory is prone to flash floods and mudflows, Quantitative Precipitation Estimation (QPE) and Quantitative Precipitation Forecast (QPF) on any leading time are very important for Georgia. Weather ground radar is the main tool for nowcasting and very short-range forecast. Two such radars operate in eastern Georgia. In this study, we presented calibration results one of them, which located in the Kakheti region. Precipitation estimation was compared to measured rainfall on 10 automated rain gauges within the radar coverage area. The calibration time step is an hour with the analysis period of 2017-18. We divided data into two subsets. The first set of 300 pairs with rainfall intensity from Georgian NHMS rain gauges network was used to calibrate the Z-R and to obtain parameters by minimizing RMSE and mean bias. The second set of 450 members was used for validation. The corresponding Z-R relationships for this region is Z = 148R1.5. The minimization of mean root square errors between the rain gauge and the radar-derived measurements of rainfall shows significant improvement of radar estimated precipitation after the calibration of Z-R dependence.

Keywords: Weather radar, Reflectivity, Calibration, Correction, Rainfall rate, Nowcasting.

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1. Introduction

Georgia's orography and it's interaction with airflows is the basic spotting factors of synoptic processes spread in the country. Peculiarities of local weather phenomena, which don't depend on the season are often characterized by diversity and extreme feature. The nowcasting (NWC) and very short-range forecast (VSRF) of the synoptic processes such as convective storms with attendant phenomena, fog and low clouds, locally forced precipitation events, wintertime weather (snow, ice, glazed frost, avalanches) have great importance for Georgia.

NWP model's predictability strength within the NWC range (0–6 h) is still relatively low. Valid NWC and very short range forecast require a high density of weather information, on the surface as well as radar and satellite observation and high-resolution local area model (LAM) output. NWC techniques commonly use an extrapolation (with the heuristic rules) of the observations to make the forecast. The ground weather radar is the main tool for the nowcasting, especially for rainfall rate. Radars have the advantage in coverage of a large area for the real-time precipitation measurement but don't have a good enough accuracy for hydrological applications. Also, the advantages of weather radar are the ability to detect the rainfall and clouds as well as their structures in real-time [1-5]. Climate applications can use these data sets as well.

The very first weather radar in Georgia was "MRL" in the 1960 year, which was mainly used for anti-hail and air navigation system. There were running 10 "MRL" before the Soviet Union's collapse but they were stopped after it. National Environmental Agency hasn't its weather Radar today, but the three other organizations officially share their weather radar data to it. Scientific technical center "Delta" recovered the anti-hail system to protect vineyards from hail in Kakheti region, using dual-polarization c-band "Selex ES" weather radar near the village Nukriani. The Georgian Air Navigation Service uses x-band dual-polarization radar from "EEC" installed near Tbilisi International Airport. Also Trabzon and Erzurum weather radars from Turkish State Meteorological Service which provide only composited pictures. These radars partially cover the country's territory [6-9].

Weather Radar estimates volume averaged rainfall rate R, based on reflectivity factor Z measured in Decibels. Z dependents on the size of the drops (to the sixth power) and their spatial distribution. R dependents on the raindrop size distribution, the size of the drops (to the third power), and the fall velocity for a given drop diameter [10-16]. Marshall et al. (1947) reported a good correlation between reflectivity (Z) and rainfall rate (R) first time. Marshall-Palmer (1948) contained the results of research relating the size distribution of raindrops as a function of rainfall rate. From this relationship, the famous Marshall and Palmer relationship of Z = 200 R^1.6 was derived (where 200 and 1.6 are empirical constants [17-21]). Because of these different relationships, the Z-R relationship is not unique, as there can be different rainfall rates for a particular reflectivity, and vice-versa.

Rain gauges are used to validate and calibrate weather radar precipitation data, as rain gauges are recognized to be the most reliable source of rainfall data. Several disadvantages should be taken into account during the comparison: 1. rain gauges give almost approximate values of point rainfall rate when it compared with gridded precipitation field from radar; 2. The values of the cloud may look stronger than observed precipitation on the ground, especially in spring and summertime, when there are convective clouds, with strong wind gusts and evaporation goes up and holds rain particles in the air and could not fall; 3. The radar beam is usually not uniformly fell with precipitation; 4. Even if the rain measurements are below the cloud base the readings affect by drifting of low-level winds, and also the time delay between radar and rain gauges causes a further discrepancy between the two measurements [22-25].

New techniques and methodologies have been made to improve the accuracy of radar estimations and measurements over time. The international scientific literature on merging rain gauge measurements and radar estimations is vast and, a few useful reviews have been published recently [26-29].

In this paper, we present the relationship between reflectivity factor (Z) empirically derived from C-band weather radar located in Kakheti and precipitation amounts (G) from 10 rain gauges within the radar coverage area, as well as the validation results reflected in the several statistical parameters.

2. Materials and methods

2.1. Weather radar data

We used archived reflectivity data of the C-band radar for selected rainy episodes in the 2017-18 period. The radar location and its coverage area are presented in Figure 1. and the characteristics of the radar in Table 1. The radar performs Volume and Azimuth scan, moving circularly, changing elevation 17 times during 3 minutes.

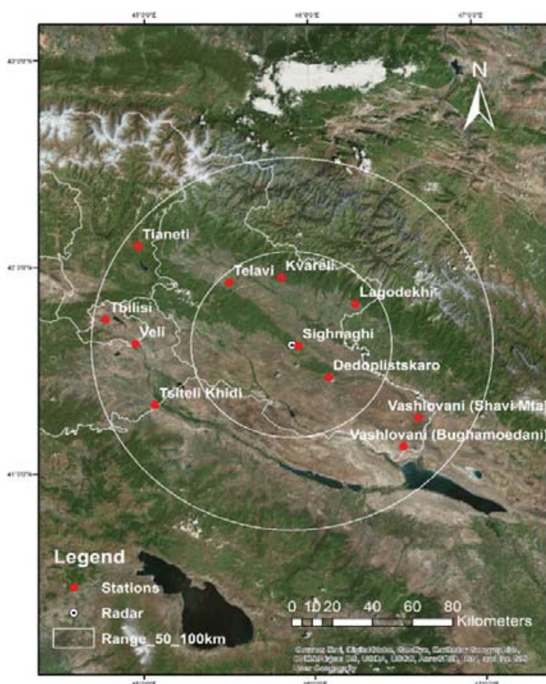


Fig. 1. *Locations of Radar and Rain gauges*

With its short wavelength (5.4 CM) and high frequency (4-8 GHZ), C-band radar can easily identify intensity of clouds and show in decibels, from weak to extreme and dual-polarization is an advantage to classify type of precipitation. This is the general purpose of this system, but to predict quantity of precipitation per hour, products with its algorithms inside weather radar are more or less useful, these data needs to be more accurate and close to the real ground rainfall, measured by rain gauge and needs to find correct way of calculation [30-31].

The 6 minute interval of volume scan data with 10 elevation angles is used. These volume data are one of the radar collections that record the reflectivity and their properties of the precipitation in the sky.

Weather radar systems. The quality control of reflectivity was performed as ground clutter and noisy signal were removed from the measured reflectivity data. The reflectivity overlapped to the other adjacent radars should be checked and it reveals almost similar in both reflectivity shape and dbz. Hence, there is only reliable radar data were used in the analysis.

Reflectivity data that were greater than 53 dbz were limited to mitigate contamination from hail [32-34]. Additionally, the reflectivity less than 15 dbz cases were also excluded from the analysis in order to avoid the effect of noise in the measured radar reflectivity.

2.1. Rainfall data collection

Rain gauges are observational instruments capable of accurately and directly measuring near-surface rainfall. However, these instruments do not provide rainfall information at high spatial resolutions, and observational errors may be introduced into their measurements by strong ground winds or calibration errors. Particularly, in the case of tipping-bucket rain gauges (widely used for automatic rainfall observations globally due to easy digitization of the signals), rainfall data may vary significantly depending on whether the center or the edge of the rain cell passes over the rain gauge.

Hourly rainfall data from 10 automatic rain gauge stations located in eastern part of Georgia and fall in radar coverage area was collected from GNHS. The location of study areas and these automatic rain gauges is illustrated in Figure 2. The quality control of gauge Rainfall data series was performed by comparing rainfall data of the considered rain gauge with rainfall data of the nearby stations. Rainfall data of the considered rain gauge should be consistent with rainfall data of the adjacent stations. All of the automatic rain gauges are of tipping bucket type with 0.245 mm accuracy. The hourly rainfall intensity of each rain gauge station from the selected rainfall event was used to calibration using average hourly reflectivity values in the gridded radar data.

2.1. Method

As it was described above, Reflectivity factor measured by radar for 2017-18 period was taken, values less than 5 and more 53 DBZ was removed and converted into Rainfall rate using default Z–R relationship ($Z = 200R^{1.6}$) formula. An average hourly reflectivity was obtained from 6 min radar readings, to make dataset in the same temporal interval (hourly) as corresponding amounts from 10 rain gauges in the coincident pixels, at 1 km resolution. Totally, 750 couple of rainguge – radar data was fitted (from 87 events). Mean bias, correlation and RMSE were calculated.

For calibration precipitation derived from radar, the 'a' and 'b' parameters from the Z-R relationship $Z=aR^b$ will be corrected by minimizing the Root Mean Square Error (RMSE) [35-37] and mean bias (ratio G/Z) between radar and corresponding rain gauge rainfall.

The constant of 'b' parameter equal to 1.5 was taken, due to several studies explaining that variation of 'b' parameter did not affect the RMSE between radar and rain gauge rainfall much [38-42].

Table 1. *Radar Characteristics*

Detail of radar	Characterictics
Type of radar	Doppler, dual polarization METEOR 750C
Radar band	C band
Radar frequency (MHz)	3000
Wave length (cm)	5.4
Beam with (degree)	0.95°
Pulse length (μs)	2
Resolution of recorded data in Cartesian coordinates (m)	400X400
Gate width (m)	250
Maximum transmission power (kW)	250
Maximum Range (km)	500
Sequence of elevation angles (10 angles)	0.5°,1.7°,3.2°,4.9°,7.1°,10.2°,14.6,21.5°,33.2°, 60°

2.1. Results and Discussion

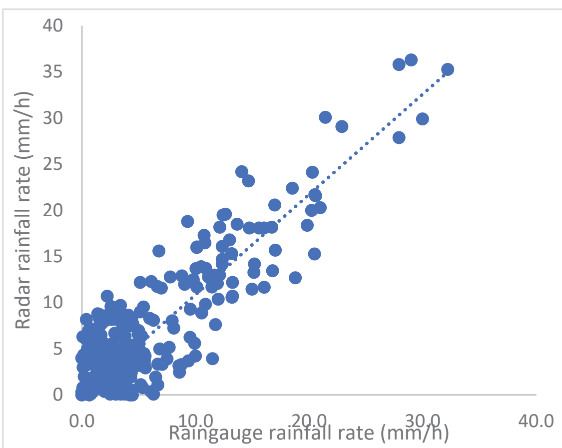
87 rainy episodes have been selected, with different rain intensity released within one or several days, due to different synoptic processes. It worth to be mentioned, that radar covers the part of the country with small yearly precipitation sums, but characterizing with intensive hourly and daily rainfall rate, especially in spring and summer, with high probability of hail. As we rejected DBZ values above 53, the events with hail are not considered in our study.

We selected 750 radar-rainfall matched pares of hourly (mm/h) for above-mentioned 10 raingauges satisfying our criteria. Dataset was devided into 2 parts 300 from them was used for minimalizing RMSE during calibration and rest of them for verification. Distribution of the full set of rainfall data is following: 80% of them are below 6 mm/h, approximately 15% is in the range of 7-25 mm/h and only 1% is above 30 mm/h. The highest observed value was 36.6 mm/h (Veli 18.06.2018 18:00) Radar estimated precipitation by default *Z–R* relationship ($Z = 200R^{1.6}$) was 41 DBZ. In the table 2. Correlation coefficients and RMSE are given for the individual raigauges for full dataset, when radar estimated precipitation is calculated for a=200 and b=1.6 default values.

By minimizing RMSE from 7.521 to 6.163 in train data sample a=148 was derived empirically, while bias (G/Z) was reduced by 0.66 and correlation coefficient increases by 0.1. In the table.B.3. all statistical parameters, for calibration and verification data with default “a”, “b” constants, and empirically derived ones are presented.

The verification results prove that the radar rainfall estimated with the new coefficients are in much better agreement with the rain gauges data.

As it is presented on the Fig. 2. In calibration dataset linear regression’s slope is 0.985, and in verification data 1.017.



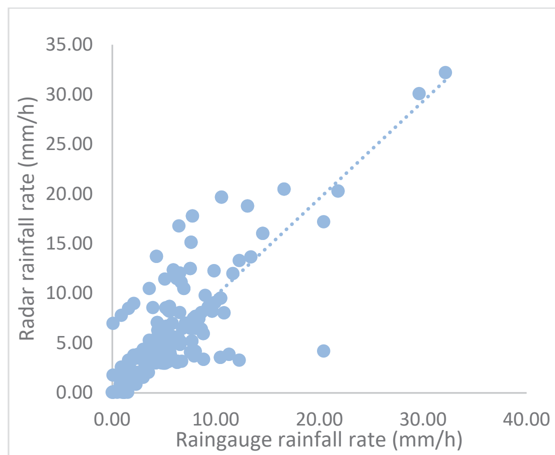


Fig. 2. *Scatter plot between measured and estimated rainfall rate for Z=148R1.5 for (left) calibration and (right) validation dataset.*

Table 2. *Correlation between hourly precipitation measured by raingauges and estimated by Radar using default Z–R relationship (Z =200R1.6).*

Rain gauges	Distance from radar (Km)	X Coordinate	Y Coordinate	RMSE	correlation
Bugha Moedani	78.7	629157.16	4553858.75	7.824	0.84
Dedoplistskaro	25.5	592031.41	4591078.94	7.783	0.96
Veli	78.6	495704.68	4608946.52	7.872	0.80
Tbilisi	93.7	480824.98	4622050.1	8.411	0.81
Tianeti	93	496996.82	4661412.79	7.974	0.70
Lagodekhi	38.7	605184.72	4630392.67	8.885	0.78
Sighnaghi	4.3	576778.71	4607994.60	8.329	0.68
Kvareli	36.5	568293.40	4644663.02	8.977	0.56
Vashlovani (Shavi Mta)	75.2	636590.77	4569408.07	7.541	0.83
Tsiteli Khidi	75.8	505473.1491	4576150.437	9.084	0.47

Table 3. *RMSEs, Bias and correlations obtained from Z-R relationships using empirically derived and default parameters.*

	$Z=148R^{1.5}$			$Z=200R^{1.6}$		
	RMSE	Bias (G/Z)	correl	RMSE	Bias (G/Z)	correl
calibration	6.163	0.985	0.95	7.521	2.01	0.857
verification	5.979	1.017	0.91	6.984	2.12	0.843337

1. Conclusion

The Z-R relationships were derived from statistical measurements of precipitation during the 2017-18 period in eastern Georgia, varying by parameter “a”, while keeping parameter “b” fixed at 1.5. 750 Z-R pairs were obtained from 87 precipitation cases, and then dataset was divided into two groups. The first set of 300 pairs with rainfall intensity from the Georgia’s NHMS raingauges network was used to calibrate the Z-R and the obtained parameters. The second set of 450 events was recognized as validation data. The relationship between point rainfall from the rain network and radar rainfall at a certain height of 1.5 km was calibrated by minimizing RMSE. The corresponding Z-R relationships for this region is $Z = 148R^{1.5}$. The result shows significant improvement with improved Z-R dependence in obtaining minimized errors from more accurate estimated rainfall. These results will provide to assess for evaluating of rainfall estimation for the sectors where accurate rainfall information is essential.

Acknowledgment

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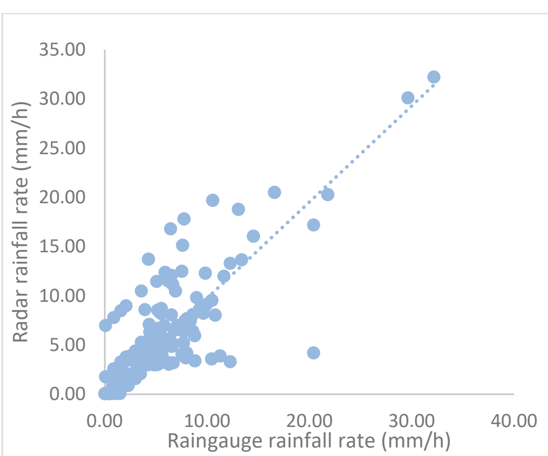

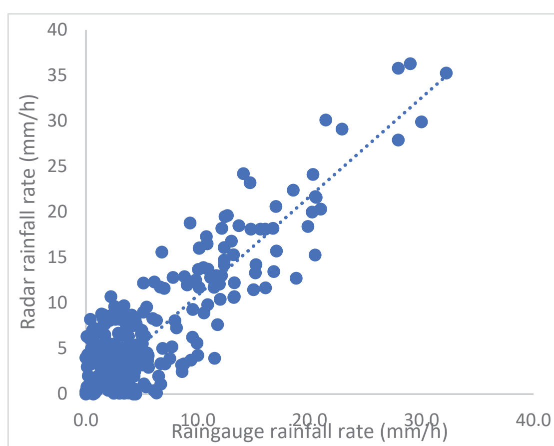

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