Processing of Radar Precipitation Data as Applied to Watershed Hydrology

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ABSTRACT

Problems of calibration of weather radar are addressed. Methods have been developed aimed at how to process the radar-based precipitation data for hydrology applications. Aggregated data (10x10 km) are suggested to be reasonably sufficient for that aim. Basic properties of precipitation fields are examined: (1) spatial coverages and areal reduction factor, (2) conditional frequency distribution function of "at-cell" rain rates by specified spatially averaged rates and, (3) spatial structural function (variogram). Examples of data processing and analysis are given to expound upon the ideas of how to describe precipitation patterns. For flood forecasting, a procedure is proffered to reveal those rain rates exceeding threshold which is correlated with antecedent soil moisture content on a small (2000 km^2) river basin.

KEYWORDS

Radar precipitation estimates; radar calibration; data processing; precipitation statistics;

1. INTRODUCTION

Radar precipitation measurements at Valday, Russia have a long history. They were carried out since 1980s targeted to update the runoff models that time (Becker et al., 1988, Rumjantsev *et al.*, 1985) and to develop the methods for flood forecasting. Problems of measurement accuracy were given attention, for that a special dense rain gauge network has been developed in western part of the radar surveillance within drainage basin of the Polomet' river. Presently a new generation radar is being installed.

Engineering hydrology mainly consists of probabilistic computations of flood runoff. Its methods should be improved if the radar-based areal precipitation data would be obtained that is important just for Russia because of low density of observational network. Special problems appear when evaluating the environmental impact of a large linear construction such as main roads and pipelines on flow generation. A convenient way of how to apply both spatial patterns and time series of precipitation to operational hydrology is only being developed (Shutov, 2002, 2004).

2. ON THE METHOD OF CALIBRATING THE RADAR DATA

Calibration of the radar in Valday was conducted with special network within the Polomet' river watershed (Becker et al., 1988). The network consisted of multiple (up to 37) pluviographs arranged in nested groups of gauges to determine both areal precipitation and its auto-correlation function. Hourly (3-hourly) rain rates obtained by pluviographs were interpolated onto grid cells 1 x 1 km each with averaging over 3 x 3 km and 10 x 10 spatial units. As was found, the ratios of G/R vary from 0,5 to 3,8 for 3-hourly rates and be less ranged (0,6 to 2,2) for daily amounts (left Figure 1). Thoroughly implemented calibrations (Michelson *et al.*, 2000) result in more scattered values: for instance, G/R = 1 at 100 km off the radar site varying from 0.5 to 2.5 if to limit by standard deviation (±σ), and from 0.2 to 5.0 by ±2σ.

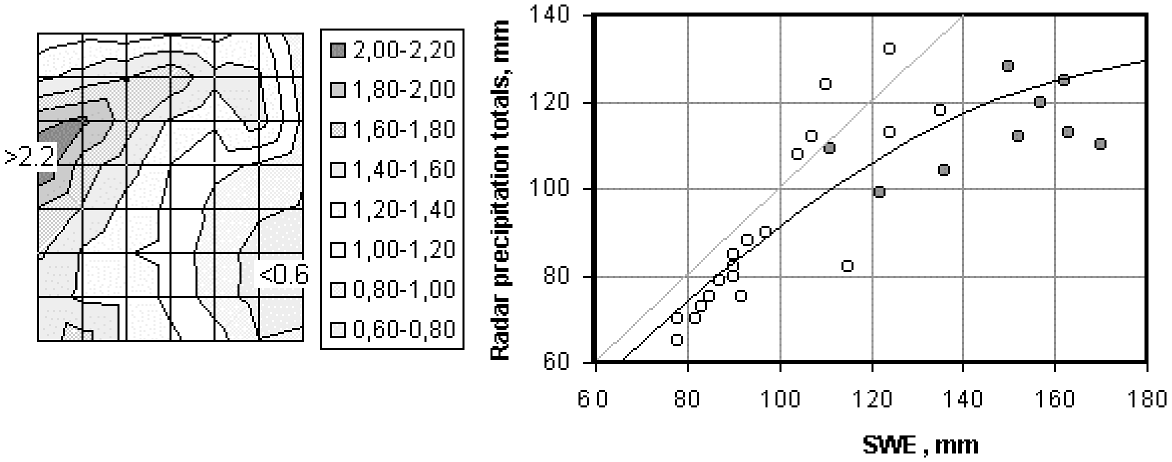

Figure 1. Calibration of the radar located at Valday against land-based observational data sources. Left: A pattern of the *G*/*R* ratios for summer rainfalls (only western part of the radar surveillance); Right: Radar precipitation totals calibrated against snow water equivalent (SWE) by snow surveys for the entire area and for the *Upper Polomet'* river basin (darkened points).

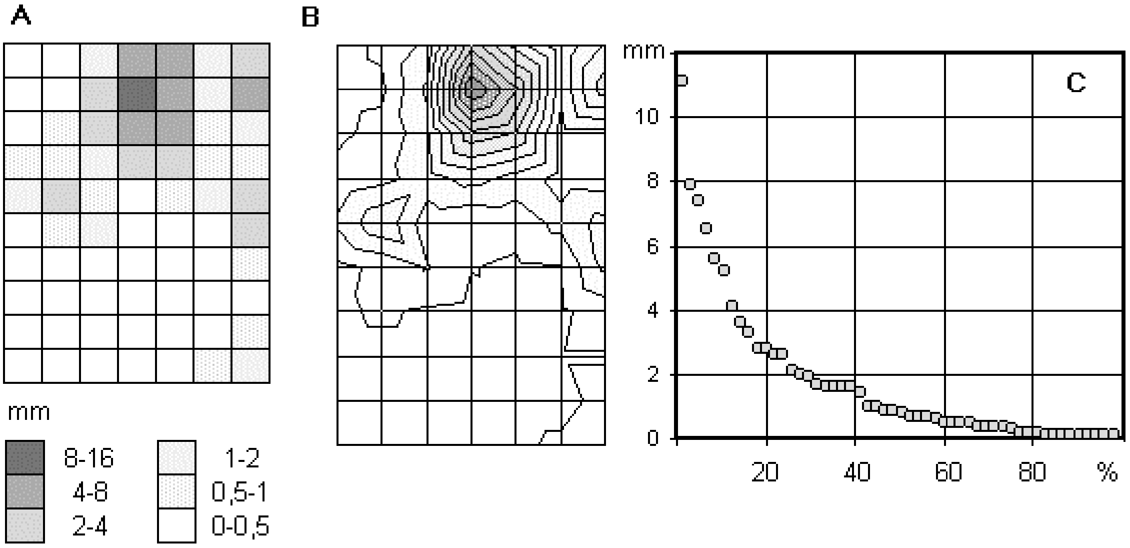

Figure 2. An example of the special radar data processing for a late August day in Valday,
A) Fragment of the traditional radar image: precipitation quantized by dB*Z* levels (in mm);
B) Contour map depicted a pattern of daily rainfall rates normalized by sigma ($(R - R_{av})/\sigma$) ;
C) Frequency distribution (spatial statistics) of "at-cell" precipitation rates (mm/day).

Of a particular importance is that G/R values are not randomly distributed (Figure 1). Analyzing upon such maps, one can infer about specific inaccuracies which are correlated with local terrain features and, more slightly, depending on what atmospheric processes are going on. Much frequently cases for the area are heavy rainfalls increasing just in front of the wind-exposed slope of the Valday Hills. Here, the rainfall rates can be underestimated (G/R > 1). Another was observed during winter, when underestimated were those snow amounts fallen onto the hills. There are considerable biases (darkened points in Figure 1) between the snow water equivalents (SWE) and the radar precipitation total estimates.

3. SPECIAL DATA PROCESSING

For engineering hydrology applications, we propose (Shutov, 1999, 2000) some additional sub-routines based on matrix algebra (the primary data are acquired as matrices), in particular:

- Accumulation over several time intervals. So, daily totals can be acquired by summing up hourly rain rates, as well as total of daily rates over an examined flood, etc.
- Association, which is to select the maximum rain rate from each couple of cells of associated matrices A and B that is: A U B = max {RA, RB}. This procedure allows to reveal those heavy rains which are able to create extreme floods, a focus of interest for hydrology applications.
- Normalizing the matrix elements by a specified value such as standard deviation σ or a rate of several frequency (quantile) to make the patterns comparable (mid Figure 2).
- Quantization of rainfall rates to reject an appointed threshold value, except for those used by pre-processing from each "at-cell" value. This allows to map those areas where rain rates exceed the threshold which may either be arbitrary or be correlated with antecedent wetness of the basin. The latter approach is to reveal the area of effective (produced runoff) rainfalls.
- Ranging the rates to develop a frequency distribution (right Figure 2). This is the most convenient and widely used in engineering hydrology.

4. PRELIMINARY RESULTS

4.1. Empirical variograms

Areal distribution of rainfall rates is mapped using an interpolation procedure which implies the structural function (variogram) obtained previously. Empirically it is determined as follows:

$$V(L) = [R(x + L) - R(x)]^2 \tag{1}$$

Where x is horizontal co-ordinate, L is the space between neighboring cells, R are precipitation estimates. The empirical variograms were approximated with the following:

$$V(L) = K \, Ln\,(L) + M \tag{2}$$

Parameters of were found varied depending on precipitation genetic type and, that is of an essential importance, on the direction (by latitude or by longitude) at which the V(L)-functions are evaluated.

4.2. Statistics of at-cell and spatially averaged values

We have found a simple way to reflect precipitation stochastically which is synthesis of the joint probability density function (PDF) of at-cell Rj and areally averaged Rav rainfall rates. The distribution summarizes multiple individual PDFs obtained using the 5-th procedure (of those mentioned above). It seems that the PDF-values of such a distribution may be proffered as a parameter in computation of rain-induced floods. Such data processing procedure has resulted in statistical estimates (partial PDFs) of rainfall rates at several grid cells by specified areal averages over entire study area.

Slow rainfalls dominate throughout most of the area (sized 80x100 km) by $R_{av} \leq 7$ mm/day, but the secondary peaks appear if there are more heavy rainfalls. They are corresponding with the areas of higher intensity within rainfall fields, which are often called embedded cells.

The frequency diagrams drawn for both areal and at-site values allow to consider precipitation as a space-time stochastic process. The data were used as "at-site"of long-term gauge observations at multiple sites located within the Polomet' river basin. Frequency curves have been found similar for space and time that is an evidence of ergodicity of rainfall patterns.

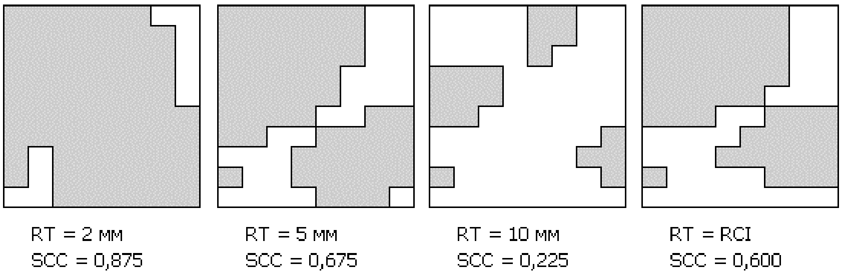

Figure 3. Sketch of radar images showing the spatial reduction of precipitation, decreasing (left to right) the spatial coverage coefficient (SCC).
The threshold values (RT) are conventional or dependent on the runoff intensity (RCI)

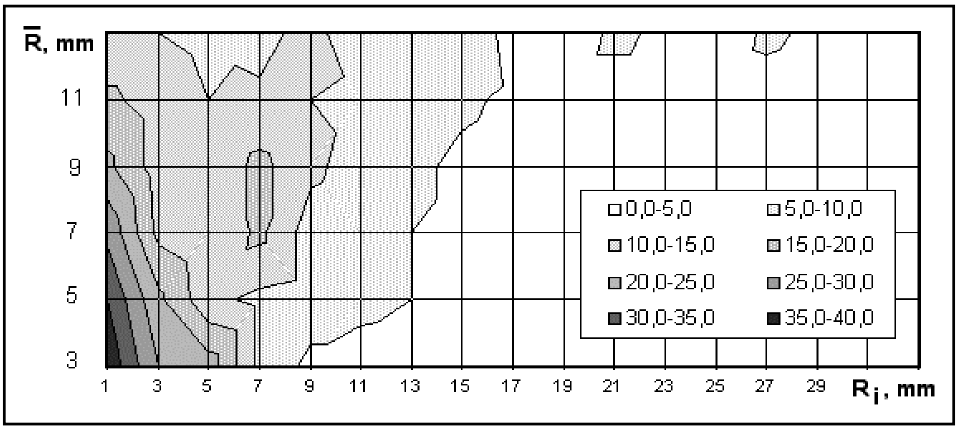

Figure 4. Conditional probability (p,%) of precipitation rates (mm/day) within several cells (Rj) by fixed spatial averages (R) for the Valday radar precipitation polygon.
Note: the diagram as well as the data we obtained at this time are preliminary and have been shown here only for illustration of the method mentioned above.

5. DISCUSSION AND A FUTURE OUTLOOK

Considering that has been mentioned on adjustment technique, for hydrological applications it is rather to use a coarse grid, whereas the finest resolution cannot be practicable (without dense rain gauge network) as resulted in undeterminable errors in both radar and gauge precipitation estimates. Recollect, the spatial units of the order of 100 km^2 quite correspond with the lower limit of the scale which are of a particular interest. Small drainage basins are, indeed, not so runoff productive to draw a great attention for flood warning. Besides, the better timing we took was one day to eliminate errors and catch a real response in runoff. Also, we should examine only that fraction of the radar surveillance for which rain gauge data are available, thereby the radar data may be presumed as sufficiently accurate.

As to spatial coverage, there appears a successive way, which is to determine spatial extent for only rainfalls exceeding a specified intensity. Quite a problem remains: how to predict this threshold depending on wetness if there are no soil moisture data available. We may operate with the water cycle components either observed or calculated. Another way is to replace the actual soil moisture data with an index, for instance, the Antecedent Precipitation Index (Seuna, 1983) defined by past rainfall events.

As was found, convective rainfalls are characterized with asymmetrical variograms, their parameters are different for rectangular directions. This fact can result from an influence of the Valday Hills oriented longitudinally. Diapason (de-correlation distance) is found equal approximately to 50-60 km for both convective and frontal rains that corresponds to the distance for snowfalls. Power function (Equation 2) testifies the self-similarity over various spatial scales that allow for the fractal models.

Existent methods to calculate runoff enable to assess that fraction of the basin area, where the runoff depths can be higher than a specified value. On the other hand, one can evaluate what runoff depth can be expected after rainfall from a selected area. With the use of detailed soil map, one would determine where these areas subjected to flood are located. Further reforms would be with an evaluation of spatially distributed runoff coefficient to replace. It will be realized based upon soil moisture and those basic soil physical properties which are responsible to infiltration.

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