P6B.10

PARAMETERISATION OF RADAR PRECIPITATION QUALITY INDEX SCHEME ON RAINGAUGE DATA

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1. INTRODUCTION

Radar-derived precipitation estimates and radar-based precipitation nowcasts constitute essential input to NWP and rainfall-runoff models. However the radar data and nowcasts introduce into final products a number of errors from different sources. For this reason their uncertainty should be determined to provide end-users with probabilistic forecasts as more reliable information about rain rate and accumulation. Therefore investigation of data quality and uncertainty in the whole processing chain is necessary.

In literature reviews of weather radar data errors and methods for their estimation are available. Due to the problem complexity it is impossible to obtain sufficient information and compute quantitatively impact of each error. Therefore it seems suitable to evaluate the radar-based data quality not by giving definition and estimation of all radar errors, but analysing the data properties, among others statistical.

2. QUALITY SCHEME FOR RADAR-BASED PRECIPITATION

2.1 Data processing chain

Proposed Quality Index (*QI*) scheme is to estimate the quality of all kinds of radar-based precipitation data that are generated in the data processing chain. It is planned to use in real-time for radar-based data from Polish national weather service. Precipitation data (see part 3.2) from weather radar POLRAD network are corrected and nowcasted by NIMROD system using data from other sources.

Generally the processing is carried out in the following steps:

- radar data corrections (ground clutter removal, VPR correction, raingauge adjustment, etc.),
- precipitation field estimation as the analyses (taking radar data and data from other sources),
- precipitation forecasting.

In presented paper the outline of quality scheme based on quality index (*QI*) approach is proposed. Six variants of the scheme can be distinguished for different kinds of precipitation data:

- composite corrected radar rate (RAD) and its accumulation (ΣRAD),
- rate analysis (NIM) and its accumulation (ΣNIM),
- rate forecast (FCS) and its accumulation (ΣFCS).

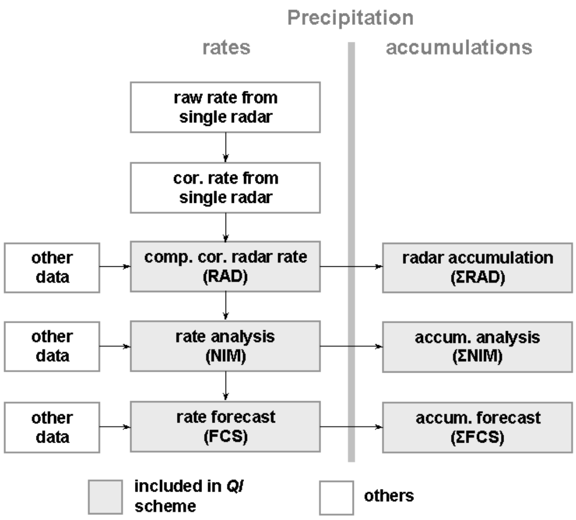

Fig. 1. Radar-based precipitation data

2.2 Concept of quality index scheme for radar-based precipitation data

The methodology is based on a concept of:

1. quality index field for all kinds of precipitation data,
2. probability density function (PDF) that is employed to characterise the phenomenon,
3. parameterisation of the PDF.

Next steps will be generation of ensemble of the PDF quantiles as input to rainfall-runoff models, and then ensemble of runoff forecasts.

3. TEST BED

3.1 Area

In Poland the Institute of Meteorology and Water Management (IMWM) is responsible for a national meteorological and hydrological service. The IMWM collects data from telemetric (meteorological and hydrological) and remote-sensing networks (weather radars, satellite, etc.).

Area interesting from hydrological point of view is a mountainous region in the south of Poland where the upper Vistula (Wisła) and Odra Rivers are the main sources of flood hazard (Fig. 2).

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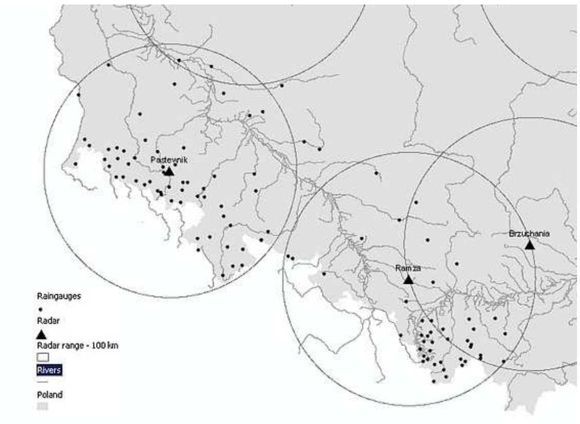

Fig. 2. Map of research area: south of Poland area with raingauge and weather radar locations.

3.2 Precipitation data

Telemetric raingauge data (*G*) as 1-hour accumulations from 107 telemetric raingauges within area shown in Fig. 2 were employed.

Radar data are provided by Polish weather radar network POLRAD that consists of 8 C-Band Doppler radars (Szturc and Dziewit, 2005). They are Gematronik radar with Rainbow software, operated by IMWM. Among products produced every 10 minutes the PAC composite is used to delivery 1-hour accumulations. The PAC is generated from SRI products that measure precipitation on constant height above the ground (in this case 0.7 km).

NIMROD system is UK Met Office software to process radar data using other measurement sources and then to produce analyses and forecasts of precipitation (Weipert and Pierce, 2003). The radar data used as a starting point in NIMROD are provided every 10 minutes in form of four PPI scans at low elevations. The following corrections are applied: ground clutter and anaprop removal, Vertical Profile of Reflectivity correction, and Mean Field Bias correction. Corrected radar data are blended with information from other measurement sources, such as ground stations, satellite, to produce NIMROD analyses every 30 minutes (Golding, 1998).

The main idea of the nowcasting philosophy adopted in NIMROD is the merging of an extrapolated rainfall analysis with output from a Numerical Weather Prediction (NWP) model. NIMROD nowcasts are generated every 30 minutes with 15-minute temporal and 4-km spatial resolution up to six hours ahead.

All employed precipitation data were gathered during rainy events in August 2006.

4. QUALITY PARAMETERS

4.1 Algorithm for total *QI* determination

First of all proper parameters that most significantly characterise the quality of precipitation data should be selected. For each quality parameter individual quality index QI_i is computed. It is assumed that the relationships between particular quality parameters and relevant individual quality indexes are linear and values x of each of i-parameter X vary between minimal and maximal values X_1 and X_0 (Szturc et al., 2006a):

$$QI_i = \begin{cases} 1 & \text{for } x \le X_1 \\ 0 & \text{for } x \ge X_0 \\ \dfrac{X_0 - x}{X_0 - X_1} & \text{for } X_1 < x < X_0 \end{cases} \qquad (1)$$

where $i = 1, \ldots, N$; N is the number of uncertainty parameters X.

Having computed all N individual QI_i fields they are summarised to an averaged *QI* field using appropriate weights:

$$QI = \sum_{i=1}^{N} QI_i \cdot W_i \qquad (2)$$

Determination of N values of the weights W_i means parameterisation of the *QI* scheme.

4.2 Determination of quality parameters

The selected quality parameters, which are to characterise all the kinds of data, have been divided into particular groups. One of them is connected to measurement geometry that depends on scan strategy, and consists of:

- DR – distance to the nearest radar,
- DEM – digital elevation map,
- MH – minimal height of radar visibility (altitude of the lower scan) that is more significant at longer distances to radar and in mountainous areas as a result of radar beam blocking, shielding etc.

Second group of parameters is associated with structure of precipitation field, and comprises:

- SV – spatial variability,
- TV – temporal variability.

The higher the parameters are, the bigger the uncertainty of the fields is.

The following parameters form the last group:

- NP – number of rain rate products incorporated in particular hourly accumulation,
- $QI_{\mathbf{RAD}}$ – starting radar data quality,
- LT – lead-time of forecast (for QPF).

Any number of other parameters can be added.

In Table 1 the most important error factors and parameters that can describe the risk level of burdening with these errors are listed. The list is valid especially for POLRAD network associated with NIMROD system. It is not feasible to produce the list strict and not unambiguous. The list was prepared basing on experiences of Radar Centre staff in the Institute of Meteorology and Water Management and other similar attempts, especially: Šálek et al., 2004; Michelson et al., 2005; NORDRAD (*Future*…). In Table 2 there is a similar list for forecast quality factors.

Table 1. Main radar errors and related quality parameters.

Error	Quality parameter	Magnitude	Frequency	Range
Hardware problems, miscalibration, pointing error, etc.	-	medium – big	continuous	continuous
Earth curvature	DR, MH	medium	continuous	continuous
VPR variability	DR, MH	medium	seasonal	continuous
Spatial resolution	DR, MH	small	continuous	continuous
Beam blocking, shielding	MH	big	continuous	local
Total beam overshooting	MH	small – big	seasonal	local
Ground clutter	DEM	small – big	continuous	local
AP clutter, propagation changes	-	small – medium	seasonal	local
Interfering emitters, jamming	-	small – medium	occasional	local
Attenuation by precipitation	DR	small	continuous	continuous
Attenuation by wet/icy radome	-	small	seasonal	local
Hail, water phase, *Z-R* relationship	SV	small	seasonal	continuous
Orographic enhancement	DEM	small – medium	continuous	local
Overhanging precipitation	-	medium	seasonal	local
Temporal resolution	NP	medium	continuous	continuous

Table 2. Main forecasting errors and related quality parameters.

Error	Quality parameter	Magnitude	Frequency	Range
Quality of starting data	QI_{RAD}	big	continuous	continuous
Lead-time	LT	big	continuous	continuous
Spatial resolution	SV	medium	continuous	continuous
Temporal resolution	NP	medium	continuous	continuous

5. DETERMINATION OF THE QUALITY PARAMETER WEIGHTS

In the proposed scheme quality index QI_x for each quality parameter X is calculated assuming linear relationship between them. This calculation is made for each radar-map pixel and in this way field of the quality index is obtained. Next all the individual fields are summarised to an averaged QI field using appropriate weights (Eqs. 1 and 2). The scheme should be calibrated in order to get objective information about data quality. It requires procedure of the scheme parameterisation that involves determining some quantities for each parameter X: its weight and lower X_0 and upper X_1 thresholds. The values are defined as follows: X_1 is boundary value X for which quality index $QI_x = 1$, and X_0 is boundary value X for which $QI_x = 0$, so beyond these thresholds the quality index QI_x values are set to 0 or 1 respectively. Moreover a critical value (X_{crit}) is introduced, which means that if the parameter X reaches the X_{crit} value then averaged QI value is set to 0 for the pixel even if other parameters are quite good.

A proposed scheme parameterisation is performed on historical dataset. It is assumed that raingauge data are exact in their locations therefore information about differences or ratio between raingauge (G) and radar (R) observations in these points can be a measure of quality. Correlation between given quality parameter X and measured errors, represented by e.g. $\log(R/G)$ or $(R – G)$, can indicate the parameter importance in terms of data quality (here R means all radar-based data).

Correlations computed for August 2006 with employed quality parameters are listed in Table 3.

Table 3. Correlations between some quality parameters and $\log(R/G)$ for 1-hour and 24-hour accumulations. Radar PACs are used as R data; precipitation threshold is 0.5 mm.

Quality parameter	Correlation	
	1 h	24 h
DR	0.325	0.357
DEM	-0.053	-0.171
MH	0.306	0.375
SV	-0.007	0.635
TV	0.127	0.608

For comparison correlations between R and G are 0.311 and 0.523 for 1-h and 24-h accumulations respectively.

Basing on these correlations the optimal weights in Eq. 2 can be determined for particular QI_x fields (Table 4). Moreover boundary and critical values for linear interpolation of these parameters are determined and finally averaged QI is computed from Eq. 2. The quality information field obtained in this way is attached to the radar-based precipitation product (see Fig. 3).

Table 4. Example of quality scheme parameters for radar-based precipitation data.

Quality parameter X	Unit	X_1 (QI_x=1)	X_0 (QI_x=0)	X_{crit}	Weights for …					
					RAD	ΣRAD	NIM	ΣNIM	FCS	ΣFCS
Distance to nearest radar (DR)	km	10	100	> 200	0.180	0.180	0.180	0.180	-	-
Digital elevation map (DEM)	km	0.5	1	> 2	0	0	0	0	-	-
Min. Height (MH)	km	0.5	5	> 5	0.190	0.190	0.190	0.190	-	-
Spatial variability (SV)	mm	0.01	0.1	> 100	0.322	0.322	0.322	0.322	0.322	-
Temporal variabity (TV)	mm	0.001	0.1	> 100	0.308	-	0.308	-	0.308	-
Number of products (NP)	-	7	3	< 3	-	0.308	-	0.308	-	0.500
QI_{RAD}	-	1	0	< 0.1	-	-	-	-	0.185	-
Lead-time (LT)	hour	0	7	> 6	-	-	-	-	0.185	0.500

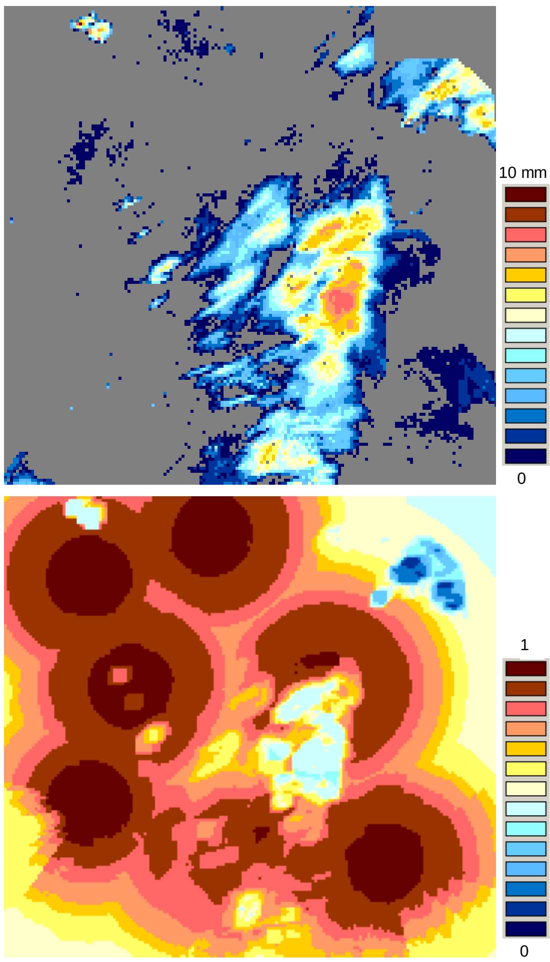

Fig. 3. Example of radar data (upper) and assigned QI field (lower) (ΣRAD data: 1-hour accumulation from 15 August 2006, 08 UTC, POLRAD network)

6. PRECIPITATION PDF

6.1 Gamma PDF

In practice the uncertainty in estimates or forecasts of precipitation can be taken into account using a specific PDF suitable to reflect physical features of rainfall. The gamma distribution might be used for this purpose (e.g. Amburn and Frederick, 2006):

$$PDF(x) = \frac{b^p}{\Gamma(p)} x^{p-1} e^{-bx} \tag{3}$$

where p and b are the PDF parameters, p, b > 0; Γ is the gamma function (see Fig. 4).

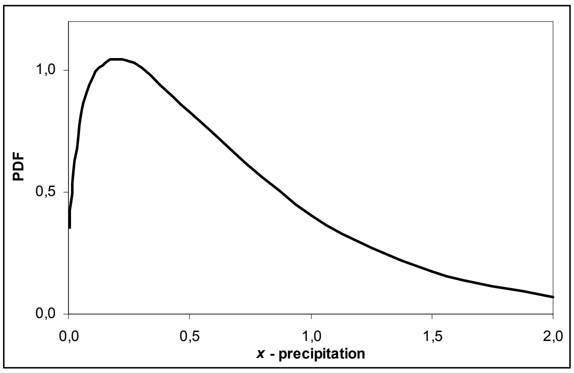

Fig. 4. Example of gamma PDF (p = 2.4; b = 2.0)

It is assumed that:

1. the PDF parameters are related to averaged QI value,
2. this relationship can be experimentally determined for each pixel of the precipitation data field.

As a consequence the probabilistic precipitation field may consist of three values for each pixel: two PDF parameters (or more in dependence on specific PDF) and QPE (or QPF).

6.2 Relationship between gamma PDF parameters and *QI* of radar-based precipitation

The *QI* field is calculated for radar-based precipitation field using Eq. 2 and weights from e.g. Table 4. The next step is to determine precipitation PDF (which can be gamma PDF from Eq. 3) for each pixel of the field. In order to solve the problem the parameterisation of the PDF is required.

The proposed concept is to determine the following quantities on historical data in consecutive steps:

1. *VAR*(*R*-*G*) that is the variance of radar-raingauge difference in raingauge locations; VAR(G/R) or VAR(log(G/R)) may be used instead.
2. Linear interpolation of relationship between *VAR*(*R*-*G*) and *QI*.

Having this relationship it is possible for particular precipitation field to estimate in real-time:

1. Precipitation statistical moments: *E*(*X*) and *VAR*(*X*).
2. PDF parameters from *E*(*X*) and *VAR*(*X*).

6.3 Relationship between *VAR*(*R*-*G*) and *QI* determined on historical dataset

If the following historical data are available: radar/NIMROD data *R*, raingauge data *G* (both as e.g. hourly accumulations), and *QI* field, then at first *QI* values (that vary in range from 0 to 1) are divided between some number *n* of classes (for instance *n* = 10). Next variance of (*R*-*G*) is calculated for each class:

$$VAR(R-G)=\frac{1}{N}\sum_{i=1}^{N}(R_i-G_i)^2-B^2(R,G) \qquad (4)$$

where *N* is the number of radar-raingauge pairs; *B*(*R*,*G*) is:

$$B(R,G)=\frac{1}{N}\sum_{i=1}^{N}(R_i-G_i) \qquad (5)$$

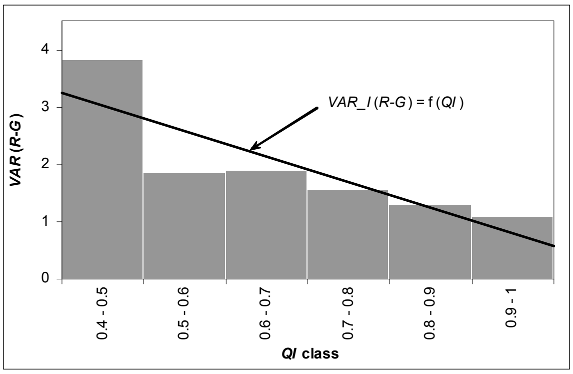

Fig. 5. Example of determination of relationship between *VAR*(*R*-*G*) and *QI* (ΣRAD 1-h data from 1-15 August 2006)

Next relationship between *VAR*(*R*-*G*) and *QI* is estimated using linear (or any non-linear) regression determining interpolated variance *VAR_I*(*R*-*G*):

$$VAR\_I(R-G)=a_1\cdot QI+a_2 \qquad (6)$$

where a_1 and a_2 are the linear regression coefficients.

In Fig. 5 an example of relationship between *VAR*(*R*-*G*) and *QI* divided into classes is shown. For this example the relationship (6) was established as: *VAR*(*R*-*G*) = -4.46·*QI* + 4.81 (with correlation coefficient *r* = 0.85).

6.4 Real-time relationship between the PDF parameters and both precipitation *R* and quality index *QI*

Gamma *PDF*(*x*) is defined by Eq. 3 (see example in Fig. 4). Relationships between the PDF parameters *p* and *b*, and precipitation statistical moments are as follows:

$$E(X)=\frac{p}{b};\quad VAR(X)=\frac{p}{b^2} \qquad (7)$$

From this equation system both *p* and *b* are:

$$p=\frac{E^2(X)}{VAR(X)},\ b=\frac{E(X)}{VAR(X)} \qquad (8)$$

In Eq. 8 expectation *E*(X) may be identified with the precipitation (radar/NIMROD) estimate *R*, whereas variance *VAR*(*X*) is calculated from interpolated relationship between *VAR_I*(*R*-*G*) and *QI* (Eq. 6):

$$E(X)=R; \qquad (9)$$

$$VAR(X)=VAR\_I(R-G)=a_1\cdot QI+a_2 \qquad (10)$$

Finally: for given data pixel with the *QI* and *R* values the *p* and *b* parameters can be calculated from the above equation system (Eq. 8).

6.5 Probabilistic precipitation – ensemble of precipitation quantiles

Next step will be to produce a probabilistic precipitation field that is an ensemble of a few deterministic inputs instead of only one. It may be done by selection of some characteristic fields. The ensemble members can be chosen as quantiles, e.g. *q*% = 5, 25, 50, 75, and 95% basing on a cumulative distribution function CDF. The *q*%-quantiles of the PDF, i.e. $P_{q\%}$ is calculated from the gamma CDF:

$$P_{q\%}=F(q\%)=\int_{-\infty}^{q\%}f(x)\mathrm{d}x=\int_{0}^{q\%}\frac{b^p}{\Gamma(p)}x^{p-1}e^{-bx}\mathrm{d}x \qquad (11)$$

This ensemble will constitute an ensemble (sequence) of inputs to deterministic rainfall-runoff model (Krzysztofowicz, 2002; Szturc et al., 2006b).

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