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Scheme of quality index for radar-derived estimated and nowcasted precipitation

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1 Introduction

Radar-derived precipitation estimates and radar-based precipitation nowcasts constitute essential input to rainfall-runoff models, especially for flash flood forecasting. However the radar data and nowcasts introduce into final flood forecasts a number of errors from different sources. Thus their uncertainty should be determined to provide end-users with probabilistic forecasts as more reliable information. Therefore investigation of data quality and uncertainty in the whole processing chain (from radar measurements through precipitation forecasts up to hydrologic forecasts) is necessary.

The methodology of dealing with radar precipitation uncertainty can be based on a concept of quality index (QI) field which is a measure for data quality characterization. Various schemes for creating such a QI field for precipitation estimate fields are proposed. An example can be DLR (Deutsches Zentrum für Luft und Raumfahrt) scheme (Friedrich et al., 2004). The schemes take under consideration main sources of radar limitations significantly affecting the accuracy of radar reflectivity measurements, like beam broadening, ground clutter contamination, attenuation by hydrometeors, and inhomogeneity in vertical profile of reflectivity. This technique requires selecting the most crucial uncertainty parameters to compute quality index fields for radar-based data.

2 Procedures of radar data quality control

A term "quality control" generally is used to describe methods designed to identify and treat errors in observational data, thus improving their quality. In Polish radar network POLRAD the quality control is mainly performed by UK Met Office NIMROD system (Golding, 1998) that is implemented in Polish Institute of Meteorology and Water Management (Weipert and Pierce, 2003).

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2.1 Precipitation estimation

The base source of precipitation data processed by the NIMROD system is radar data from Polish weather radar network POLRAD (Fig. 1). Since the radar data is burdened by a number of different errors then various procedures of the data improvement are employed in order to get the best estimates of both rain rate and accumulation. Radar data is quality controlled using data from other sources (weather stations, lightning detection system, meteorological satellite, and NWP) in the following steps:

– recognition and removal of non-precipitation echoes (ground clutter, anaprop),
– VPR (vertical profile of reflectivity) correction,
– MFB (Mean Field Bias) correction.

After these procedures surface precipitations from particular radars are joined into radar composite.

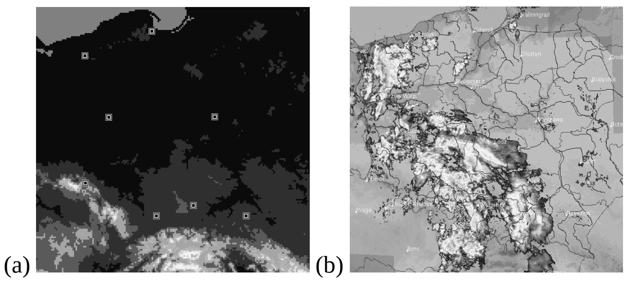

Fig. 1. Polish radar network POLRAD: (a) radar locations, (b) example of radar composite from 31 March 2006, 0530 UTC.

Final analysis of precipitation rate is obtained from: radar rain rate composite, satellite rain, surface weather rain, and a previous rain rate forecast. Precipitation rate analysis is the base for precipitation forecast.

2.2. Precipitation nowcasting

Forecasts of precipitation rate and accumulation are produced by merging extrapolation nowcasts (advection of precipitation analysis) and NWP forecasts.

Extrapolation nowcast is object-oriented: precipitation field is divided into clusters with movement vectors assigned by tracking their positions in previous steps. The vectors can be derived from cross-correlation or NWP wind field.

Final extrapolation forecast is merged with forecast of precipitation rate from NWP. For this purpose a weighting function is used that assigns smaller weights to extrapolation forecast for smaller lead-times whereas for the longer ones (maximum is 6 hours) NWP-derived forecasts have bigger weights. Moreover the weighs depend on reliability of both forecasts in previous time steps.

3. Uncertainty parameters for radar-based data

3.1 Selection of parameters

The methodology of dealing with radar-based precipitation uncertainty is based on concept of quality index (QI) field. The QI field scheme for both precipitation estimates and forecasts is proposed. It takes under consideration analysis of precipitation field rather than conditions and limitation of measurements. Different quality parameter fields are chosen to characterise the two types of data.

Two major kinds of uncertainty parameters are employed: (1) topography-dependent and (2) resulting from spatial and temporal distribution of radar-based data. For real-time application it should be remembered that the particular quality parameters must be easily determinable.

For quality of precipitation accumulation a number of rain-rate products that compose a given sum is important and is introduced as an additional quality parameter.

Two next parameters incorporated into the proposed scheme are used only for forecasts. They are the lead-time (*LT*) of forecasts and quality index previously determined for estimated precipitation (*QIE*).

3.2 Topography-dependent parameters

Distance from radar (*DR*) is a crucial parameter as radar beam expands with distance from radar site. Moreover the curvature of the Earth surface results in increasing vertical distance of radar beam to the ground. For the lowest scan the beam height above the ground can reach over 2.5 km at a 200-km distance from radar (Fig. 2b).

The next parameter is a spatial pattern of altitude (*DEM*) that is represented by DEM (digital elevation map). The important effects resulting from the presence of higher mountain peaks are radar data contamination by ground clutters, radar beam blocking, and shielding (Fig. 2a).

Third topography-dependent parameter is a height of the lowest scan (*MH*). This height indicates the lowest point of vertical profile of atmosphere that can be visible by any radar beam since the lower altitudes are shielded by terrain between radar site and given location. It can be seen that this parameter combines both previously mentioned parameters (Fig. 2a, 2b, 2c). The *MH* field differs from *DR* mainly in mountainous area (in Poland it is in the South of the country, see Fig. 2a).

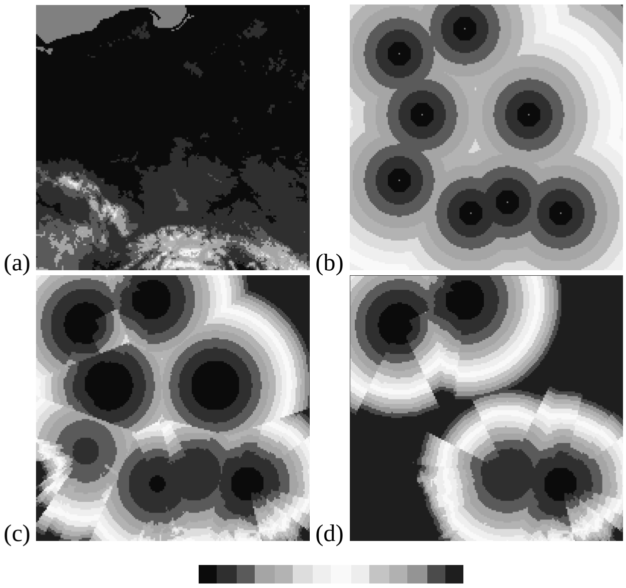

Fig. 2. Topography-dependent maps of (a) *DEM*, (b) *DR*, and (c, d) *MH* parameters for Polish radar network. The *MH* map is shown for two cases: when all radars (c) and only half of them (d) are running. Scale: (a) 0 – 2.5 km; (b) 0 – 400 km; (c, d) 0 – 4 km.

These three parameters are dependent on each other; especially *DR* and *MH* are highly correlated. Correlation coefficient between the fields is 0.919 whereas between *DR* – *DEM* and *MH* – *DEM* is much lower (only 0.026 and 0.111 respectively). For this reason the *DEM* and *MH* maps are chosen as uncertainty parameters in the proposed quality index scheme.

3.3 Spatial and temporal variability of precipitation fields

Next spatial (*SV*) and temporal (*TV*) variability of data fields are investigated and used as measures of data uncertainty.

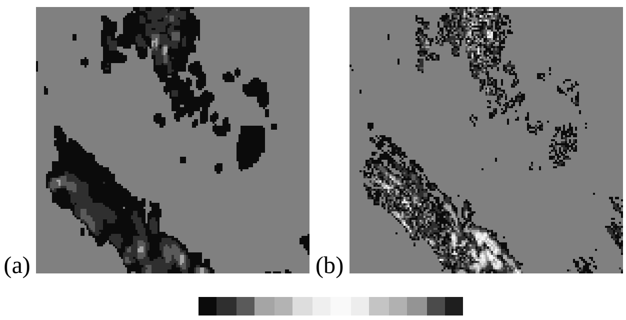

Fig. 3. Example of variability-dependent maps of radar data: (a) *SV* and (b) *TV* parameters for Polish radar network. Hourly accumulation generated on 22 June 2005 03 UTC. Scale: 0 – 100%.

Spatial variability (*SV*) is determined for each pixel on grid bigger then radar pixel size. The grid can be e.g. 3 x 3 or 5 x 5 pixels (in our case), i.e. of size 12 or 20 km, if pixel size is 4 km. Measure of the variability is AAPE (Fig. 3a).

Temporal variability (*TV*) is determined for each pixel on n-hour moving time-window (where $n = 6$ in our scheme). If 1-hour accumulation is as input then six previous time steps is taken in case of QPE and six subsequent forecasts in case of QPF. Measure is AAPE as well (Fig. 3b).

3.4 Representativeness of accumulations

An uncertainty of precipitation accumulation estimate is strongly dependent on a number of rain rate products (*NP*) incorporated in particular hourly accumulation (from 0 to 7 maps). The parameter value results from the POLRAD network and NIMROD time-steps. *NP* values are effect of running radar set during the given hour.

3.5 Lead-time of forecasts

An uncertainty depending on lead-time (*LT*) is determined directly from lead-time value expressed in hours. For forecasts *LT* varies from 1 to 6 hours as maximal 6-hour radar-based nowcasts are generated in NIMROD system. The same values of *LT* are taken for the whole map.

3.6 Quality index for estimated precipitation

Quality of advection forecasts (nowcasts) strongly depends on *QIE* – quality of initial field i.e. an estimate of precipitation. Therefore averaged quality index *QI*, calculated from formula (2) for that estimate, constitutes an important factor QI_{QIE} in forecast quality as well. Then the field of averaged *QI* for estimate is taken as the last parameter of forecast quality.

4 Quality index

4.1 Estimation of quality indexes from uncertainty parameters

In the proposed *QI* scheme values x of each listed above uncertainty parameter X vary between minimal and maximal values X_1 and X_0 respectively. Resulting QI_X varies between one and zero. It is assumed that the accuracy of both the precipitation estimation and forecast decreases linearly with increasing individual *QI* based on parameter X:

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

The above formula is not applied to QI_{QIE} field that is directly taken from *QI* value for estimation (*QIE*).

4.2 Average quality index field

All individual QI_X fields are summarised to an averaged *QI* field. The influence of each quality index field on the average field is determined according to the application through the appropriate weights. Averaged *QI* field is calculated as follows:

$$QI = W_{DEM} QI_{DEM} + W_{MH} QI_{MH} + W_{SV} QI_{SV} + \\ + W_{TV} QI_{TV} + W_{LT} QI_{LT} + W_{NP} QI_{NP} + W_{QIE} QI_{QIE} \qquad (2)$$

with condition for the weights:

$$W_{DEM} + W_{MH} + W_{SV} + W_{TV} + W_{LT} + W_{NP} + W_{QIE} = 1 \qquad (3)$$

The QI_X fields calculated on the base of the parameters X using Eq. (1) are assumed to be fixed for a given radar location and are independent of weather situations in the case of *LT*, *DR*, and *MH*. Since composite maps are used instead of single site radar, the *DR* and *MH* maps (Fig. 4) cannot be fixed when not all radars operate at given time. The QI_X fields based on *SV* and *TV* (Fig. 5) have to be calculated for each time step separately.

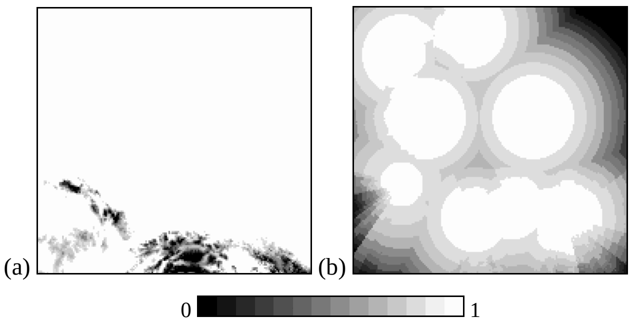

Fig. 4. Individual topography-dependent QI_x maps of (a) *DEM* and (b) *MH* parameters for Polish radar network (in the case of all radars running).

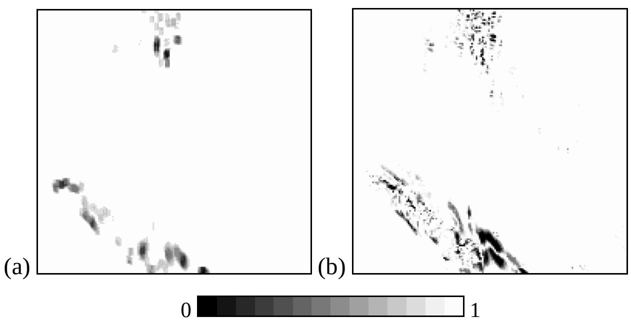

Fig. 5. Individual variability-dependent QI_x maps of (a) *SV* and (b) *TV* parameters for Polish radar network. Hourly accumulation generated on 22 June 2005 03 UTC.

In the first approach the *QI* weights are equal and $W_X = 0{,}20$ for estimates and $W_X = 0{,}25$ for forecasts. They can be identified more accurately in an experimental way.

The information regarding the quality parameters is summarised in Table 1. Moreover some critical thresholds

X_{crit} are incorporated into the scheme. It means that if any threshold is exceeded then averaged *QI* value is set to 0. These critical thresholds are listed in Table 1 as well.

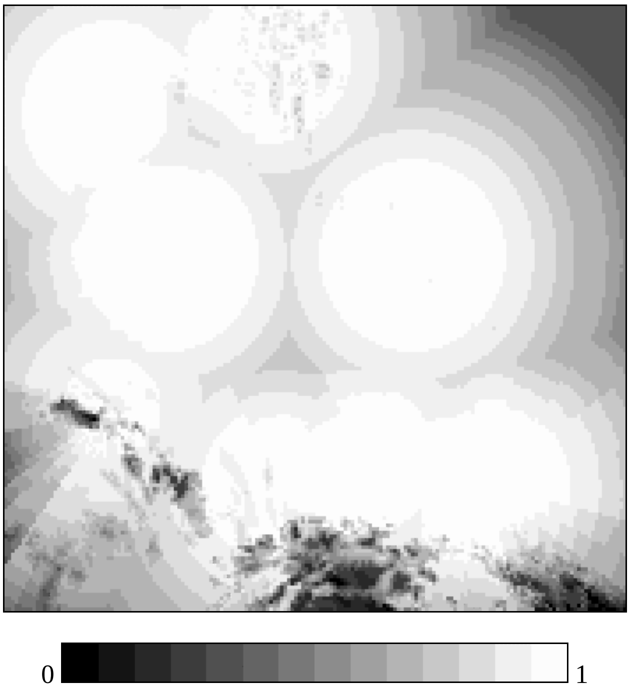

Fig. 6. Averaged *QI* map for Polish radar network. Hourly accumulation generated on 22 June 2005 03 UTC.

Table 1. Summary of the individual uncertainty parameters *X*.

X	Unit	X_1 (QI = 1)	X_0 (QI = 0)	X_{crit}	W_X estim.	W_X forc.
DEM	km	0.5	1	> 2	0.20	0
MH	km	0.5	5	> 5	0.20	0
SV	%	10	90	> 100	0.20	0.25
TV	%	10	90	> 100	0.20	0.25
NP	-	7	3	< 3	0.20	0
LT	hour	0	7	> 6	0	0.25
QIE	-	1	0	< 0.1	0	0.25

5 The quality index field application

The field of quality index defined in the paper incorporates information about quality of precipitation data in each pixel of the estimated and nowcasted fields. The information makes possible to deal with uncertainty of the data and its further propagation to models and applications. For example the data quality fields can be used to generate probabilistic input to hydrological rainfall-runoff model that is described in Szturc et al. (2006).

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