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# Uncertainty in radar-derived estimated and nowcasted precipitation inputs to flash floods modelling

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## 1 Introduction

Radar-based estimates and nowcasts may constitute valuable precipitation input to rainfall-runoff models in the case of flash floods forecasting, whereas for bigger catchments the NWP-derived forecasts play key role. However the radar data, nowcasting and hydrological modelling are all burdened with a number of errors from different sources. Since the deterministic runoff forecast is not reliable enough then an end-user should be provided with uncertainty information related to deterministic forecasts. Therefore dealing with uncertainty along the whole processing chain (from radar measurements through precipitation nowcasts up to hydrologic forecasts) is necessary.

For very small mountainous catchments (the South of Poland) rainfall-caused flash floods are the most dangerous hydrological events so the radar-driven precipitation inputs may be the most crucial. They differ in terms of spatial and temporal resolutions, validation time (lead-time), and their uncertainty. Therefore the radar-based inputs, their uncertainties, and propagation to hydrological modelling are a subject of this paper.

## 2 Outline of methodology

The presented methodology of dealing with radar precipitation uncertainty propagation to runoff forecasts is based on a concept of (Fig. 1):

(1) quality index (QI) field for all kinds of precipitation input data,
(2) probability density function (PDF) that is chosen to characterise the phenomenon,
(3) ensemble of the PDF quantiles as input to rainfall-runoff models,
(4) ensemble of runoff forecasts.

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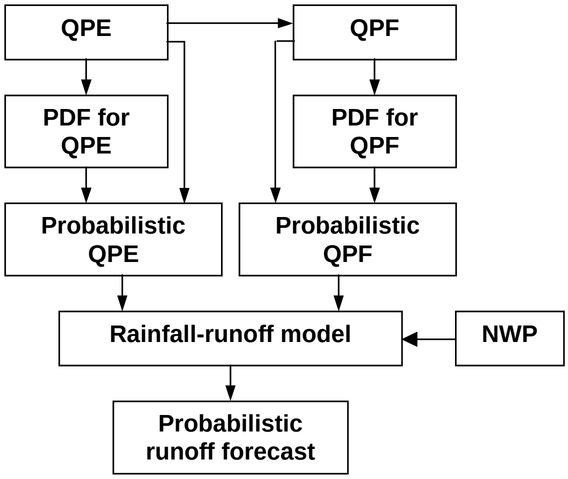


**Fig. 1.** Scheme of the probabilistic hydrological forecasting.

## 3 Quality Index of precipitation input

The quality index technique requires selecting the most crucial uncertainty parameters for both radar estimates and radar-based nowcasts. They are: (1) topography-dependent parameters (like digital elevation map and height of the lowest scan), (2) spatial and temporal variability of the data, (3) reliability of accumulation (a number of rain-rate products composing a given sum), and additionally for nowcasts: lead-time and quality index of the initial precipitation estimate. On the basis of particular quality indexes an averaged quality index fields is computed using the weighting formula (Szturc et al., 2006). The index is a starting point for parameterisation of specific PDF.

## 4 Precipitation PDF

4.1 Gamma PDF

Uncertainty can be included into estimates or forecasts of precipitation using a specific probability density function (PDF) suitable for physical features of rainfall. The gamma distribution is one of proper PDFs.

The gamma PDF is described by the following formula (where $\alpha > 0$):

$$f(x) = \frac{1}{\Gamma(\alpha+1)\mu^{\alpha+1}} x^{\alpha} e^{\frac{-x}{\mu}} \tag{1}$$

where $\alpha$ and $\mu$ are the shape and scale parameter, respectively; $\Gamma$ – gamma function. In Fig. 2 influence of the parameters on shape of the gamma PDF is shown.

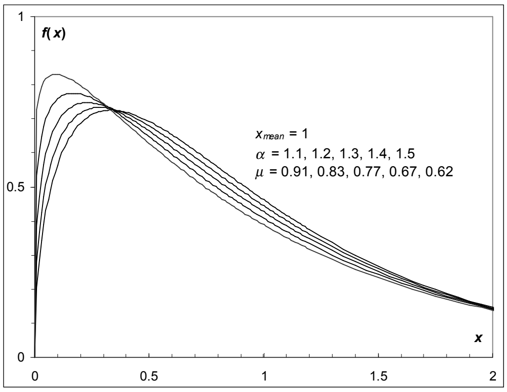


**Fig. 2.** Gamma PDFs for different parameter sets using relationship (Eq. 2) and $x_{mean} = 1$ (curves from the highest to the lowest): $\alpha = 1.1, \mu = 0.91$; $\alpha = 1.2, \mu = 0.83$; $\alpha = 1.3, \mu = 0.77$; $\alpha = 1.4, \mu = 0.67$; $\alpha = 1.5, \mu = 0.62$.

For the gamma PDF the following relationship between mean value $x_{mean}$ of variable $x$ (precipitation) and the PDF parameters is expressed as follows:

$$x_{mean} = (\alpha + 1) \cdot \mu \tag{2}$$

4.2 Estimation of gamma PDF parameters

It is assumed that the PDF parameters are functions of quality index *QI*. The relationship between the averaged *QI* and the parameters $\alpha$ and $\mu$ is experimentally determined for each pixel of the data field.

The parameter $\alpha$ is calculated taking a linear relationship between $\alpha$ and *QI*. Next the deterministic QPE (or QPF) values of precipitation ($R$) are assumed to be mean values of precipitation PDF. Therefore the second parameter $\mu$ of gamma PDF can be calculated from:

$$\mu = \frac{R}{\alpha + 1} \tag{3}$$

In this way for precipitation map two fields of PDF parameters (or more in dependence on specific PDF) are determined (Fig. 3).

## 5 Estimation of PDF quantiles

5.1. Probabilistic precipitation

The main difference between probabilistic QPE (or QPF) and deterministic one is that it is not a map of single values but map of precipitation PDFs. Practically it means that probabilistic precipitation field consists of three values for each pixel: two PDF parameters and QPE (or QPF).

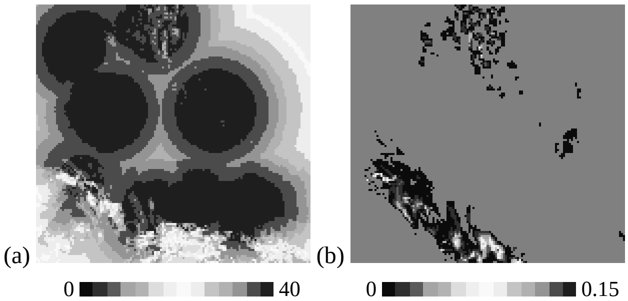


**Fig. 3.** Maps of gamma PDF parameters: (a) $\alpha$ and (b) $\mu$ for Polish radar network for hourly accumulation generated on 22 June 2005 03 UTC.

However the rainfall-runoff model is a deterministic model that requires deterministic precipitation as its input, not probabilistic one. In order to overcome this difficulty a common solution is to produce an ensemble of a few deterministic inputs instead of only one. It may be done by selection of some characteristic maps. From a practical aspect a number of members of ensemble cannot be too big. The members can be chosen as quantiles, e.g. 5, 25, 50, 75, and 95%. This ensemble will constitute a sequence of inputs to deterministic rainfall-runoff model.

5.2. CDF for probabilistic precipitation

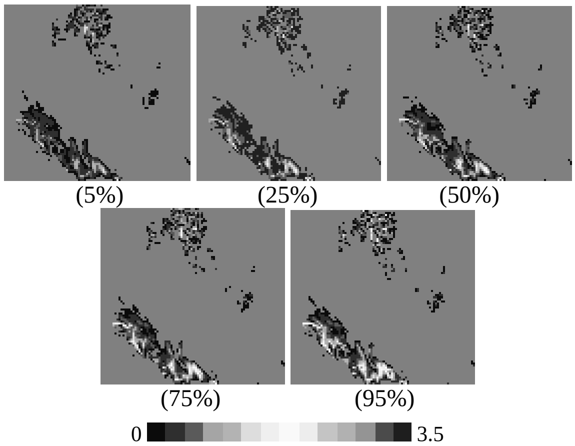


**Fig. 4.** Maps of $R_{5\%}$, $R_{25\%}$, $R_{50\%}$, $R_{75\%}$, and $R_{95\%}$ quantiles of gamma PDF for Polish radar network for hourly accumulation generated on 22 June 2005 03 UTC.

To prepare ensemble of precipitation fields certain quantiles of PDF are to be determined, e.g. $R_{5\%}$, $R_{25\%}$, $R_{50\%}$, $R_{75\%}$, and $R_{95\%}$ (the probability thresholds should be defined for a specific situation). This is achieved basing on a cumulative distribution function (CDF) $F(q)$. The $F(q)$ values for gamma PDF are tabulated or can be calculated using the following formula:

$$F(q)=\int_{-\infty}^{q} f(x)\mathrm{d}x=\int_{0}^{q}\frac{1}{\Gamma(\alpha+1)\mu^{\alpha+1}}\,x^{\alpha}e^{\frac{-x}{\mu}}\,\mathrm{d}x \qquad (4)$$

In this way for each selected *p*-quantile a separate map of $R_{p\%}$ is generated. All the maps constitute an ensemble of precipitation fields (Fig. 4).

## 6 Using PDF-based probabilistic precipitation fields in hydrologic model

Since input to rainfall-runoff model is probabilistic that means that an ensemble of precipitation fields is provided. In consequence the hydrological model needs to be activated 5 or 7 times according to a number of quantiles. As output from rainfall-runoff model the same number of 5 or 7 discharge hydrographs will be obtained (Fig. 5) which define classes of runoff uncertainty.

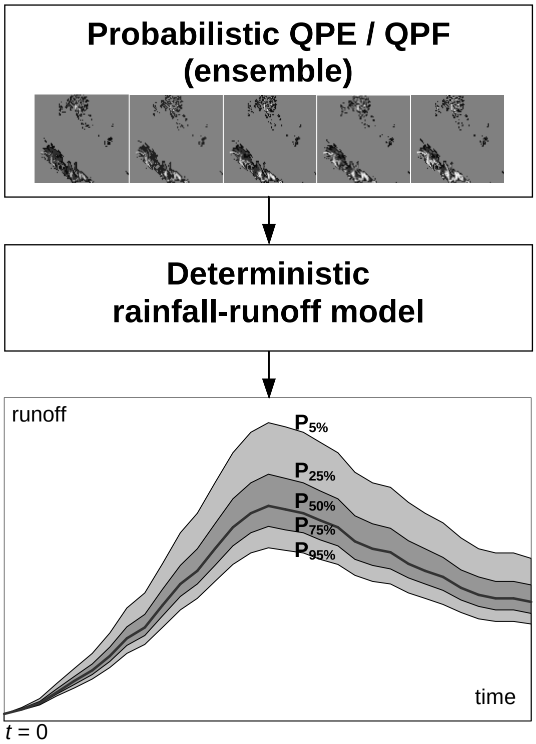


**Fig. 5.** Ensemble of probabilistic precipitation fields as input to rainfall-runoff model and resulting ensemble of hydrographs.

Classes of runoff probability will be determined basing on statistical investigation of a big number of rainfall flood events (Gouweleeuw et al., 2005; Roulin and Vannitsem, 2005). More advanced way of direct using probabilistic input to deterministic rainfall-runoff model and deriving probabilistic runoff forecast is Bayesian forecasting system proposed by Krzysztofowicz (Kelly and Krzysztofowicz, 2000; Krzysztofowicz, 2002; Herr et al., 2002).

## 7 Future works

The presented methodology is to be tested on small mountainous catchments in the Odra basin (Poland) where flash floods are the most dangerous hydrological phenomena. Rainfall data will be provided by Polish weather radar network POLRAD, nowcasts will be produced by NIMROD system, and spatially distributed rainfall-runoff model LISFLOOD is to be employed. Uncertainty of the precipitation inputs will be introduced according to the scheme proposed by Szturc et al. (2006).

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