Universität Stuttgart

Institute of Hydraulic Engineering
Department of Hydrology and Geohydrology

Environment State Agency
Rhineland-Palatinate
Germany

Probability Forecast of Intensive Precipitation and Floods for Small Catchments of the Rhine basin - Experimental Results and Operational Design

J. Bliefernicht[1], A. Bárdossy[1] and N. Demuth[2]

1: Institute of Hydraulic Engineering, Universität Stuttgart, Germany

2: Environment State Agency Rhineland-Palatinate, Germany

contact: Jan.Bliefernicht@iws.uni-stuttgart.de

Motivation

It is well known that forecasts of precipitation or discharge are uncertain. The uncertainty arises from sources such as the incomplete description of the atmosphere state due to the lacks of the observational system and the simplifications made during the model development. To describe the forecast uncertainty, ensemble prediction systems (EPS) and statistical forecasting techniques are developed in meteorology and hydrology.

In this investigation we present a statistical approach which transfers the large-scale information of a global numerical weather prediction (NWP) model to provide a probabilistic precipitation forecast for small river basins. Furthermore, we also illustrate a way how to transfer the precipitation ensemble through a distributed hydrological prediction model to determine a probabilistic discharge forecast.

Probabilistic Precipitation Forecast

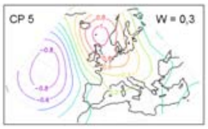
The precipitation model should meet the requirements of a flood warning system which is designed to forecast the discharge process in small river basins (750 and 5000 qm^2). The general structure of the model can be divided into the following steps:

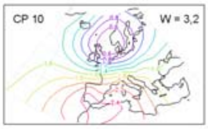
1. The daily areal precipitation is predicted for the basin of interest.
2. The areal information is disaggregated into precipitation realizations with a high spatiotemporal resolution.

Finally, the model provides a probabilistic precipitation forecast for up to seven days. In the following a brief description of both steps is given.

Step 1: Forecasting Daily Areal Precipitation

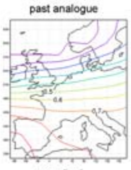
An objective classification scheme (Bárdossy et al., 2002) is selected to determine circulation patterns (CP) with a high risk of intensive precipitation for each day of the forecast horizon. The predictor is the mean sea level pressure.

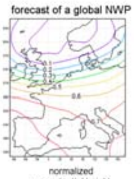




The example shows the anomaly maps of the driest (left) and the wettest CP (right) determined for the Rhine basin (Germany). The wetness index W measures the deviation from mean observed precipitation. The larger the index is, the wetter is a CP. A wetness index equal to 1 indicates a pattern which is not different to climatology. The Rhine classification used in this investigation consists of 12 CPs.

If a wet CP is detected, the analogue method is chosen to forecast the daily areal precipitation (Obled et al., 2002). The basic principle of the analogue method is as follows:

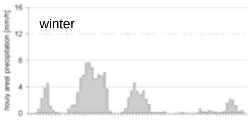


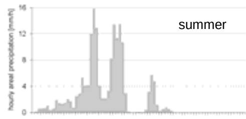


The atmospheric pattern of a global NWP model is compared to an archive of past patterns. If a similar (analogue) pattern is identified, the observed precipitation of the analogue is selected as forecast. Afterwards, the search algorithm is repeated to identify the k-nearest analogues which are used to describe the forecast uncertainty for the variable of interest.

Step 2: Simulation of Hourly Precipitation

The second component of the methodology is activated if the daily areal precipitation exceeds a certain warning threshold (e.g. 10 mm/d). Then, the areal information is disaggregated into hourly precipitation fields for the river basin of interest. The objective of the simulation is to reproduce the variability of the precipitation process (e.g. the moving direction of precipitation fields and the intensity of a precipitation event) during an extreme.

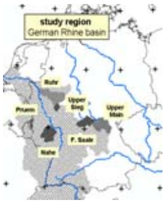




The example shows one realization of the hourly areal precipitation for an intensive event in winter and in summer. Note that the average precipitation of a river basin (Upper Main) is considered.

Results

The precipitation model is tested for head catchments and the basins of small tributaries of the Rhine basin in Germany. The model is developed in a reanalysis framework to evaluate the performance over a long time period (1958 – 2001).



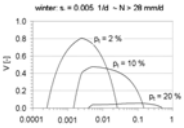
The statistical precipitation properties for the classification are listed in the tables on the right side. The risk index R should indicate CPs with a high risk of intensive precipitation. The index has similar properties like the wetness index. A risk index of three indicates a CP with a threefold higher risk of intensive precipitation.

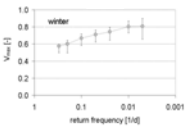
CP	CP-occurence [%]	rainfall probability [%]	wet-day amount [mm]
1	9.2	50.1	8.2
2	10.9	25.8	5.3
3	6.2	15.4	2.9
4	5.1	61.0	6.6
5	8.7	80.3	13.0
6	8	55.5	5.9
7	6.9	65.7	8.4
8	8	24.4	5.4
9	15.4	21.3	5.0
10	9.8	15.9	4.9
11	7.5	64.7	8.3
12	4.2	54.0	8.4

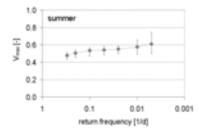
CP	wetness index [-]	Nr. of extremes	risk index [-]
1	1.3	7.5	0.4
2	0.4	0.5	0.1
3	0.1	0.0	0.1
4	1.2	3.0	1.6
5	3.2	26.5	5.5
6	1.0	5.8	1.6
7	1.7	8.8	1.2
8	0.4	2.3	0.1
9	0.3	3.3	0.2
10	0.2	0.8	0.1
11	1.7	9.3	0.8
12	1.4	3.5	2.3

The model performance of the analogue method is evaluated in terms of a binary warning system. The aim of the model development is to find a suitable compromise between the number of alarms and the number of misses. To analyze this question, a cost-loss approach is selected which describes the consequences of a decision making process (cost for protection and losses if an event is missed).

For users with low costs and high losses (e.g. 0.001) it is recommended to select a low probability threshold (p_t = 2 %) for decision making (see upper left figure). In this case, the warning system triggers many alarms but the number of misses is reduced so that those users can gain a high benefit. Here, the benefit is expressed in terms of the economic value V (Richardson, 2003). To determine the forecast performance over the entire range of the predictand, the maximum economic value V_{max} is calculated for summer and for winter precipitation (see the right figures).



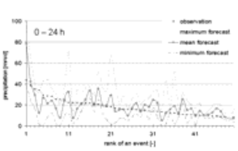




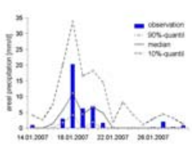
Probabilistic Flood Forecast

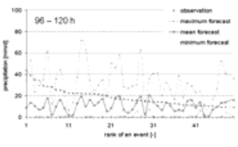
Precipitation forecast of EPS and statistical forecasting techniques are characterized by a tremendous forecast uncertainty for small river basins, in particular for longer lead times. The ensemble mean seems to be a poor choice for the detection of extremes. To illustrate this problem two examples are given below:

COSMO-LEPS



Analogue Forecasting





The figures on the left side show the daily precipitation forecast of a mesoscale EPS (COSMO-LEPS, Marsigli et al., 2005) which are compared to the observations. The data is sort according to the precipitation amount where the largest observed event has the rank one. For shorter lead times (0-24 h) the ensemble mean is a suitable indicator for the extremes of the observation period (Jan. 2007 to Nov. 2007). But for longer lead times this warning strategy is poor. The same problem holds also for the analogue method (right figure).

Operational flood forecasting requires a reasonable compromise between the ensemble size and the computing time needed to issue a flood warning. In the aforementioned examples, it is recommended to reject those ensemble members which are below a certain warning threshold (e.g. 10 mm/d) so that a suitable number of realizations can be transferred through the hydrological prediction model. Finally, the ensemble of discharge realizations is again formulated as forecast probabilities exceeding a certain warning threshold of a gauging stations without neglecting the previous knowledge.

Outlook

In the near future, the precipitation model will be tested as one component of the operational flood warning system which is running at the Environment State Agency Rhineland-Palatinate (LUWG), Germany. It will provide a short-range forecast every six hours for several catchments located in the German Rhine basin. Furthermore, the concept of transferring the ensemble forecast of the statistical approach will be tested on behalf of the LUWG for three subcatchments of the Rhine basin.

Some results presented in this investigation are part of the outcomes of the research projects PREVIEW (Prevention, Information and Early Warning, see www.preview.com) and HORIX (A German abbreviation for Flood Risk Management of Extreme Events).

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