Urban Flood Prevention Based on Ensemble Precipitation Forecasts

L’utilisation d’ensembles de prévisions de pluie pour la prévention des inondations urbaines

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RÉSUMÉ

Des stratégies sophistiquées sont nécessaires pour une alerte de crues urbains dûs aux pluies fortes convectives. Ici nous présentons une approche d’amélioration de prévisions à courte échéance basée sur une combinaison d’ensembles d’une prévision radar avec des ensembles de la prévision numérique COSMO de la Météo Allemande DWD. Les ensembles de prévision combinée sont disponibles toutes les 5 minutes. Leur utilisation est d’une part l’introduction au Service d’Annonce des Crues de la ville de Hambourg (www.wabiha.de) et d’autre part la simulation en temps réel dans le modèle hydrologique KalypsoHydrology pour le bassin versant de la Kollau. Cette dernière application est présentée avec ses ensembles d’hydrographes prévus. L’étendu des ensembles résultants est illustré sur un événement de l’été 2016. Surtout la gestion d’un bassin de retention peut être amélioré grâce aux prévisions de pluie.

ABSTRACT

Sophisticated strategies are required for flood warning in urban areas regarding convective heavy rainfall events. An approach is presented to improve short-term precipitation forecasts by combining ensembles of radar nowcasts with the numerical weather predictions COSMO-DE-EPS of the German Weather Service. The combined ensemble forecasts are produced operationally every 5 min. Applications involve the Flood Warning Service Hamburg (WaBiHa) and real-time hydrological simulations with the model KalypsoHydrology. Ensemble forecast flood hydrographs for the urban catchment Kollau are presented in this work. The range and quantiles are illustrated for a convective storm event in summer 2016. A flood management measure is improved by using precipitation forecasts in a flood control reservoir.

KEYWORDS

basin control, ensemble forecast, flood warning, online simulation, operational warning system

1 INTRODUCTION

The high variability of local intense rainfall events and the short response time in generating surface runoff in urban catchments require improved methods for flood warning and flood prevention. The presented work is part of the German research project StucK "Long term drainage management of tide-influenced coastal urban areas with consideration of climate change". A key aspect of this project is to improve short term forecasts of heavy rainfall by combining ensembles of radar nowcasts with numerical weather prediction ensembles (Jasper-Tönnies et al., 2018).

In this paper we present the results of a case study of runoff simulations using ensemble precipitation forecasts as input to illustrate the potential of combined ensemble forecasts for urban water management and flood prevention based on reservoir control in Hamburg.

2 MATERIALS AND METHODS

2.1 Ensemble precipitation forecasts

2.1.1 Numerical Weather Predictions

Numerical weather predictions produced by the German Weather Service (DWD) are used: COSMO-DE is a non-hydrostatic model with a horizontal resolution of 0.025° (2.8 km). The deterministic forecasts COSMO-DE and the ensemble forecasts COSMO-DE-EPS (Kühnlein et al. 2014) are provided every 3 h with a lead time of 27 h. COSMO-DE forecasts are currently used as input data for flood warnings by the Flood Warning Service Hamburg (WaBiHa: http://www.wabiha.de).

2.1.2 Ensemble Precipitation Nowcasts

The basis of the nowcasts are

- Radar data from 4 DWD radar stations: Boostedt, Rostock, Hannover and Emden. The radar product (DX) is a PPI with a resolution of 1 km x 1° and 5 min.
- Rain gauge measurements of 400 stations (Hamburg/ Northern Germany, dt 5 min – 1h)
- The radar data are processed and corrected with the software SCOUT, using several filter and correction methods (Jasper-Tönnies & Jessen, 2014). The rain gauge measurements are continuously used for the adjustment of radar measured rainfall sums, based on data of the past 3 h. A composite with a resolution of 1 km x 1 km is produced every 5 min from the data of the four radar stations. An example of the adjusted composite is shown in Fig. 1.

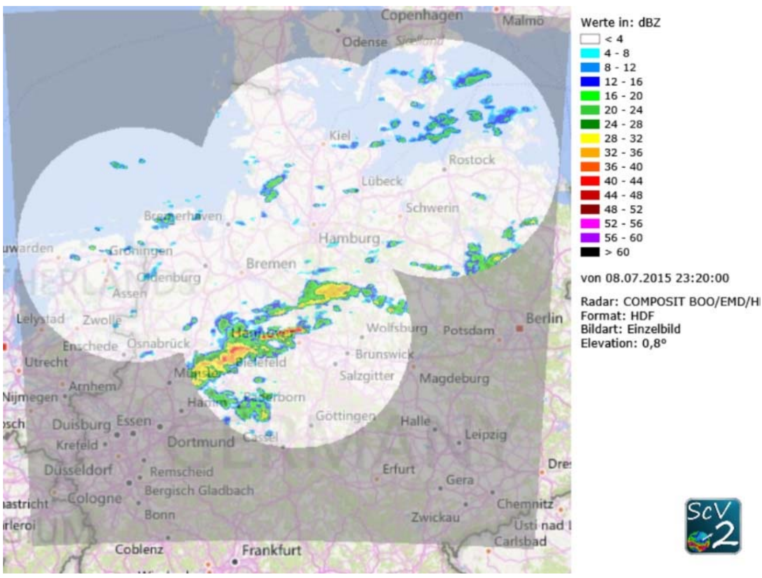

Figure 1. Operational North German composite from four radars Boostedt, Emden, Hannover, Rostock in dBZ

- The radar composites of the last 30 min serve as input for calculating nowcasts with a lead time of 1-3 h. The method is a further development of the nowcast described by Tessendorf and Einfalt (2012).

- Ensemble nowcasts are generated by variation of the forecast parameters. The size of the variation depends on the variance of the parameters found by cell-tracking and on assumptions about potential changes of the wind field and measurement errors.

2.2 Ensemble flood forecasts

The precipitation forecasts serve as input data for the semi-distributed rainfall runoff model KalypsoHydrology and the calculation core KalypsoNA to model the hydrological processes in the Kollau catchment, Hamburg (Figure 2, size: 33.6 km²; lag time: 1 hour). The model supports the simulation of the hydrological processes on the surface and the main processes in the subsurface (TUHH, 2013 and Hellmers & Fröhle, 2017).

The radar data is assigned to each element of the hydrological model as the area weighted mean of all radar grid cells based on the intersection with the hydrological spatial element, as illustrated in Fig. 2 (right).

The simulation of the initial soil moisture is performed over the past 3 years to obtain the most recent soil moisture conditions. The operational forecast model starts four days before the current time, using radar measured precipitation data extended by ensemble forecasts as input. For each ensemble member, the flood hydrograph is computed at each node of the river network and transferred to water levels for a comparison with the measured water levels. The simulations are updated every 15 minutes.

The hydrological model has been extended with control system functions for advanced flood management. The criteria of the setpoints for the flow control of flood management devices (retention ponds, flood gates etc) are defined by an automatic control system. To increase the potential retention volume for storm water, the devices can be pre-emptied before the event. The control criteria for the outlet valve of the device are modified according to forecasted rainfall amounts.

The flood control reservoir (FCR) "Steinwiesenweg" with a volume of 30 400 m³ has been extended with a throttle valve which is controlled by rainfall forecasts. The location of the flood control reservoir is illustrated in Figure 2 (left).

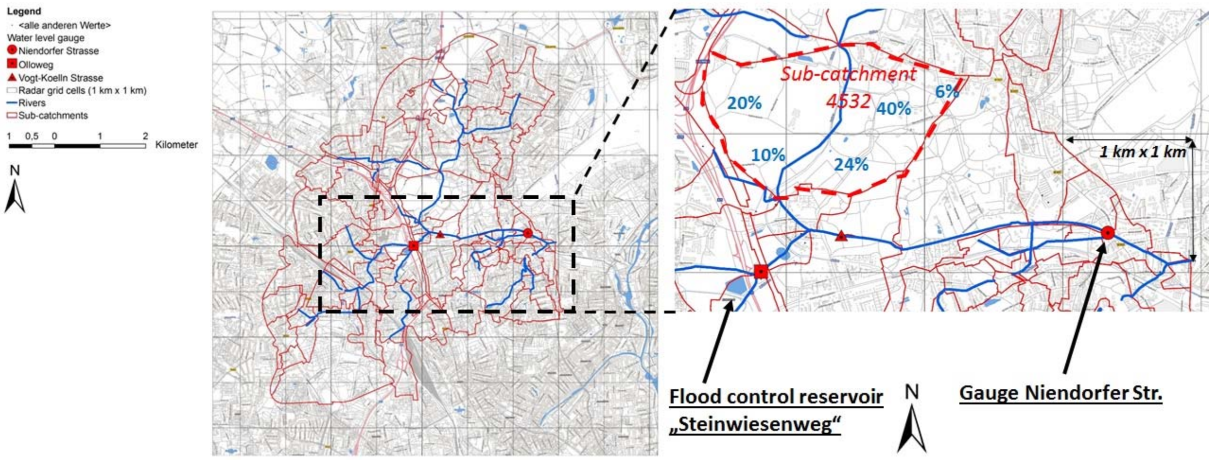

Fig. 2. Map of the Kollau catchment (33.6 km²), location of water level gauges, illustration of the intersection of precipitation data with hydrological elements and the location of the FCR 'Steinwiesenweg'.

3 RESULTS AND DISCUSSION

The runoff simulations of the convective precipitation event on 28 August 2016 in the Kollau catchment are evaluated in more detail as an example for using the ensemble nowcasts as model input. The precipitation came from two intensive rain cells which moved over the catchment between 14:00 and 16:00 UTC. The simulated flood hydrographs and water level measurements of the event are presented in Fig. 3 as quantile plots. The simulated water levels based on radar are shown in blue, the measured water level data in red. The moderate warning level at 620 cm NHN is exceeded at the gauge station at 19:45 UTC.

In the Kollau catchment, out of 22 FCR with an overall volume of about 153 513 m³ only the FCR 'Steinwiesenweg' is a retention pond constructed as bypass. The FCR is designed for large storm events with a return period of about once in 100 years. In this paper, this design is modified (1) by installing an automatic valve which is reducing the outflow according to the forecasted precipitation and (2) enabling an earlier inflow at lower inflow rates to the FCR from upstream. The results are presented for the convective rainfall event August 2016. The peak water level at the downstream gauge ‘Niendorfer Str.’ can be reduced by 6cm (Fig. 3 b). This result shows the potential for the improvement by actively controlling further FCR.

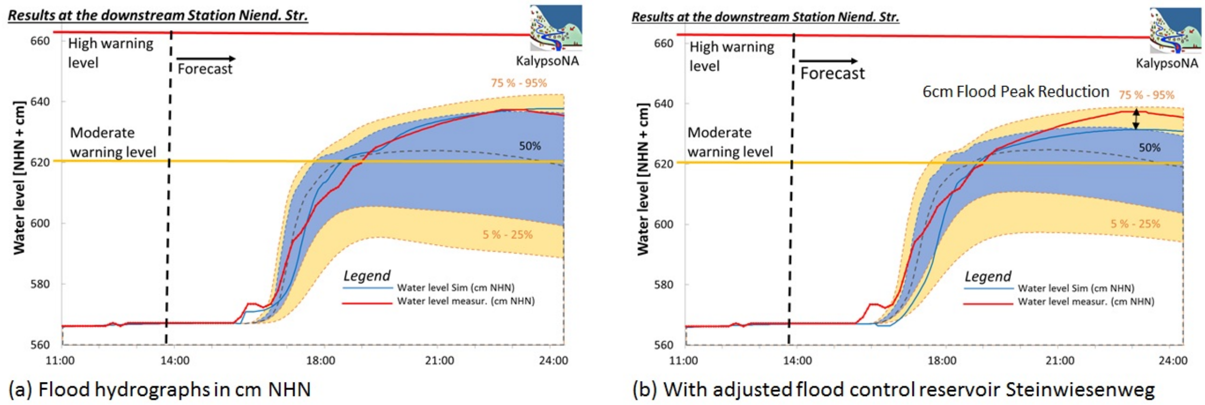

Fig. 3. (a) Quantile plot of the flood hydrographs of 10 ensembles member runs in cm NHN of the rainfall event 28 August 2016 at the station Niendorfer Str.. Flood hydrographs based on radar measurements (blue) and water level measurements (red). (b) Plotted flood hydrograph results of the adjusted FCR Steinwiesenweg illustrating the reduction of 6cm in peak water level.

4 CONCLUSIONS

The results show the integration of combined precipitation forecasts of radar nowcasts and COSMO-DE-EPS into the operational flood warning system. A real-time implementation of runoff simulations with the software KalpysoHydrology using the ensemble precipitation forecasts was realised in 2017 and shall improve warnings of the Flood Warning Service Hamburg.

The improvement of a flood management measure by using precipitation forecasts and the active control of the flood control reservoir Steinwiesenweg is described. The results illustrate the potential to improve the flood retention management as well for small events by enabling a larger flexibility to use control systems coupled with precipitation forecasts.

5 ACKNOWLEDGEMENTS

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