Optimisation of Rainfall Runoff Modelling for Urban Flood Management with Ensemble Radar Nowcasts

Optimiser la modélisation de l'écoulement des eaux pluviales pour la gestion des inondations en milieu urbain avec des ensembles de prévisions de radar à court terme (Nowcasts)

Sandra Hellmers[1], Alexander Strehz[2], Nina Sophia Leese[1], Thomas Einfalt[2], Peter Fröhle[1]

[1]Hamburg University of Technology (TUHH) – http://www.tuhh.de/wb - Denickestrasse 22 21073 Hamburg, Germany
[2]hydro & meteo GmbH & Co. KG (hm) – http://www.hydrometeo.de/ - Breite Str. 6-8 D-23552 Lübeck, Germany

RÉSUMÉ

Il est nécessaire d'avoir accès à des stratégies plus performantes pour évaluer l'influence des précipitions à l'échelle locale sur les prévisions et les avertissements de crue lors de tempêtes, en particulier en milieu urbain. Dans cette communication, une approche est présentée se basant sur des ensembles de prévisions de radar à court terme (Nowcast) et des modèles d'écoulement de l'eau pluviale afin d'améliorer le système de gestion des inondations. Les ensembles nowcasts déterminent différentes précipitations possibles et permettent de faire des prévisions en se basant sur les informations statistiques qu'ils fournissent. Pour chaque ensemble, le logiciel SCOUT calcule dix prévisions nowcasts avec un incrément de temps de 5 minutes et une période de prévision de 60 minutes. Dans le cadre du projet de recherche allemand StucK ("Gestion de drainage à long terme en milieu urbain sous influence des marées, en prenant en considération les changements climatiques"), des ensembles de prévisions de radar nowcast avec une résolution spatiale d'1 km² sont utilisés comme données d'entrée dans les modèles d'écoulement de l'eau pluviale du logiciel KalypsoHydrology. Ce logiciel fait partie du progiciel Kalypso utilisé pour la gestion des inondations à Hambourg. La zone d'étude, le bassin versant de la Kollau d'une superficie d'à peu près 35 km² situé à Hambourg, est caractérisée par divers temps de réactions hydrologiques. Les résultats de cette étude mettent en avant l'utilité de cette technique pour évaluer les effets des inondations à l'échelle locale.

ABSTRACT

Especially in urban areas, improved strategies are required to assess the influence of small scale precipitation patterns of local heavy rainfall events in a flood warning context. In this paper an approach is presented based on ensembles of radar nowcasts and a rainfall runoff modelling tool as part of a flood management system. Nowcast ensembles produce several possible future rainfalls and can help in forecast applications by providing statistical information. Ten nowcast ensemble members have been produced by the SCOUT software with a time step of 5 minutes and a forecast horizon of 60 minutes each. Within the German research project StucK ("Long term drainage management of tide-influenced coastal urban areas with consideration of climate change") ensemble radar nowcasts with a spatial resolution of 1 km² serve as an input for rainfall runoff modelling with the software KalypsoHydrology which is part of the Kalypso product used for flood management in Hamburg. The study area of the Kollau catchment (ca. 35 km²), Hamburg, is characterized by different hydrological reaction times. The study results show the usefulness of the technique for assessing local flood impacts.

KEYWORDS

Ensembles, Radar Data, Rainfall Runoff Modelling, Urban Flood Management

1 INTRODUCTION

The high variability in local intense rainfall events and the short lag time of flood discharges in urban catchments demand improved methods in flood warning systems. The smaller the regarded hydrological systems are defined, the higher is the spatial heterogeneity and the temporal variability (Gentine et. al, 2012). And the greater the degree of heterogeneity, the smaller the considered scale has to be set to represent such diverseness (Ryan Fedak, 1999; Woods 2004). Local heavy rainfall is a difficult forecast parameter in flood warning systems, because of its high variability at small temporal and spatial scales. In urban areas, this demands precipitation data with a high spatial and temporal resolution to model the impact on the discharge of flood prone areas. Furthermore, approaches are required to quantify the uncertainty of nowcasts of local heavy rainfall events and its impact on the generated flood waves in the urban river systems.

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” (2015 - 2018; www.stuck-hh.de). In this project, the hydrological interaction and the impacts of extreme events from heavy rainfall as well as from storm surges are analysed to develop optimised drainage strategies. The simultaneous occurrence of pluvial extreme events and high storm surges causing high tidal water levels induce a critical situation in urban coastal areas. This paper presents the first steps in the research project: (1) developing a methodology to compute ensemble nowcasts of local heavy rainfall events, (2) integration of small scale radar rainfall nowcasts in a rainfall runoff model and (3) visualizing the results with percentiles to optimize the Flood Warning Service Hamburg.

2 METHOD

Ensemble radar nowcasts

The method used to generate nowcast ensembles is based on radar precipitation data with a high spatial resolution (cp. Figure 1). The measured radar data is processed and corrected with the software SCOUT (Hydro & Meteo, 2009). Radar data quality issues have been investigated in detail in the EU FP5 Project VOLTAIRE and validated in COST Action 717, to support the use of radar observations in hydrological and numerical weather prediction models (Michelson et al., 2005). Numerous data quality items from this European Cooperation Projects have been implemented in the software-system SCOUT. The ensemble nowcasts are generated by variation of several forecast parameters within the boundaries of the uncertainty of the observed parameters (Tessendorf et al., 2012). Specifically, an extrapolation of velocity vectors and growth rates of observed precipitation cells is used for predicting the near future. The aim is to generate ensembles whose spread reflects the uncertainty of the nowcasts.

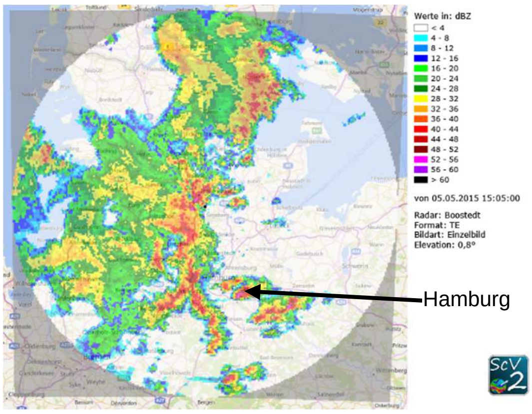

Figure 1: Processed radar data for North Germany, Hamburg; station Boostedt (res.: 1km²) for the 5th of May, 2015

Ensemble flood hydrographs

The ensemble radar nowcasts are further processed in the semi-distributed rainfall runoff model Kalypso-Hydrology. It is an open-source software model for the simulation of the land-based water balances in river catchments on the basis of given precipitation time series (TUHH, 2013). The hydrological model supports the simulation of snow, evapotranspiration, evaporation from water surfaces in retention ponds, soil moisture, interflow, baseflow and groundwater flow processes. The catchment is divided into smaller hydrological systems. These are subcatchments and hydrotopes (a.k.a. hydrologic response units), i.e. units with distinguished land use, drainage and soil characteristics,

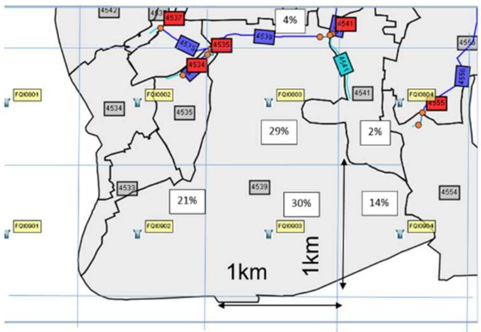

Figure 2: Spatial integration of data: Area weighted mean of radar grid elements and intersection with the hydrological areal units.

for which the water balance is computed. Depending on the level of detail, the defined landuse units are composed of small scale heterogeneous elements on the scale of buildings.

The detailed ensemble radar nowcasts with a spatial resolution of 1km² are distributed over the spatial elements in the semi-distributed hydrological model by an area weighted mean (Figure 2). The precipitation is assigned to each element of the hydrological model as the area weighted mean of all radar grid cells with an intersection with the hydrological spatial element. In this way a detailed spatial integration of the precipitation data into the rainfall runoff model is achieved.

For each ensemble radar nowcast member the flood hydrograph is computed with the rainfall runoff model. The ensemble results are used to optimise the Flood Warning Service Hamburg (WaBiHa: http://www.wabiha.de) by evaluating the flood risk level for the regarded gauging stations.

3 CASE STUDY RESULTS

The presented methodology has been applied to the catchment area of the river Kollau in the northwest of Hamburg, Germany. The Kollau catchment has a size of 32km² and the main river has a length of 7,3km. This urban area with a high imperviousness of industrial spaces, large infrastructures and dense residential areas is drained by 7 tributaries into the main river of the Kollau. The lag time, i.e. interval from the time of the main rainfall till the highest rate in discharge at the downstream outlet point, is short in this urban catchment area (approximately 1h).

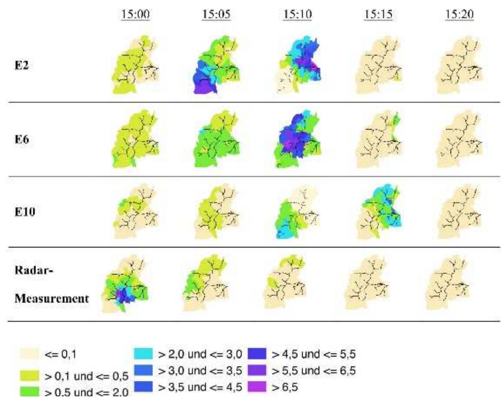

Figure 3: processed nowcast ensemble member results for an urban case study area in Hamburg, Kollau

Radar data ensembles are generated on the basis of the methodology described above. One example is the short-term local rainfall event of May 5th, 2015 in the selected example catchment. The measured radar data of the station Boostedt (about 60km north of Hamburg) which covers the example area is processed and corrected with the software SCOUT to generate 10 nowcast ensemble members (Figure 1 and Figure 3). The nowcast is computed for the full area covered by this radar with a maximum lead time of 60 minutes. The temporal resolution is 5 minutes and the spatial resolution of the data is approximately 1km x 1km. Three of the 10 ensemble members and the measured radar data are given in Figure 3.

The three members illustrate a wide spread of nowcast ensemble members. The ensemble member E6 shows a high rainfall intensity at 15:10 in the centre of the urban catchment, which causes the highest discharge of all members at the downstream outlet of the catchment (Figure 4). The ensemble member E2 illustrates an earlier start of rainfall at 15:05 in the southern region; the resulting hydrograph shows an earlier but lower peak flow than E6. The ensemble member 10 shows a later and weaker rainfall intensity, which causes a lower discharge rate. The observed radar data shows an early onset of precipitation at 15:00 with the highest intensity in the southern part of the catchment and the resulting hydrograph features an early and relatively low maximum discharge rate. This highlights the uncertainty in predicting discharge curves related to small scale storm events.

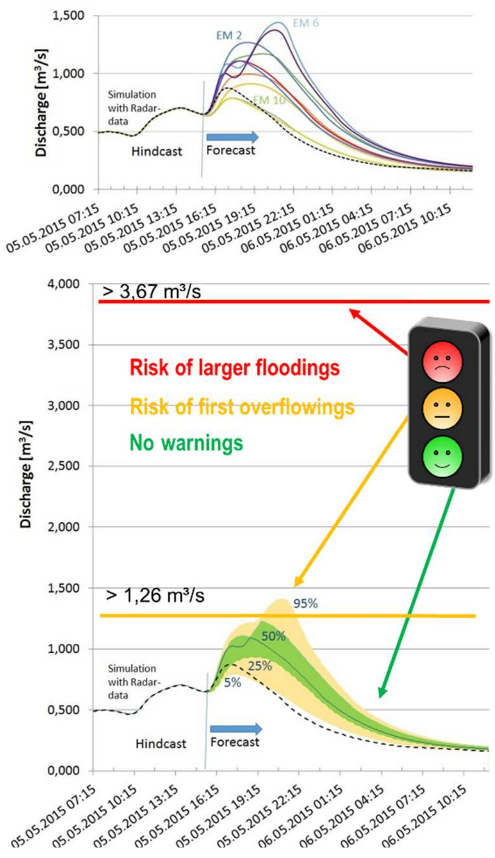

Figure 4: Discharge hydrographs of the 10 nowcast ensemble member results (top) and evaluation of the flood risk level.

The percentiles of the ensemble flood hydrographs are computed to evaluate the flood risk level on the basis of the defined warning levels for the regarded gauging station using state discharge relationships (Figure 4).

4 SUMMARY

The results of the case study show a wide range of possible precipitation scenarios given by the radar nowcast ensemble members for this local rainfall event (5th of May, 2015). This results in a large uncertainty in the predicted discharge curves. Furthermore, the need for taking small scale precipitation features and the impact of variability and heterogeneity on the flood discharge curves in urban areas into account are highlighted.

In this paper, the first steps of the project StucK (2015 till 2018) in developing an optimized flood warning system for small urban catchments are presented: (1) developing a methodology to compute ensemble nowcasts of local heavy rainfall events, (2) integration of small scale radar rainfall nowcasts in a rainfall runoff model and (3) visualizing the results with percentiles to optimize the Flood Warning Service Hamburg. Within the project different statistical approaches will be analysed to improve the online forecast system. The results will be used to design an operative flood warning system for small scale urban catchments.

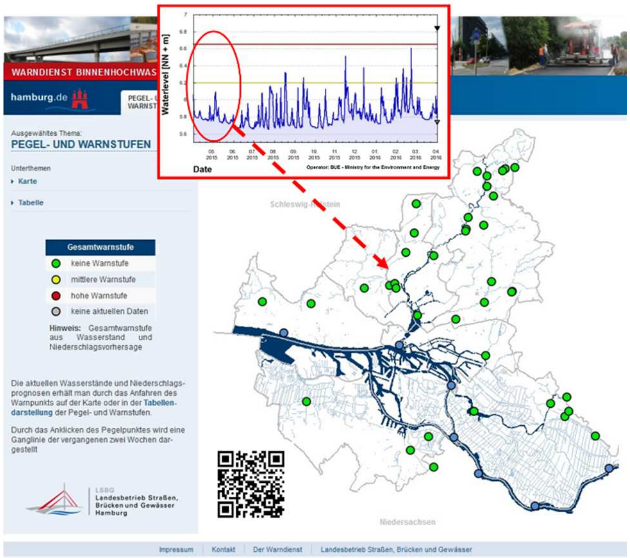

Figure 5: The results of the ensemble radar nowcasts (Figure 3) and the ensemble flood forecasts (Figure 4) are used to optimise the Flood Warning Service Hamburg (WaBiHa: http://www.wabiha.de)

5 ACKNOWLEDGEMENT

StucK is a joint project in the funding measure “Regional Water Resources Management for Sustainable Protection of Waters in Germany” (ReWaM) sponsored by the German Federal Ministry of Education and Research (BMBF). ReWaM is part of the BMBF funding priority “Sustainable Water Management” (NaWaM) within the framework programme “Research for Sustainable Development” (FONA3).The authors acknowledge gratefully this support.

LIST OF REFERENCES

Fedak, R. (1999). *Effect of Spatial Scale on Hydrologic Modeling in a Headwater Catchment*. Master’s thesis, Blacksburg.

Gentine, P., Troy, T. J., Lintner, B. R., and Findell, K. L. (2012). Scaling in surface hydrology: Progress and challenges. Journal of Contemporary Water Research & Education, 2012(147):28–40.

Hydro & Meteo (2009) The SCOUT Documentation, version 3.30. Lübeck, 69 pp.

Michelson, D., Einfalt, T., Holleman, I., Gjertsen, U., Friedrich, K., Haase, G., Lindskog, M. & Jurczyk A. (2005) Weather radar data quality in Europe – quality control and characterization. Review. COST Action 717, Working document, Luxembourg 2005.

TUHH (2013). Software-Entwicklung Niederschlag-Abfluss-Modell KalypsoNA. Homepage: http://www.tuhh.de/wb/forschung/software-entwicklung/kalypso/kalypso-na.html (actualised in 2013)

Woods, R. (2004). The impact of spatial scale on spatial variability in hydrologic response: experiments and ideas. In: Scales in Hydrology and Water Management/Echelles en hydrologie et gestion de l'eau (IAHS Publ. 287, 2004, 153 – 167.