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StucK: Improving the warning system for urban floods in Hamburg

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Abstract

The German research project StucK (Long term drainage management of tide-influenced coastal urban areas with consideration of climate change) investigates the increasingly challenging task of mitigating flood risk in coastal urban areas. Urban areas are often characterized by a growing degree of impervious surfaces causing fast run-off times. An additional challenge often met in coastal areas is that drainage can be restricted by tides. As part of its existing flood risk management strategy, the city of Hamburg operates a warning system (WaBiHa, www.wabiha.de). One of the main aspects of this project was to improve the warning system by providing more and better information. To evaluate the practical value of the new information an operational test warning system was implemented. This test warning system incorporates measured radar rainfall as well as a newly developed merged forecasts of radar nowcast ensembles and numerical weather prediction (NWP) ensembles into the warning scheme.

1. Introduction

StucK (2015-2019; www.stuck-hh.de) is a multi-discipline research project, which aims to find solutions to improve the flood prevention strategy of the city of Hamburg that are also applicable in other coastal urban areas. The project is part of 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). An emphasis of the project is on drainage in the case of short precipitation events with high intensities.

The fast run-off times often observed in urban areas result in flood waves with short rise times and short but high maxima. In the case of Hamburg many of the smaller waters drain into the river Elbe which is tide influenced and has a mean tidal hub of 3.68 m measured at the level St. Pauli (Hamburg Port Authority 2014). This means that under normal conditions many creeks can only drain during low tide. An increased flood risk results from storm events with unusually high water levels of the Elbe and coinciding heavy local rainfall, e.g. an event associated with the low pressure system “Xaver” in 2013 (Gönnert et al. 2014). Under climate change an increasing probability of these events is likely.

To communicate the current flood risk to the public and to flood risk managers the city of Hamburg operates a warning system. A major goal of StucK is to improve the operational warning system and to validate these improvements. Consequently, an operational test warning system was implemented and is running since the beginning of summer 2018.

2. Input Data

Rainfall data and water level data forms the basis of this warning system. Therefore, several datasets from the German weather service are acquired in near real time:

1. Rain gauge station data (hourly resolution for Northern Germany and one-minute resolution for two stations in Hamburg)

2. Radar data of four radars in Northern Germany (DX-product of radar Boostedt, Rostock, Hannover and Borkum; low level scan at 0.8° elevation with a spatial resolution of 1° x 1 km and time resolution of 5 minutes)
3. Numerical weather forecast data from COSMO-D2-EPS (Baldauf et al. 2018).

3. Processed Data

In a first step a radar composite has been constructed from the four radars. This requires correcting the radar data. Using the SCOUT software for analyzing and processing radar data, several quality control filters were applied. The impact of the corrections is illustrated on the example of data from Rostock radar. The data has three mayor shortcomings (Figure 1):
- a hotel close to the radar site is blocking part of the radar beam
- ships frequently cause radar echoes with varying positions but on fixed routes
- wind farms cause radar echoes in fixed locations.

To correct for these effects, 6 months of radar data was analysed. Based on the findings, the correction procedures were configured. Pixels associated with fixed echoes from wind farms are flagged and consequently deleted from all radar images. Other pixels which temporarily show artificial radar echoes, for example caused by ships are flagged differently. For these pixels, the corresponding filters will be applied more strictly. Subsequent filters, which are applied to the whole image include speckle filter and Gabella filter (Gabella and Notarpietro 2002). These filters remove unusually small and isolated echoes, respectively. Interpolating the radar images in the time domain converts the instantaneous reflectivity measured by a radar to a five-minute average intensity. The settings for the correction filters have been optimized for each of the four radars and are applied in an operational near real time system.

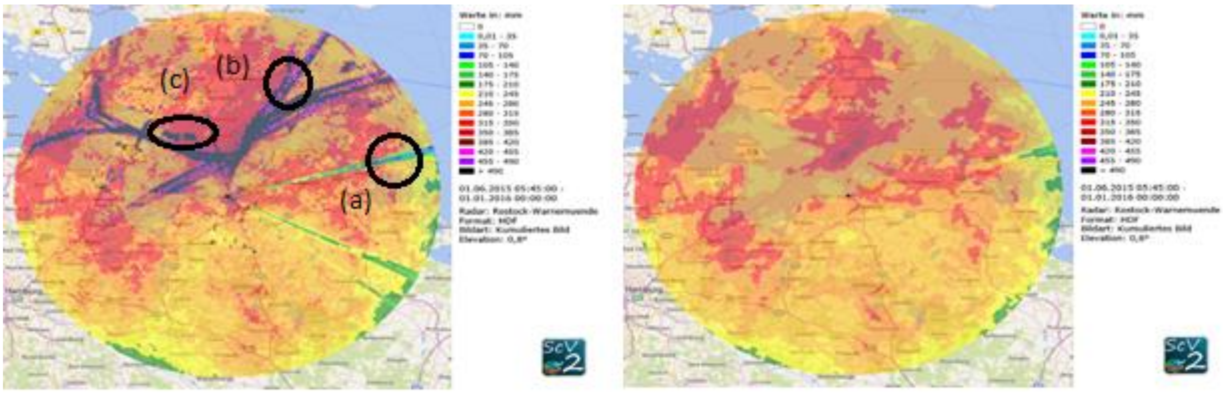

Figure 1: Radar data correction shown on the example of the Rostock/Warnemünde radar. The left panel shows the DX-product from the German weather service accumulated over 6 months before corrections. Three major problems can be observed: beam blockage (a), non-meteorological echoes along shipping routes (b) and non-meteorological echoes at fixed locations (c). The panel on the right shows the same data after correction.

The data thus prepared can be mapped on a 1 km by 1 km rectangular grid forming a radar composite. Next, the radar data is adjusted by 229 rain gauge stations distributed over the whole area covering the radar composite. This procedure is performed every 5 minutes.
The adjusted radar composite forms the basis for the derivation of radar nowcast ensembles. Within the StucK project, a method was developed for combining 10 nowcast ensembles with 20 ensembles of the numerical weather prediction COSMO-D2-EPS. The merged forecast consists of three parts:
1. First and second hour: only radar nowcast ensembles are used.
2. Hour three and hour four: A weighted average of radar nowcast ensemble and COSMO-D2-EPS is used.

3. Hour 5 to hour 20: Only COSMO-D2-EPS is used.

This results in 20 ensemble members with a lead time of 20 hours and a time resolution of 5 minutes in the first two hours and an hourly resolution afterwards (Jasper-Tönnies et al. 2017).

4. The Test Warning System

The newly available information has been combined into an operational test warning system. This system consists of two parts, backend and frontend. The backend is responsible for the automated data processing to generate the data described in section 3 and to automatically analyse this data in order to infer warning levels. The frontend is used to display the data, which is realised via a website. During the evaluation phase the whole website is password restricted. However, the idea is that certain information like the warning levels is available to the public, while other information can only be accessed by flood risk managers to support their decision-making.
For the frontend three separate warning levels are computed:

- a water level warning,
- a measured precipitation warning, and
- a forecasted precipitation warning.

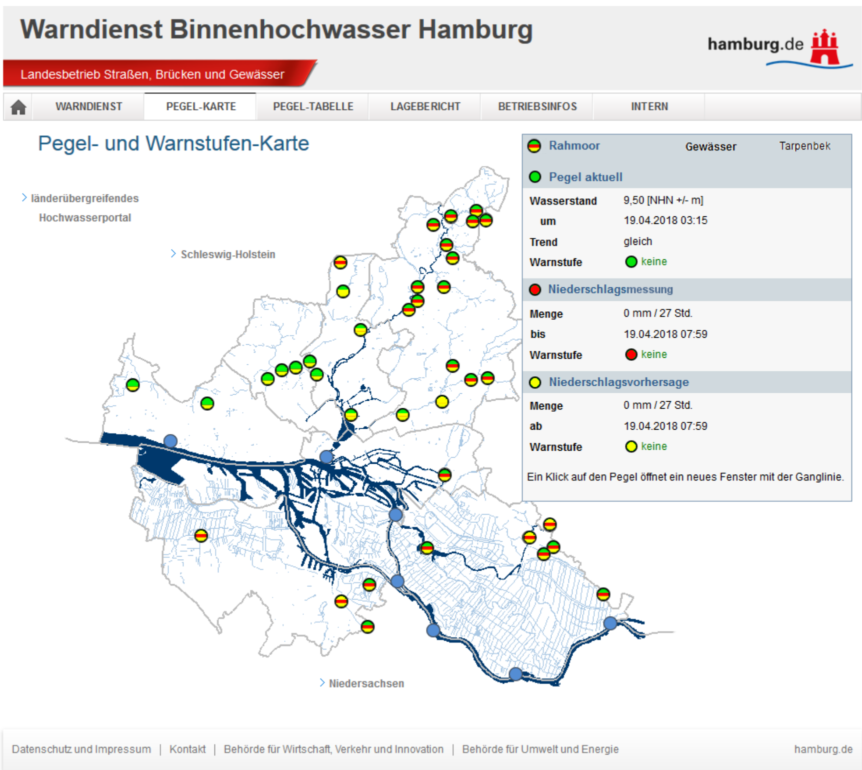

Figure 2: Map as part of the operational test platform for WaBiHa within StucK. Shown are the three-part warning symbols at each water level gauge location and an info box that provides more detailed information for one selected water level gauge location.

The computation of the water level warning is done individually for each level based on configured thresholds for a medium and a high warning level. The past rainfall inferred from the adjusted radar composite has high spatial accuracy. Therefore, an individual warning level for the measured precipitation is computed for each catchment. Each catchment time series is scanned for different time spans (1h and 6h) and the highest warning level is adopted for this catchment.

In the evaluation of the forecast information all grid points in the area of Hamburg of all ensemble members are analysed. The time series from all grid points are scanned for threshold exceedances for four different time spans (1h, 6h, 12h and 20h). Both radar nowcasts over 2 to 4 hours and numerical weather predictions exhibit spatial uncertainty. Therefore, the highest inferred warning level determines the warning level for the entire domain. For this probabilistic forecast different quantiles were investigated as warning criteria. However, issuing warnings based on the 5%-quantile offered the best results (Jasper-Tönnies et al. 2017).

While a combined warning level is computed in WaBiHa, for the test warning system it was decided to display all three warning levels in a three-part symbol on a map (see Figure 2). The three separate warning levels are displayed at each water level gauge location thus providing a good overview at one glance. Moving the mouse over the gauge of interest provides more detailed information in an info box such as the water level and its measurement time, the measured precipitation amount that is responsible for the warning along with the event duration and time and the forecasted precipitation amount that resulted in the corresponding warning level as well as the time for which the precipitation is forecasted. If no warning level for the measured precipitation is calculated the total precipitation in the past 24 hours is shown instead. The data availability in the corresponding time span is also given. For both the forecasted and the measured precipitation the general criteria of the German weather service are adopted (DWD, 2018).

While the above information is calculated and displayed automatically from the available data another substantial part of the warning platform is an assessment of the flood risk written by a flood risk manager. In this way the public is supported in interpreting the complex information that is provided.

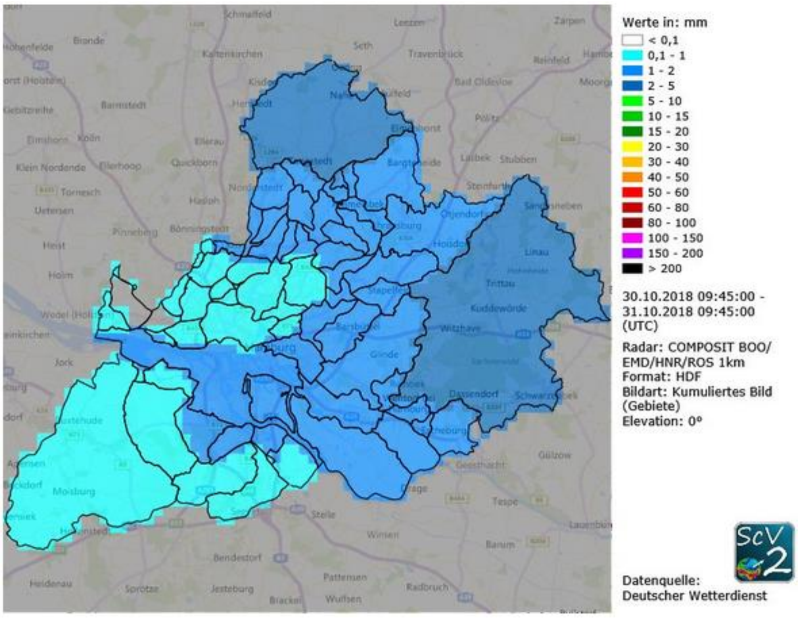

Figure 3: Map as part of the operational test platform for WaBiHa within StucK, showing the rainfall amount for the past 24 hours for each catchment.

Additional information is displayed for the flood risk manager on a password restricted part of the test warning system to facilitate his decision-making process. This information includes:

- an animation of the first ensemble member of the combined forecast
- an animation of the measured radar composite for the past hour for the entire composite and as a zoom on Hamburg,
- a map of the measured precipitation over the last hour (for the entire composite and for a zoom on Hamburg)
- a map of the measured precipitation over the last 24 hours (for the entire composite and for a zoom on Hamburg)

- a map of the measured precipitation of each catchment for the last 2, 6, 12 and 24 hours (Figure 3), and
- cumulated forecasts of all ensemble members for the coming 2, 6, 12 and 20 hours (Figure 4).

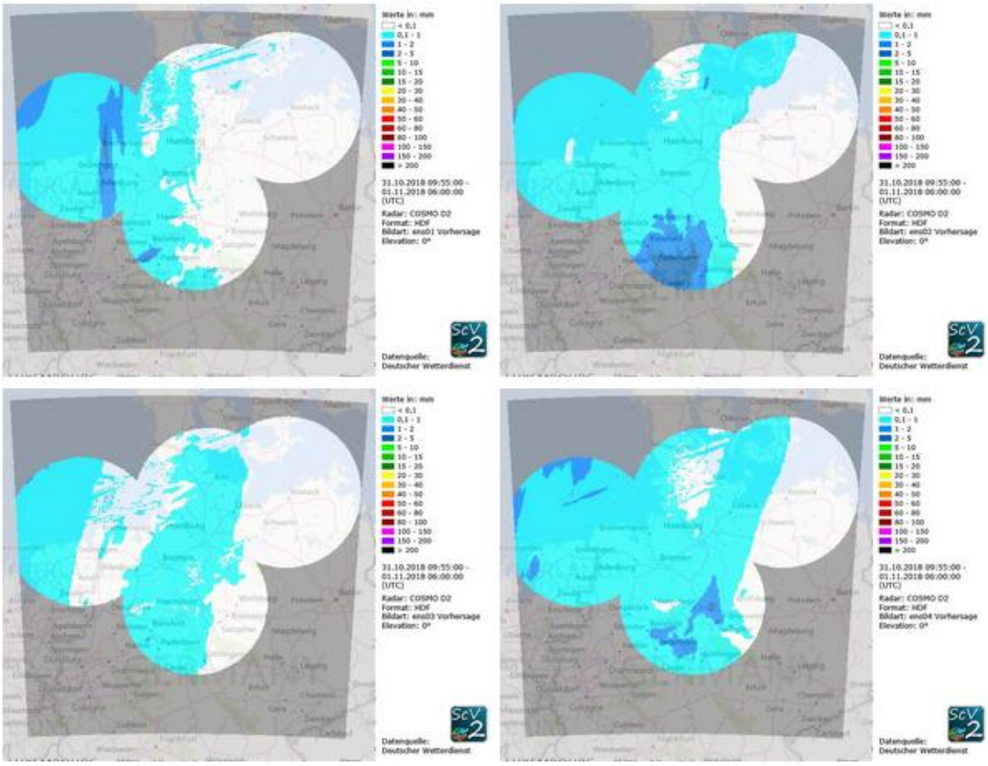

Figure 4: Maps showing four of the 20 ensemble members that are available to the flood risk managers via the website of the operational test warning system. Accumulated precipitation for the coming 20 hours is shown here.

5. Conclusions

Within StucK, an operational test warning system has been developed which provides detailed and high quality information to both the public and the flood risk manager. One key aspect is the newly developed merged precipitation forecast, which combines the advantages of radar nowcasts and numerical weather forecasts. Another important addition is the quantitative analysis of the past rainfall. The introduction of a three-part symbol which shows the warning levels for the water level gauge measurement, the measured precipitation and the forecasted precipitation is still under evaluation. However, a more sophisticated matrix would be needed to compute the overall warning level than the one that is currently used in WaBiHa.

Another point for possible future improvements is to derive individual thresholds for each catchment based on the measured precipitation and the predicted precipitation.

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