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a danisk case study

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RADAR BASED FLOW AND WATER LEVEL FORECASTING IN SEWER SYSTEMS – A DANISH CASE STUDY

by

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ABSTRACT

This paper describes the first radar based forecast of flow and/or water level in sewer systems in Denmark. The rainfall is successfully forecasted with a lead time of 1-2 hours, and flow/levels are forecasted an additional ½-1½ hours using models describing the behaviour of the sewer system. Both radar data and flow/water level model are continuously updated using online rain gauges and online in-sewer measurements, in order to make the best possible predictions. The project show very promising results, and show large potentials, exploiting the existing water infrastructure in future climate changes

Keywords: rain gauge, weather radar, forecast, runoff modelling, WaterAspects, CO-TREC,

1 INTRODUCTION

Climate changes and increased urbanization are causing increased pollution due to discharge of untreated storm and waste water during heavy rainfall. This environmental problem will most likely only increase in the future and can be solved in two ways, either by reconstruction of sewer systems, by expanding basin volumes, pipes dimensions, and treatment facilities or by optimizing the exploitation of the existing infrastructure. This paper presents an investigation of the latter by use of radar based precipitation forecasting and urban runoff simulations. By the use of weather radars, it is possible to measure and forecast the spatially distributed rainfall over an urban catchment. Applying the forecasted rain as input to a runoff model, it is possible to forecast flow at key points within the sewer system, thereby improve the real time operation of the sewer and wastewater treatment system, and thus reduce the discharged combined sewer overflow volumes. The system is evaluated on seven urban catchments located in an equivalent number of municipalities, and is the first online system in Denmark. As until now only the forecasting part of the project have been evaluated, and hence none of the involved municipalities have used the system in real time operation.

The project includes application of both X-band radars of the Local Areal Weather Radar (LAWR) type, developed by DHI (Jensen and Overgaard 2002) as well as meteorological C-band radars operated by the Danish Meteorological Institute (Gill et al., 2006)

Several authors has investigated the concept of flow, water level or flood forecasting, using rain gauge data as model input, e.g. Young (2002) and Campolo et al. (1999), and using radar data, e.g. Bedient et al. (2000), Mecklenburg et al. (2000), and Mimikou and Baltas (1996), but only on large rural catchment in which the transport time is very large compared to urban catchments. In these cases it is possible to use the transportation time as part of the potential forecast lead time. In urban catchments the transportation time is much smaller, and hence the potential lead time is equally smaller. By use of forecast on radar data, it is possible to increase this lead time, as suggested by e.g. Aspegren (2001), Einfalt et al. (2004), and Achleitner et al. (2009).

The concept described in this paper is somewhat similar to other approaches to forecast urban runoff using radar data, e.g. Achleitner et al. (2009), however this model setup differs as it includes a dynamical calibration of the radar against rain gauges in real time as well as a continuously adjustment and update of the runoff model according to online measurements in the sewer systems.

The paper presents a description of the applied radar calibration techniques and forecast model (2) which is based on the CO-TREC model (Li et al. 1995). Secondly, the applied runoff model is presented (3). This is based on the WaterAspects concept (Grum et al. 2004). A short description of the different cases the concept is tested on is described in (4) along with some result examples. A conclusion is presented in (5).

2 METHOD, RADAR DATA FORECAST

The radar data applied in this study originate from both X- and C-band radars as presented in the introduction. These radar types are quite different. The X-band radars has large attenuation, short range (60 km, and 20 km quantitative), and high spatial resolution (500 x 500 m), whereas the C-band radar has less attenuation, larger range (240 km, approx. 100 km quantitative), and a smaller spatial resolution (2000 x 2000 m). Moreover, the X-bands radars scans the atmosphere continuously in integrated time steps of 5 minutes where data is averaged, whereas the C-band radar scans the atmosphere in different elevations once every 10 minutes. The application of X-band radar data requires a thorough calibration of each radar against historical rainfall data from a number of rain gauges. This static calibration approach is described in detail in Thorndahl and Rasmussen (2009a) and Thorndahl and Rasmussen (2009b). The C-band radar data is calibrated using a standard calibration based on Vejen and Steffensen (2005).

During the initial evaluation of the radar performance it was observed that both X- and C-band radars performed quite good with regards to rain volumes compared to rain gauges. However, some difference in intensity levels was observed, especially did the radar underestimate the very high rain intensities. As these peak intensities are important with regards to urban runoff, it was decided to implement a dynamical calibration procedure, adjusting the radar intensity level continuously against a number (3-7) of rain gauges in real time. Practically, the dynamical calibration is performed by averaging the ratios between rain intensity observed in the gauges and the intensity measured in the same points by the radar. The radar intensity level is then adjusted by this average ratio. Furthermore, a number of constraints is defined in order control the initialization of the dynamical calibration procedure, e.g. that at least 1 mm of rain must be recorded before the procedure is initialized in order to avoid adjustment on an uncertain basis.

It is of cause questionable, if it is realistic to adjust the whole spatial extent of the radar range using a few point measurements, but as the applied rain gauges are centred around the simulated urban catchment, and the data only is used in this area, it is considered a valid method. The method should be considered a type of data fusion rather than a calibration of the whole radar range.

2.1 Forecast model

The simplest forecast model and the one applied in the initial phase of this project, model is a so-called global vector model. Here there correlation between two radar images are calculated by which a global speed and direction can be obtained. The latest radar image is then prognosed a number of time steps using this speed and direction. The second generation forecast is also based on correlation between images. The TREC-algorithm (TRacking of Echoes with Correlation, Rinehart and Garvey 1978) and the CO-TREC (Continuous-TREC, Mechlenburg 2000; Li et al. 1995) are applied. The TREC-model divides the radar image into subsets and the correlation is calculated for every subset. Hereby, a vector field of the movement of the rain is obtained. In order to avoid unrealistic movement of the radar image the CO-TREC-model is used to smooth the vector field. This is done by implementing a moving average between the radar images over time and defining some constraints on the variations of speeds and directions. The concept of the forecast model is illustrated in figure 1.

The forecast is compared to real time data in order to evaluate the forecast continuously. The correlation coefficient (R^2) for the whole radar image is calculated, as well as the maximum correlation coefficient, and the critical success index (CSI, Li et al. 1995). These correlation measures are used to estimate the maximum effective lead time, which obviously depends on the range of the radar. The maximum effective lead time of the X- and C-band radars is determined to 1 hour and 2 hours, respectively.

Currently, the development of the third generation forecast model is in progress. This includes, besides the tracking of the rain field movement, also tracking of changes in rain intensity levels, and therefore also prognosis of the varying rain intensities. This will almost certainly lead to better forecasting of especially convective raincells.

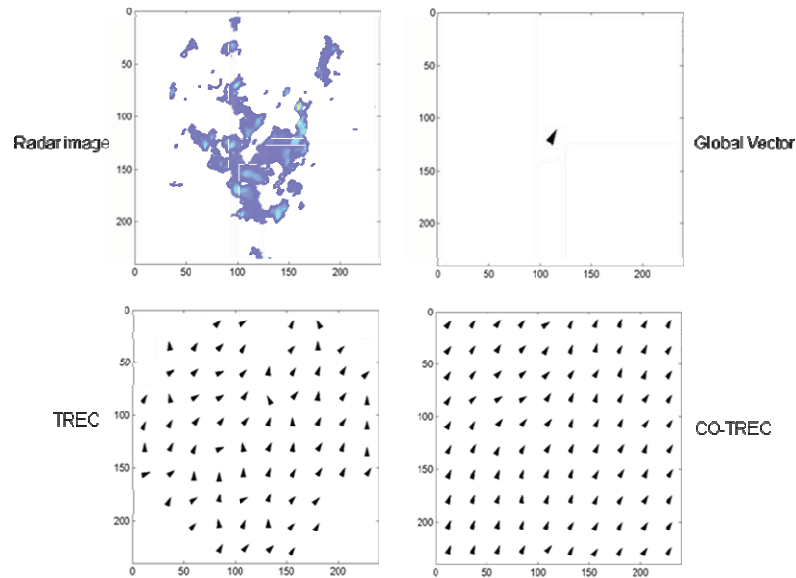
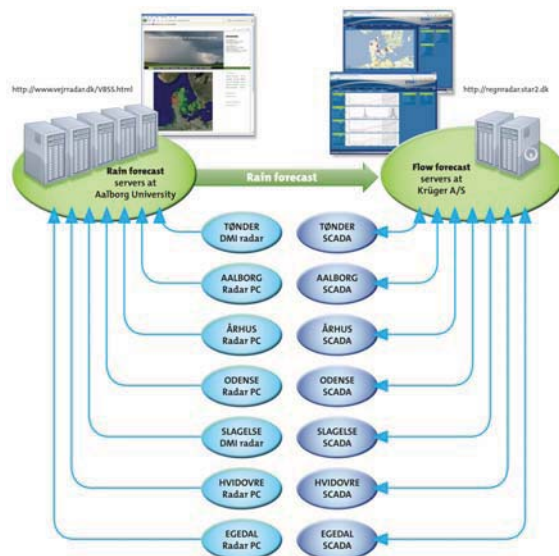


Figure 1 – Principles of the forecast model.

3 METHOD, FLOW/WATER LEVEL FORECAST

The runoff model applied in the study is the simple and non physically based flow routing model, WaterAspects (Grum et al. 2004; Grum et al. 2005). Using the overall structure of the sewer system, a simple model is set up and interrelated timeseries of rain and observations in the drainage system is then used to calibrate the model. It is then evaluated if the model describes the observations satisfactory – if not more processes or structures are included in the model. The purpose of the iteration approach is to obtain a model setup that fits the observation in a certain point of the drainage system and therefore provides the best possible description of the relationship between rain and runoff. This initial evaluation and calibration of the model is performed manually using historical data.

Using the forecasted radar data the model is set up to run in real time, such that either flow or water level in the calibration points is forecasted. In order to make the most reliable forecast the model is continuously adjusted against real time measurements in the drainage system using a Bayesian update algorithm.



On-line applications:

Radar data and rain forecast:
<http://www.vejrradar.dk/VBSS.html>

Flow and water level data and forecast:
<http://www.regnradar.star2.dk>

Figure 2 – Data flow in the forecast model.

4 CASES

In total seven municipalities are involved in this project. Some possess their own X-band radar and some use online C-band data from the Danish Meteorological Institute. Each municipality has chosen an urban catchment in which different types of observations are recorded and transmitted online to a server, be it either, flow, water level, pump discharge, overflow registration, etc. Some of the municipalities have several observation points, whereas other only have one, and some apply a catchment covering a whole city (and thus the inflow to the waste water treatment plant) and some apply small catchments covering only small parts of a town. On this basis it is possible to test the forecast system on very diverse and different size systems. The data infrastructure is shown in figure 2, and the online applications system can be found on the webpages shown in the right part of figure 2.

Examples of forecasted and measured rain is shown in figure 3 using the city of Aalborg as case. Figure 4 presents the modelled flow at the inlet to Aalborg West Wastewater treatment plant in the same period of time.



Figure 3 – Example of real time and forecasted data.

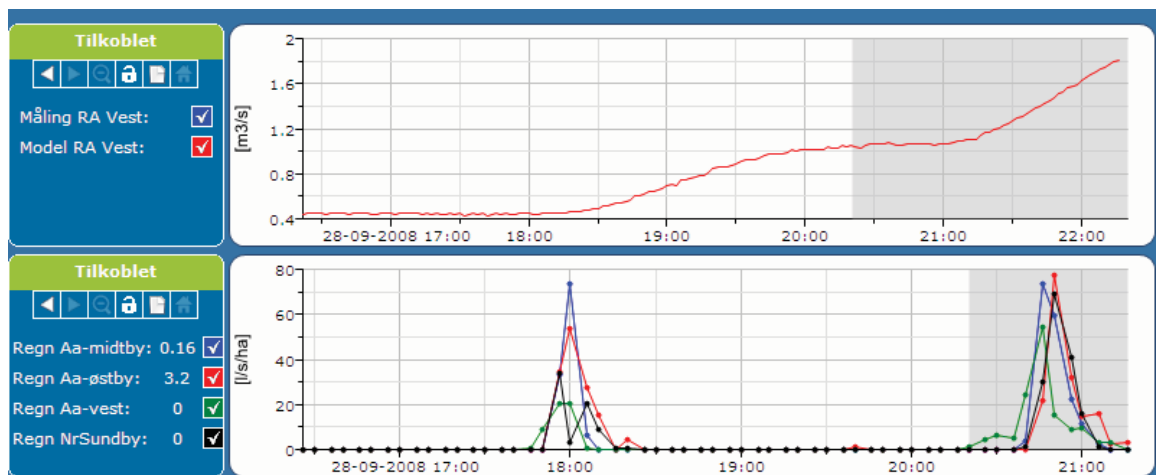


Figure 4– Top: Modelled inlet flow to Aalborg West WWTP, and bottom: measured and modeled rain on different parts of the catchment. Grey areas are the forecast.

5 CONCLUSION

A radar based forecast of flow and/or water level is implemented on seven urban catchments in Denmark. It is shown possible to forecast rain with a lead time of 1-2 hours depending on the type of radar, and furthermore the total lead time is extended to 1.5-3.5 hours due to the transportation time in the drainage system. Radar data is calibrated statically using historical data dynamically applying on-line rain gauges in real time.

The simple flow routing model, WaterAspects, is calibrated against historical data, and continuously updated using online in-sewer measurements.

Hereby, it is shown possible to forecast flow and water levels in specific points of the drainage system, e.g. inlets to large detention basins or inlets to wastewater treatment plants. The system is ready, but not yet tested in real time operation. But there is a large potential using the forecast, e.g. to retain water in detention basins in order to minimize combined sewer overflow and loads on wastewater treatment plants, to switch between dry and wet weather operation in wastewater treatment plants, economical operation of pumps, etc. The system is currently running online and is tested for a year, until spring 2010.

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