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Pedersen, Jonas Wied; Pedersen, Jonas Wied; Vezzaro, Luca; Madsen, H.; Mikkelsen, Peter Steen

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Ensemble forecasts of urban runoff from a deterministic Numerical Weather Prediction model by use of spatial neighborhood sampling

J.W. Pedersen*[1], L. Vezzaro[1,2], H. Madsen[3], P.S. Mikkelsen[1]

1 DTU Environment, Technical University of Denmark, Kgs. Lyngby, Denmark
2 Krüger A/S – Veolia Water Technologies, Gladsaxe, Denmark
3 DTU Compute, Technical University of Denmark, Kgs. Lyngby, Denmark

*Corresponding author: jowi@env.dtu.dk

Abstract

Many problems related to integrated management of urban drainage systems and wastewater treatment plants require forecasts at time horizons longer than the 2-3 hours that radar rainfall extrapolation forecast at most can provide. Numerical Weather Predictions (NWP) provide longer horizons but with worse spatio-temporal resolution, which is critical for urban runoff predictions.

NWP models contain large uncertainties regarding the amount, location and timing of rainfall. They furthermore require large computational efforts, especially when run in high enough resolution for urban drainage purposes and are therefore only able to provide a single deterministic forecast or a small ensemble of scenarios at every forecast cycle. A single deterministic forecast cannot reflect the uncertainty in a given situation. Ben Bouallègue et al. (2013) showed how a post-processing method based on spatial neighborhoods improved the skill of an NWP ensemble. Courdent et al. (2018) used this method for urban runoff predictions, with low temporal resolution but on long horizons up to two days ahead. In this work, we use the neighborhood method to generate an ensemble from a single, higher resolution deterministic NWP and use this to predict flow exceedance at the outlet of an urban sewer catchment.

The case study is the Dæmningen sewer catchment in Copenhagen, Denmark, which has an area of 30 km^2 and is a combined sewer system (see Fig 1). Forecasts are evaluated against flow data from a gauge at the catchment outlet during the period of May-July and October-December, 2017. A lumped conceptual model based on three linear reservoirs in series is used to simulate the runoff at the catchment outlet. This model is calibrated with rainfall observations from seven rain gauges.

The NWP product is developed by the Danish Meteorological Institute and is based on the HIRLAM NWP model. The resolution of the NWP grid is 0.03°, which corresponds to around 3.3 km over the case area, while the temporal resolution is 10 minutes. The forecast horizon is 10 hours and a new forecast is made once an hour. This product has a special feature in that it assimilates radar observations into the NWP model in the two hours leading up to the time of forecasts. This is done to improve forecast accuracy on short lead times. Korsholm et al. (2015) details the operational NWP setup.

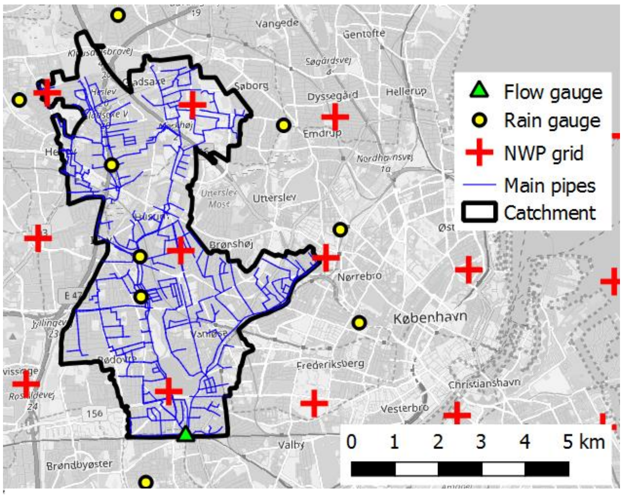

Fig 1: Dæmningen case area.

The neighborhood post-processing method works by viewing rainfall that is predicted to fall in the vicinity of the catchment as a potential scenario for what might occur directly above it. This can be understood as sampling the location of the catchment within different parts of the surrounding area. The spatial uncertainty in NWP models can be substantial and we thus consider a neighborhood of up to 109x109 km around the catchment, resulting in an ensemble with roughly 1,000 members if the full neighborhood is used.

Flow forecast performance is evaluated with Precision-Recall (PR) curves, which can be used to evaluate threshold exceedance problems, such as sewer overflow and switching between dry and wet weather operations at a treatment plant. A PR diagram plots the True Positives Rate (TPR) against the Positive Predictive Value (PPV). TPR is the number of correctly predicted values above a threshold divided by the total number of observations above the threshold, and describes how many of the actual events that were correctly predicted. PPV is the number of correctly predicted flow values above a threshold divided by the total number of predicted values above the threshold, and describes how trustworthy a prediction of threshold exceedance is. Both scores range from 0 (worst) to 1 (perfect). A good forecast is in upper right corner of a PR diagram. We use a flow threshold of 4,000 m^3/hr, which signifies the difference between dry and wet weather situations.

Fig 2 shows PR curves for different sizes of the spatial neighborhood at different forecast horizons. Each of the points in the figure shows the performance of an operational system that needs “x” number of ensemble members to predict exceedance of the threshold before an action is taken. The use of ensembles based on spatial neighborhoods allows operation at many different points rather than at the single point from the deterministic forecast. The choice of operational point for a specific purpose then depends on how risk tolerant a given decision maker is. The fact that the curves move towards the lower left corner as we go from small (a) to larger (c) forecast horizons in Fig 2, shows the degree to which forecast performance decreases with longer forecast horizons.

The ensembles from spatial neighborhoods cannot be interpreted as actual probabilities of event occurrence. Future work will therefore look into how this type of ensemble information can be used to estimate actual probabilities through statistical post-processing, or how it can be used to scale the diffusion term in runoff models based on stochastic differential equations.

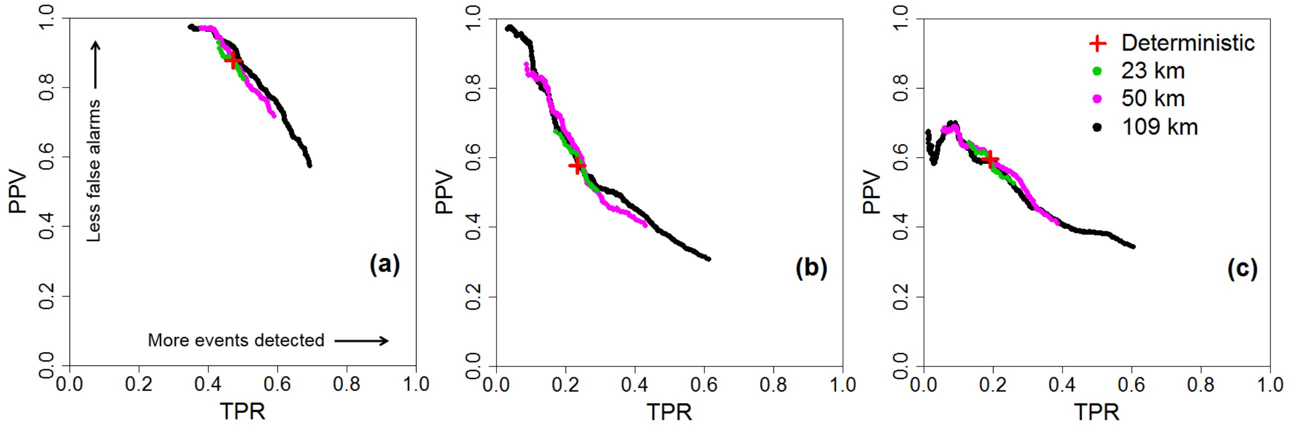

Fig 2: PR curves for different neighborhood sizes at horizons of (a) 0-3 hr, (b) 3-6 hr, (c) 6-10 hr.

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