# Advanced real-time precipitation components for urban hydrological applications as part of a digital twin for the city of Hanover

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## Composantes avancées de la précipitation en temps réel pour des applications hydrologiques urbaines dans un jumeau digital pour la ville de Hanovre

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## RÉSUMÉ

Dans le cadre du projet collaboratif « ZwillE », financé par le ministère fédéral allemand de l'éducation et de la recherche (BMBF), un jumeau numérique de la ville de Hanovre est en cours de développement, avec le but de créer une image virtuelle du réseau d'assainissement et de la station d'épuration et, sur cette base, de fournir des mesures et des recommandations d'action en cas d'événements pluvieux extrêmes. Nous présentons les travaux et les premiers résultats dans le domaine de la mesure et de la prévision des précipitations. Nous décrivons et évaluons les progrès réalisés dans la préparation en temps réel des estimations de précipitations basées sur le radar et dans les prévisions en court terme basées sur les données radar et pluviométriques fournies par le service météorologique allemand. Ceux-ci comprennent une augmentation de la résolution spatiale des scans radar polaires, de 1 km x 1° à 250 m x 1° actuellement. Une nouvelle routine flexible d'ajustement des données radar aux pluviomètres a été développée, optimisée pour une application dans des systèmes en temps réel. En outre, il y a un contrôle automatique des données pluviométriques basé à la fois sur les données des pluviomètres et des radars et la production de prévisions à court terme avec une résolution accrue. En plus de la génération de "nowcasts" d'ensemble et d'une combination avec les prévisions numériques, les nouvelles procédures seront utilisées pour fournir des données pour les applications hydrologiques en temps réel, telles que la simulation et le contrôle des réseaux d'assainissement. D'autres travaux de recherche porteront sur le développement d'une prévision des inondations à court terme.

## ABSTRACT

In the joint project « ZwillE », funded by the German Federal Ministry of Education and Research (BMBF), a digital twin for the city of Hanover is being developed, with the aim of creating a virtual image of the drainage system, and, based on this, providing measures and recommendations for action in the case of extreme rain events.
We present the work and first results in the project topic "precipitation measurement and forecasting". We describe and evaluate advances regarding the real-time preparation of radar-based precipitation estimates and nowcasts based on radar and rain gauge data provided by the German Weather Service. These include an increased spatial resolution of the polar radar scans from 1 km x 1 ° to currently 250 m x 1°. A new, flexible radar-rain gauge adjustment routine has been developed, optimized for the application in real-time systems. Further developments are an automatic rain gauge check based on both rain gauge and radar data and the production of nowcasts at an increased spatial resolution. Together with the generation of ensemble nowcasts and a blending procedure to combine nowcasts and the ensemble numerical weather forecasts ICON-D2-EPS, the new procedures will be used to provide input for real-time hydrological applications such as the simulation and control of sewer systems. Further research work will address the development of a short-term flooding forecast.

## KEYWORDS

Digital twin, precipitation extremes, radar- rain gauge adjustment, radar nowcasts, inundation forecasts

# 1 INTRODUCTION

Extreme rainfall in urban areas is an ongoing challenge for water authorities and decision makers as well as for researchers (e.g. Thorndal et al., 2017). Flood warning systems and adjustments of infrastructure are important measures to reduce damages especially at vulnerable locations. However, current solutions are often not satisfying. An integrated view of water extreme events and their effect on the urban drainage infrastructure may help to deal with current and future challenges.

The joint research project ZwillE aims to support the management of water extreme events building up a digital twin of the drainage infrastructure for the city of Hanover in Germany. It is supposed to give an integrated view of the current state of the infrastructure with sewer system and sewage treatment plants under the respective current hydrological and meteorological conditions and under future extreme scenarios. The aim is to better anticipate impacts of extreme rain events in order to improve the management of such events and to support planning decisions for an increased resilience. An AI- based assistant is being developed using the information of the digital twin together with formalized experiential knowledge to derive comprehensible recommendations for actions. The target users are employees of the municipal wastewater company of Hanover (« Stadtentwässerung Hannover SEH »).

This paper focuses on precipitation measurements and predictions in the real-time system. As precipitation is the most important driving factor for urban drainage models, improvements will have a direct impact on the quality of the results.

# 2 PRECIPITATION REAL-TIME COMPONENTS

Radar data in many places provide the best data source for current precipitation estimates. Particularly in real-time systems, compromises in data quality often have to be accepted, since rapid data availability is more important than the best possible preparation. In Germany, there are single site radar data with a resolution of 250m x 1° from the German Weather Service DWD, which are available via DWD Open Data and provide a good data basis for real-time systems. With the help of correction procedures prepared and adjusted using past data, a good correction of errors such as clutter and beam blockage can be achieved in real time (Michelson et al., 2004). The (quasi-)adjustment with rain gauge data is problematic, since these can be supplied only for a past period, and many station measurements are not available in time, so that it is necessary to work with a smaller number of stations compared to a subsequent processing. Thus, the German Weather Service produces the « quasi-adjusted » radar product RADOLAN YW (Winterrath et al., 2018) on a Germany-wide 1 km x 1 km grid with a time delay of 25 min, thus not sufficient for real-time applications in the sewer network for example.

In the following, we outline which components of the precipitation QPE (Quantitative Precipitation Estimation) and QPF (Quantitative Precipitation Forecast) are newly developed or improved and evaluated, to provide the data basis for subsequent hydrological applications in the ZwillE project.

## 2.1 QPE

### *2.1.1 Improved rain sums*

Deriving rain sums from radar measurements is one step to locally approach rain gauge measurements. The rain sums are used as a basis for radar-rain gauge adjustment procedures and are also useful for further calculations and visualisation. In order to achieve improved radar rain sums, we

- use the high-resolution original data on the 250m x 1° grid instead of a coarser composite grid
- conduct an advection correction on the fine polar grid

as is described by Jasper-Tönnies et al. (2014). The effects of the increased resolution (250 m x 1° versus 1 km x 1 km) in combination with the advection correction are evaluated.

### *2.1.2 Automatic rain gauge check*

An automatic check of the incoming rain gauge data is implemented (Fennig et al., 2022) to account for measurement errors. In addition to fixed thresholds and a comparison with data from neighboured stations to find inconsistent and unplausible data, a comparison between radar and rain gauge data is conducted. Unplausible measurements are excluded from the radar-rain gauge adjustment. The impact of the rain gauge check in the real-time environment is investigated.

#### *2.1.3 Radar-rain gauge adjustment optimised for real-time applications*

A « quasi-adjustment » is performed in real-time with the software SCOUT, enabling adjustment procedures with factor and difference fields (Strehz et al., 2021). Both, factors and differences to correct for differences between radar and rain gauge measurements are determined spatially, resolved for each point on the radar grid. Several innovations have been implemented:

- A flexible adapting algorithm in dependence on the number of modelling stations with valid precipitation information and their distance to the considered grid point
- An underlying error model : For radar and rain gauge measurements, assumptions over the measurement inaccuracy are considered, in dependence on the measured precipitation intensity. A linear regression function is computed to map radar precipitation sums to the precipitation measured by the rain gauges.
- Advection correction of the adjustment parameters : Since rain gauge measurements are only available for a past period, a past period (we use up to 3 hours) is considered where overlapping radar and rain gauge data are available. The resulting adjustment fields are valid for this past period. In order to achieve the best possible correction for the current radar measurement, an advection of the adjustment fields is calculated to take into account the spatio-temporal movement of the precipitation field. The methods of cell detection and advection from nowcasting are used for this procedure. The advection of the calibration field on the grid is calculated using the Semi-Lagrange method.

### 2.2 QPF

Radar nowcasts and nowcast ensembles are calculated with the software SCOUT (hydro & meteo 2009, Jasper-Tönnies et al., 2018). The nowcast method is based on a cell-tracking algorithm, finding displacement vectors for cells which are tracked based on their position and size. These vectors are plausibility-checked and spatially interpolated into a 2D advection field. A Semi-Lagrange scheme is used to forecast the advection of the rainfall field.

Special and new features are :

- The consideration and advection of adjustment parameters, deriving « quasi-adjusted » nowcasts.
- Ensemble-Nowcasts allowing for the quantification of uncertainties which can also be transferred to impact models. They are generated by varying initial forecast conditions and by an estimation of the uncertainty as function of the variance of the observed variables during the past 30 min.
- The lead time of the nowcasts is extended by a blending procedure (Jasper-Tönnies et al., 2018) blending ensemble nowcasts with the ensemble numerical weather forecasts ICON-D2-EPS of the DWD
- A fast calculation of nowcast ensembles and blended ensembles in less than 5 min.
- Calculation of nowcasts with an increased spatial resolution related to the increased resolution of the radar scans.

## 3 EVALUATION

An evaluation of the precipitation components is conducted using a real-time simulator simulating the process chain and the actual data availability in the corresponding real-time environment. Precipitation input from radar and rain gauge measurements is used in a test period over several months. Independent rain gauge stations are used for verification. The described improvements comprise QPE, QPF and derived products. The results are assessed in terms of their benefit for urban hydrological applications.

## 4 OUTLOOK

The precipitation measurements and predictions will be used for setting up a digital twin of the city's wastewater system, incorporating modeling of the sewer networks and the wastewater treatment plants with the software SIMBA# (ifak, 2021; Schütze et al., submitted). The simulation of a sewer network control system is planned to follow. Another application area is flooding prediction and warning. For this, further research work is planned in the ZwillE project.

## 5 ACKNOWLEDGMENTS

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## LIST OF REFERENCES

Fennig, C., Einfalt, T., Jessen, M. (2022). *Improvement of automatic rain gauge checks relevant to radar data adjustment.* ERAD 2022–The 11$^{th}$ European Conference on Radar in Meteorology and Hydrology, 29$^{th}$ Aug- 2$^{nd}$ Sep 2022, Locarno

hydro & meteo 2009 *The SCOUT Documentation*, version 3.30. Lübeck, 69 pp.

ifak (2021): Simba# water, Version 5. Manual, Institut für Automation und Kommunikation e. V. (ifak), Magdeburg

Jasper-Tönnies, A., and Jessen, M. (2014*). Improved radar QPE with temporal interpolation using an advection scheme.* In Proceedings of ERAD 2014–The 8$^{th}$ European Conference on Radar in Meteorology and Hydrology, 1-5.

Jasper-Tönnies, A., Hellmers, S., Einfalt, T., Strehz, A., & Fröhle, P. (2018). *Ensembles of radar nowcasts and COSMO-DE-EPS for urban flood management.* Water Science and Technology, 2017(1), 27-35.

Michelson, D., T. Einfalt, I. Holleman, U. Gjertsen, K. Friedrich, G. Haase, M. Lindskog, A. Jurczyk (2004) *Weather Radar Data Quality in Europe: Quality Control and Characterization*, Report of COST 717, EU, 91 pages.

Schütze, M., Förster, L., Hübner, C., Alex, J. (submitted): A Digital Twin platform for purpose-driven modelling; submitted to: 11th Novatech 2023; Lyon, 03. – 07.07.2023

Strehz, A., Behnken, U., Einfalt, T. (2021) *Analyse der Datenqualität angeeichter Radardaten*. Poster at Tag der Hydrologie, Potsdam. 1.9.2021.

Thorndahl, S., Einfalt, T., Willems, P., Nielsen, J. E., ten Veldhuis, M. C., Arnbjerg-Nielsen, K., Rasmussen, M., Molnar, P. (2017). *Weather radar rainfall data in urban hydrology*. Hydrology and Earth System Sciences, 21(3), 1359-1380.

Winterrath, T., Brendel, C., Hafer, M., Junghänel, T., Klameth, A., Lengfeld, K, Walawender, E., Weigl, E., Becker, A. (2018): RADKLIM Version 2017.002: *Reprozessierte, mit Stationsdaten angeeichte Radarmessungen (RADOLAN), 5-Minuten-Niederschlagsraten (YW)* DOI: 10.5676/DWD/RADKLIM_YW_V2017.002