Opportunistic sensing for urban rainfall monitoring: what spatial and temporal resolutions can be resolved by personal weather stations and commercial microwave links?

Author(s):
de Vos, Lotte W.; Leijnse, H.; Overeem, A.; Uijlenhoet, R.; Raupach, T.H.; Berne, A.

Publication date:
2019

Permanent link:
https://doi.org/10.3929/ethz-b-000347530

Opportunistic sensing for urban rainfall monitoring: what spatial and temporal resolutions can be resolved by personal weather stations and commercial microwave links?

L.W. de Vos*[1,2], H. Leijnse[1], A. Overeem[1,2], R. Uijlenhoet[2], T.H. Raupach[3], A. Berne[3]

1 Royal Netherlands Meteorological Institute, de Bilt, the Netherlands
2 Wageningen University, Wageningen, the Netherlands
3 École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland

*Corresponding author: lotte.devos@wur.nl

Abstract

Urban areas typically have a large fraction of impervious surfaces, resulting in runoff dynamics characterized by fast response times. Extreme rainfall events over cities can result in urban flooding, impacting a large number of people and leading to considerable economical damage. As these extreme rainfall events are expected to occur more often in the future (Madsen et al., 2014), cities need to be designed in a way to reduce the occurrence and/or impact of resulting water damage.

High-resolution urban flood models, incorporating the heterogeneity of urban areas, cannot yield meaningful hydrological predictions unless they are driven by equally high-resolution rainfall data (Cristiano & van de Giesen, 2017). Traditional measurement techniques like weather radar generate rainfall fields with good spatial coverage at high spatial and temporal resolution. Nevertheless, radar rainfall estimates are suggested to improve significantly with the inclusion of ground measurements, as the rainfall estimates are based on indirect measurements of atmospheric volumes aloft. A limiting factor with these ground measurements is their low spatial density, especially for real-time rainfall data.

Opportunistic sensing techniques provide in-situ rainfall observations that may bridge the gap towards the required high-resolution rainfall data for urban applications. Privately owned personal weather stations, sharing rainfall measurements in real-time on online platforms, form a dense rain gauge network of on average 1 gauge per ~4.3 km^2 in the Amsterdam metropolitan area (93 stations over a 400-km^2 area), measuring at approximately 5 min temporal resolution. Additionally, commercial microwave links, installed and maintained by telecom providers for the purpose of telecommunication, can be used for rainfall monitoring. Attenuation over link paths between transmitting and receiving antennas, logged instantaneously every 15 minutes, is increased by hydrometeors. From this rainfall attenuation, path-averaged rainfall intensity can be calculated.

The ability of these two opportunistic sensing techniques to estimate the space-time dynamics of rainfall are examined in two parts; Firstly the error caused by the sampling strategy and spatial lay-out of the networks is identified. Secondly, their capacity to accurately detect small-scale rainfall is determined when typical measurement errors are taken into account.

In a simulation study two rainfall events described in terms of drop size distributions at 100 m * 100 m resolution and 30 s time steps are used. Rainfall measurements from commercial microwave links and personal weather stations are derived based on the locations of the sensors in the 20 km * 20 km study area in Amsterdam, the Netherlands, and validated with the ground-truth rainfall intensities calculated directly from the simulated drop size distributions. The first part of the study addresses the errors due to network lay-out and sampling only, by assuming perfect measurement accuracy.

The second part consists of a similar simulation study where in addition typical measurement errors are included. These have been identified by validation studies on datasets of rainfall observations by actual personal weather stations and commercial microwave links, using a gauge-adjusted radar product as ground-truth. De Vos et al. (2017) did a first analysis on rainfall measurements from crowdsourced personal weather stations, with suggestions for improvement. These are taken into account in a new validation study spanning more personal weather stations and a longer period.

The measurement errors are quantified and added to the rainfall observations that were derived from the rainfall simulation, before validating the results in the same way as for the first part of the study. For both cases (i.e. perfect measurement accuracy vs realistic measurement performance), the spatial and temporal scales of rainfall patterns that can be resolved by both techniques is established. For the first case, both opportunistic sensing techniques are most limited by their temporal sampling strategies. Strong reductions in small-scale rainfall observation accuracy only occur when the networks would be reduced by more than half the respective number of sensors.

References

Cristiano, E., and van de Giesen, N. (2017). Spatial and temporal variability of rainfall and their effects on hydrological response in urban areas–a review. Hyd. and Earth Sys. Sci., 21(7), 3859-3878.

Madsen, H., Lawrence, D., Lang, M., Martinkova, M., and Kjeldsen, T. (2014), Review of trend analysis and climate change projections of extreme precipitation and floods in Europe*.* J. Hydrol*.,* 519 (D), 3634-3650.

De Vos, L. W., Leijnse, H., Overeem, A., and Uijlenhoet, R. (2017). The potential of urban rainfall monitoring with crowdsourced automatic weather stations in Amsterdam. Hyd. and Earth Sys. Sci., 21(2), 765-777.