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Applicability of open rainfall data to event-scale urban rainfall-runoff modelling

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ABSTRACT

Rainfall-runoff simulations in urban environments require meteorological input data with high temporal and spatial resolutions. The availability of precipitation data is constantly increasing due to the shift towards more open data sharing. However, the applicability of such data for urban runoff assessments is often unknown. Here, the feasibility of Finnish Meteorological Institute's open rain gauge and open weather radar data as input sources was studied by conducting Storm Water Management Model simulations at a very small (33.5 ha) urban catchment in Helsinki, Finland. In addition to the open data sources, data were also available from two research gauges, one of them located on-site, and from a research radar. The results confirmed the importance of local precipitation measurements for urban rainfall-runoff simulations, implying the suitability of open gauge data to be largely dictated by the gauge's distance from the catchment. Performance of open radar data with 5 min and 1 km^2 resolution was acceptable in terms of runoff reproduction, albeit peak flows were constantly and flow volumes often underestimated. Gauge adjustment and advection interpolation were found to improve the quality of the radar data, and at least gauge adjustment should be performed when open radar data are used. Finally, utilizing dual-polarization capabilities of radars has a potential to improve rainfall estimates for high intensity storms although more research is still needed.

1. Introduction

Urban catchments are characterized by a complex mosaic of constructed surfaces, fast surface runoff generation, and a rapid storm flow response to rainfall events (Shuster et al., 2005; Sillanpää and Koivusalo, 2015). An adequate replication of catchment runoff in urban hydrological simulations therefore requires rainfall information at fine spatial and temporal resolutions (Bruni et al., 2015; Müller and Haberlandt, 2016; Schilling, 1991). The requirements become progressively more stringent with decreasing catchment area (Berne et al., 2004; Ochoa-Rodriguez et al., 2015; Segond et al., 2007).

The traditional rainfall measurement device, rain gauge, is still a frequently used data source in urban rainfall-runoff studies (e.g. Krebs et al., 2014; Notaro et al., 2013; Sun et al., 2014), as the gauges are low in cost, easily operable, and capable of providing accurate point measurements at high temporal resolutions. Meteorological offices operate national and regional rain measurement networks but unfortunately their spatial resolution is often inadequate for urban hydrological studies (Berne et al., 2004). Recently, the use of weather radar has gained in popularity (e.g. Ochoa-Rodriguez et al., 2015; Rico-Ramirez et al., 2015; Schellart et al., 2012; Smith et al., 2005; Villarini et al., 2010), mainly due to the wide spatial coverage of radar compared to the sparse rain gauge networks. In urban catchments, stormwater management practices, such as low impact development tools, are realised in small scales and therefore usable radar data must also be of high temporal and spatial resolution (Emmanuel et al., 2012; Gires et al., 2013, 2012; Wright et al., 2014). The resolution of commonly provided data products from national radar networks, consisting of mainly

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S- and C-band radars, is in the order of 5 min and 1 km^2 (Berne and Krajewski, 2013), but this may not be sufficiently high for runoff modelling in urban areas (Bruni et al., 2015; Gires et al., 2012, 2013).

The resolution requirements depend also on the storm spatial structure and therefore storm type (Emmanuel et al., 2012; Peleg et al., 2013; Shucksmith et al., 2011). In a relatively homogeneous rain field, e.g. in widespread frontal rain, the variability within a storm is relatively low, and even a coarse rain gauge network or low resolution radar data may be sufficient for most hydrological analyses. On the other hand, more heterogeneous storm types such as convective summer showers require high resolution rainfall measurements in order to capture the spatial variability of the rain field. Too coarse a gauge network may either miss the convective cells, or especially with small catchments, measure additional rain if the gauges are located outside the catchment. Radar measurements, on the other hand, suffer from sampling errors especially if the spatial resolution is coarser than the length scale of the rain feature (Shucksmith et al., 2011). This can lead to over- or underestimation of rainfall amounts. While this is a problem also for frontal storms, the conventional 1 km^2 radar resolution is even more restrictive for observing the small scale rainfall variability in convective events (Gires et al., 2012).

In recent years the availability of meteorological data has greatly improved due to web-services providing access to such data in a machine readable form. At the same time, changes in legislation and governmental policies are increasingly urging national agencies to openly share the data produced with public funding. In Europe, the INSPIRE directive (European Parliament, 2007) was established to create a European infrastructure for delivering integrated spatial information to all end-users. As a result of the INSPIRE directive, e.g. the Finnish Meteorological Institute (FMI) has made a large amount of continuous real-time observations, historical time-series, and model forecast data open for public use via an online service (Honkola et al., 2013).

The objective of this paper is to study the feasibility of using open rainfall data as an input source in small scale urban hydrological simulations. The open gauge and radar rainfall data from FMI are used as an input for the Storm Water Management Model (SWMM) (Huber and Dickinson, 1988; Rossman, 2015) at a very small (33.5 ha) urban catchment in Helsinki, Finland. The applicability of the open data sources is evaluated against simulation results produced with rainfall data available from two research gauges, one of them located on-site, and from one research radar. Suggestions are provided on how to improve the reliability of the data sets for stormwater flow simulations.

2. Material

2.1. Study site

The Pihlajamäki catchment (60°14′05.9″N 25°00′37.0″E) (Fig. 1) is a very small 33.5 ha urban catchment located in the city of Helsinki, Finland. It belongs to the boreal climate zone with a mean annual air temperature of 5.9 °C and a mean annual precipitation of 655 mm, with late summer and autumn months being the wettest time of the year (Pirinen et al., 2012). The rain events causing excessive runoff in urban areas of Helsinki are typically intensive convective summer showers with a short duration (Aaltonen et al., 2008).

The catchment is located in a suburb built in 1960s and is characterized by tall concrete buildings surrounded by yards, small forested patches, and several rock outcrops. Based on a 2 × 2 m^2 land use raster, the catchment has a total fraction of imperviousness of 47.1%, distributed mostly between asphalt (26.4% of total catchment area), rooftops (12.9%), and rock outcrops (7.5%). Vegetated areas cover 47.4% and sand or gravel areas 5.2% of the total area. A small pond comprises 0.3% of the catchment area. The granite bedrock at the catchment is very close to the surface overlain only by a thin layer of topsoil. The catchment is located on a hill resulting in an average elevation of 32.2 m.a.s.l. (elevation range from 9.1 to 46.3 m.a.s.l.) and rather varying terrain (slope range from 0 to 54.7%) with a moderate median slope of 5.1%.

2.2. Rainfall data

Open rainfall data from two FMI products were used in the analysis. Open gauge data were available from Kumpula, 5 km south-west from the catchment (Kumpula gauge in Fig. 1). The gauge belongs to the operative weather station network of FMI (WMO-ID 02998). It is a weighing type rain gauge with a Tretyakov wind shield providing data at 10 min temporal resolution.

Radar data from a C-band radar in Vantaa (WMO-ID 02975), 8.8 km north-west from the catchment (Vantaa radar in Fig. 1) corresponds to the data released for public through the FMI Open data interface. The data were provided as rain intensity maps with a temporal resolution of 5 min and processed to a Cartesian grid with a resolution of 1 × 1 km^2. The open radar data are, due to storage constraints, available only for the past 5 days and therefore the data utilised in this study were reprocessed from archives of raw radar observations analogously to the production of the open data. As only capital area data were needed, the location of the grid differs slightly from the nationwide open data product, hence causing small differences in pixel values between the actual open data product and the product utilised here. The data have first undergone standard signal processing steps involving (a) removal of the stationary targets and (b) adjustment of the weakest and strongest signals according to the radar. Secondly, it has gone through the post processing steps for (c) correction for the effects of the vertical profile of reflectivity (VPR), (d) removal of non-meteorological targets, and (e) conversion from radar reflectivity (dBZ) to rain intensity (mm/h) based on a $Z(R)$ relation $Z = 223R^{1.53}$ which Leinonen et al. (2012) derived from 5 years of disdrometer observations in Finland. Even though the Vantaa radar has a dual-polarization capability, the dual-polarization parameters are used only for removing false echoes due to non-meteorological targets and filling the resulting gaps (Peura, 2012).

In addition to the open data, two fully automatic tipping-bucket rain gauges (Decagon ECRN-100 High Resolution Rain Gauge) recorded precipitation during the snow-free periods of 2014 and 2015. The first gauge was installed at the studied catchment (On-site rain gauge in Fig. 1) to provide reference on-site rainfall measurements, and the second gauge at the nearby Veräjämäki catchment 2.5 km south-west from the study catchment (Veräjämäki gauge in Fig. 1). The gauges reported the rainfall intensity as a number of tips (0.2 mm) per one minute (2014) or two minutes (2015). They were installed on top of low-rise kindergarten buildings to minimize interference due to vandalism and to be less prone to obstruction from the urban environment than at the street level. The gauge measurements are based on the manufacturer-provided calibration with no compensation e.g. for wind effects.

Finally, Vaisala Oyj operates a research radar in Kerava, 18 km north of the catchment (Kerava radar in Fig. 1), and provided rainfall intensity maps with a nominal resolution of 250 × 250 m^2. As there were several scan programs operated on the radar, the time between the scans varied from 45 s to 7 min 41 s with an average of 2 min 29 s, and the actual scan resolution varied from 1° angular and 100 m range resolution to 2° angular and 4000 m range resolution. Depending on the scan, the elevation angle varied from 0.4° to 1.0°. The data were quality controlled by removing the