The need for high resolution precipitation data to improve urban drainage modelling

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Abstract
In this study high resolution precipitation data are used, derived from polarimetric X-band radar at 100 m, 1 min resolution. The data are used to study the impact of different space-time resolutions of rainfall input on urban hydrodynamic modelling response for 9 storms, in 7 urban catchments. The results show that hydrodynamic response behaviour was highly sensitive to variations in rainfall space-time resolution, more strongly so for changes in temporal than in spatial resolution. Under- and overestimations of flow peaks amounted to up to 100% with respect to the original 100 m, 1 minute rainfall input.

Keywords
Rainfall space-time resolution; Radar rainfall; Urban hydrology; Urban hydrological response modelling;

INTRODUCTION

Cities are particularly sensitive to flooding induced by short-duration, high-intensity precipitation, due to their high degree of imperviousness, resulting in fast runoff processes and lack of available water storage. Moreover, the high density of population and economic assets in urban areas results in high vulnerability to flooding. Based on climate models, increases in the frequency and intensity of heavy precipitation are projected for the 21st century in several regions of the world (Kundzewicz, 2014).

High resolution data at urban scales

The spatial-temporal characteristics of urban catchments and stormwater drainage systems are generally small, often of the order of 1-10 km2 and a few minutes, respectively (Arnbjerg-Nielsen et al., 2013; Ochoa-Rodriguez et al., submitted). Cities typically display high spatial variability in land-use, small catchment areas and a high degree of imperviousness. Stormwater drainage systems are predominantly man-made and consist of complex networks of channel and pipe networks. This implies that precipitation information needs to be available at high resolution to reliably predict hydrological response and potential flooding.

METHODS AND DATASET

Urban catchment characteristics

Seven urban catchments, located at each of the four partner countries of the EU-funded RainGain project, were adopted as pilot locations in this study. With the aim of facilitating inter-comparison of results, catchment areas of similar size (3-8 km^2) were selected for testing. The main characteristics of the selected pilot catchments are summarised in Table 1. Moreover, images of the boundaries and sewer layouts of all pilot catchments can be found in Figure 1.

Table 1. Summary characteristics of pilot urban catchments

	Cran brook	Tor-quay	Morée-Sausset	Sucy-en-Brie	Herent	Ghent	Kralingen
Area (ha)	865.2	570.03	560.4	269	511.5	649.33	670
Catchment length and width (km)*	6.1/1.4	5.4/1.1	5.3/1.1	4.0/0.7	8.2/0.6	4.7/1.4	2.1/3.2
Catchment shape factor (-)	0.23	0.2	0.2	0.17	0.08	0.29	1.49
Slope (m/m)***	0.0093	0.0262	0.0029	0.0062	0.0083	0.0001	0.0003
Main flow direction (deg)	239	270	198	138	40	235	152
Type of drainage system	Mostly separate branched	Mostly combined branched	Mostly separate branched	Separate branched	Mostly combined branched	Mostly combined branched	Mostly combined looped
Is flow mainly driven by gravity?	Yes	Yes	Yes	Yes	Yes	Yes	No
Control elements	3 storage lakes	3 storage tanks, 1 pumping station	2 storage tanks	1 storage basin, 1 pumping station	5 main CSO's with control	15 pumping stations	20 pumping stations
IMP (%)****	52%	26%	37%	34%	27%	41%	48%
Predominant land-use	R&C	R&C	R&C	R&C	R	R	R&C
Population density [pp/ha]	47	60	70	95	20	24	154

*Length = Length of longest flow path (through sewers) to catchment outfall; Width = Catchment Area / Catchment Length;
**Shape factor = Width / Length (this parameter is lower for elongated catchments)
***Catchment slope = Difference in ground elevation between upstream most point and outlet / catchment length
****IMP: total proportion of impervious areas in relation to total catchment area

Precipitation dataset: dual-polarimetric X-band radar

While radar rainfall products are under development in the four pilot cities or RainGain, high resolution data were obtained for this study from a polarimetric research radar located in Cabauw, the Netherlands (Leijnse et al., 2010). Data were derived for nine storms in the period 2011-2014

and were used to conduct analyses of the space-time scales of storm cells and study hydrological modelling response at a range of space-time resolutions.
The estimated spatial and temporal characteristics of the nine storm events are summarised in table 2. For information on the method applied for estimating space-time scales of the storms we refer to Ochoa-Rodrigues et al. (2015).

Table 2. Summary characteristics of pilot urban catchments

Storm Event ID	Spatial range (m)	Mean Velocity (m/s)	Anisotropic coefficient (-)	Required Spatial Resolution (m)	Required Temporal Resolution (min)
E1	4057	9.8	0.38	1695	5.8
E2	3525	9.9	0.38	1473	4.9
E3	4655	14.0	0.55	1945	4.6
E4	3219	11.7	0.34	1345	3.8
E5	2062	14.1	0.59	861	2.0
E6	3738	11.7	0.26	1561	4.5
E7	1703	14.0	0.24	711	1.7
E8	3644	18.4	0.36	1523	2.8
E9	2355	17.0	0.08	984	1.9

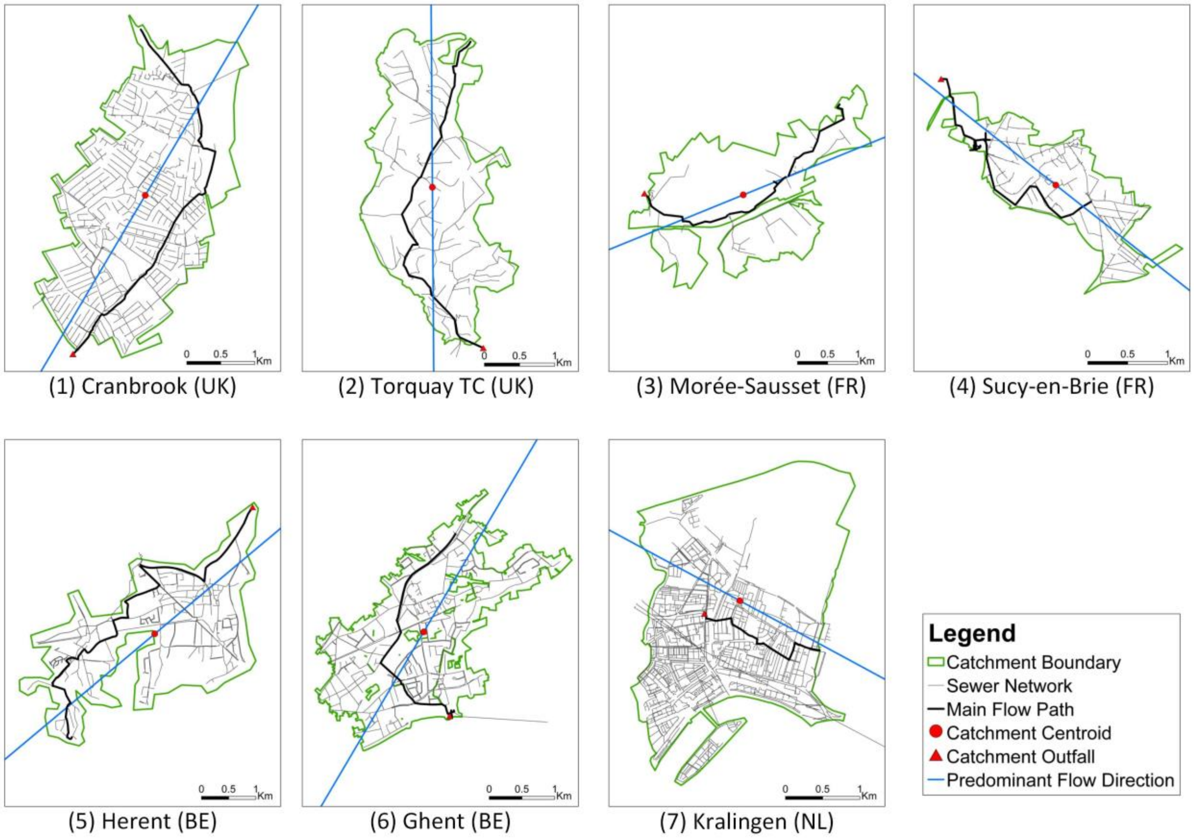

Figure 1. Catchment boundary and sewer layout for the pilot urban catchments

RESULTS AND DISCUSSION

Storm characteristics

Mean velocity of the nine storms varies from 6.4 m/s to 19.3 m/s (34 to 69 km/h) and storm ranges vary from 1700 to 4660 m. The combination of storm velocity and storm range, together with catchment dimensions, determines the time during which the storm core passes through a given catchment. For the storms and catchments considered in this study, this time varied between ~2-12 min.

Hydrological response: sensitivity to space-time resolution

In order to investigate the sensitivity of urban drainage models to the spatial-temporal resolution of rainfall inputs, the high-resolution precipitation data for the nine (9) storm events, initially at 100 m and 1 min, were aggregated to a number of coarser temporal and spatial resolutions (up to 3000 m and 10 min) and were applied as input to the urban drainage models of the seven (7) pilot catchments. Results were analysed at different drainage areas of varying sizes (~ 1 ha to ~ 800 ha) within each pilot catchment. Some of the main findings of the hydrological response analysis are summarised in this paper; for an in-depth analysis please refer to Ochoa-Rodriquez et al. (2015).

The results showed that hydrodynamic response behaviour in urban catchments is highly sensitive to combinations of temporal and spatial resolutions of rainfall input. For the storms investigated in this study, hydrodynamic response behaviour was more sensitive to temporal than to spatial resolution. Temporal resolution coarsening beyond the estimated required resolution (between 2 and 6 min) led to under- and overestimations of flow peaks by up to 100% with respect to the original 100 m, 1 minute rainfall input. Similarly, it resulted in low explained variance (down to 20% explained variance, median value, at the level of the entire hydrograph) and flow underestimation at the level of the entire hydrograph (figure 2, illustration of results for 1 catchment, 1 storm). Spatial resolution coarsening led to underestimation of hydrographs for spatial scales between 500 m and 1 km for drainage areas of 1 to 100 ha. A special feature observed in the analysis is the strong interaction between the spatial and temporal resolution of rainfall estimates: the two resolutions must be consistent with each other to prevent loss of information from the higher resolution (more detail in Ochoa-Rodriguez et al., 2015).

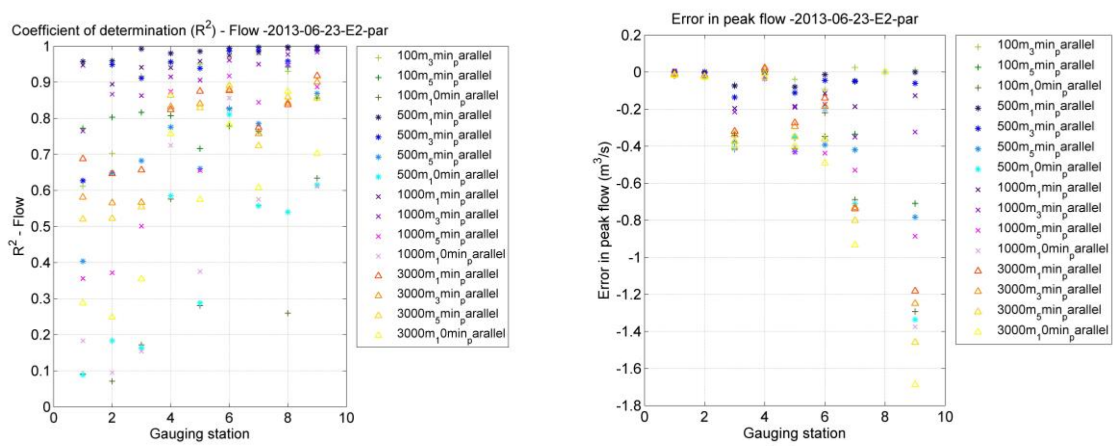

Figure 2. Example of hydrological response characteristics for 1 storm event, 1 catchment, 16 resolution combinations. Coefficient of determination and absolute error in peak flow are plotted for nine gauging stations corresponding with drainage area size increasing from ~1 ha to ~ 800 ha. The original input resolution of 100 m, 1 minute resolution is taken as a reference.

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REFERENCES

Arnbjerg-Nielsen, K., Willems, P., Olsson, J., Beecham, S., Pathirana, A., Gregersen, I. B., ... & Nguyen, V. T. V. (2013). Impacts of climate change on rainfall extremes and urban drainage systems: a review. Water Science & Technology, 68(1), 16-28.

Kundzewicz, Z. W., Kanae, S., Seneviratne, S. I., Handmer, J., Nicholls, N., Peduzzi, P., ... & Sherstyukov, B. (2014). Flood risk and climate change: global and regional perspectives. Hydrological Sciences Journal, 59(1), 1-28.

Leijnse, H., Uijlenhoet, R., van de Beek, C. Z., Overeem, A., Otto, T., Unal, C. M. H., Dufournet, Y., Russchenberg, H. W. J., Figueras i Ventura, J., Klein Baltink, H. & Holleman, I. (2010). Precipitation Measurement at CESAR, the Netherlands. Journal of Hydrometeorology, 11 (6), 1322-1329

Ochoa-Rodriguez, S., Wang, L.-P., Gires, A., Pina, R.D., Reinoso Rondinel, R., Bruni, G., Ichiba, A., Gaitan, S., Cristiano, E., Van Assel, J., Kroll, S., Murlà-Tuyls, D., Schertzer, D., Tchiguirinskaia, I., Onof, C., Willems, P., ten Veldhuis, M. (2015). Impact of spatial and temporal resolution of rainfall inputs on urban hydrodynamic modelling outputs: A multi-catchment investigation. Journal of Hydrology, in press.