Improved rainfall estimates and forecasts for urban hydrological applications

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Innovyze User Days - Drainage and Flooding User Group

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Contents

1. Context
2. Radar rainfall processing techniques
3. Improved rainfall monitoring in urban areas
4. Conclusions and outlook
1. CONTEXT

• The RainGain Project
• Why improving rainfall estimates?
THE RAINGAIN PROJECT

Advanced observation and rainfall prediction for urban pluvial flood management
(Sep 2011 – Jul 2015)

Objective: to **improve fine-scale measurement and prediction of rainfall** and to **enhance urban pluvial flood prediction** in order to enable urban water managers to adequately cope with intense storms, so that the vulnerability of populations and critical infrastructure can be reduced.
Project Partners

1) TU Delft (NL)
2) Zuid-Holland Province (NL)
3) Gemeentewerken Rotterdam (NL)
4) KU Leuven (B)
5) Aquafin NV (B)
6) Ecole des Ponts ParisTech (F)
7) Marne-la-Vallée (F)
8) Seine-St.-Denis (F)
9) Météo France (F)
10) Imperial College London (UK)
11) Met Office (UK)
12) Local Government Flood Forum (UK)
13) Véolia (F)
Model Assembly for storm water drainage modelling, forecasting and management

Rainfall Estimation / Forecasting
Flow Modelling / Forecasting
Management (urban planning, RT control, emergency management)

Supported by data (monitoring)

The temporal and spatial scales characteristic of urban drainage systems, as well as their complexity, make each of these components more challenging
• The rainfall events which generate pluvial flooding are often associated with **thunderstorms of small spatial scale** (~10 km), whose magnitude and spatial distribution are **difficult to monitor and predict**

• Due to the small spatial scale and fast response of urban catchments, rainfall estimates/forecasts with fine spatial and temporal resolution are required
“... *Rainfall* is the main input for urban pluvial flood models and the uncertainty associated to it dominates the overall uncertainty in the modelling and forecasting of these type of flooding...”

(Golding, 2009)

We really need to get the rainfall right!
Two essential characteristics of rainfall estimates

- **Accuracy (getting the values right):** this is critical! Especially for urban hydrological applications, where errors in rainfall estimates are magnified by the small scale.

- **Resolution (spatial & temporal):** for urban hydrological applications spatial and temporal resolution must be high.
Sensors commonly used for estimation of rainfall at catchment scales

<table>
<thead>
<tr>
<th></th>
<th>RAINGAUGE</th>
<th>RADAR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy</strong></td>
<td><img src="image" alt="Smiley" /></td>
<td><img src="image" alt="Smiley" /></td>
</tr>
<tr>
<td><strong>Coverage, spatial</strong></td>
<td><img src="image" alt="Sad" /></td>
<td><img src="image" alt="Smiley" /></td>
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<tr>
<td><strong>characterisation of rainfall field</strong></td>
<td><img src="image" alt="Sad" /></td>
<td><img src="image" alt="Smiley" /></td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td><img src="image" alt="Sad" /></td>
<td><img src="image" alt="Sad" /></td>
</tr>
</tbody>
</table>

Further processing of radar rainfall estimates can improve its applicability (in terms of accuracy and resolution) to urban hydrological applications.
Why we need to adjust radar rainfall data?

Beal HS raingauge rainfall depth accumulations: 23/08/2010 event

Urban drainage models are normally calibrated using raingauge data
Tackling the Challenges

- Improving accuracy: Gauge-based adjustment of radar rainfall estimates
- Improving resolution: Rainfall downscaling
- Improved rainfall monitoring (X-band radar, high quality radar protocols, rain gauge networks)
These techniques are being tested in 3 pilot locations in the UK

- Cranbrook (London Borough of Redbridge)
- Purley (London Borough of Croydon)
- Torquay City Centre (Torbay, Devon)
Cranbrook Catchment (LB Redbridge)

- **Area**: aprox. 900 ha
- **Cran Brook**: 5.75 km (5.69 km culverted)
- **Predominantly urban catchment**
- **Sub-catchment of Roding River catchment**
- **Subject to fluvial & surface flooding**
Monitoring System

Local Sensors

Met Office
C-band radars
2. RAINFALL PROCESSING TECHNIQUES

• Aimed at improving accuracy and resolution of rainfall estimates

• Two techniques have been developed and tested:
  ▪ Adjustment of radar rainfall estimates based on raingauge measurements
  ▪ Rainfall spatial downscaling
2.1. RADAR-RAINGAUGE MERGING OR ADJUSTMENT

**Aim:** To combine the advantages of radar and raingauge sensors to have a better spatial description and local accuracy of urban rainfall.

Based on their assumption, gauge-based radar rainfall adjustment techniques can be classified into two types:

- Mean Bias Correction
- Error Variance Minimisation
Principle of Bayesian Data Combination

In this process the variance of the error is minimised.

[Image: Ehret et al., 2008]
[Source: Todini, 2001]
Four recorded events in the period of 2010 – 2012 over the Cranbrook catchment were studied.

<table>
<thead>
<tr>
<th>Event</th>
<th>Duration</th>
<th>RG total (mm)</th>
<th>Radar@RG total (mm)</th>
<th>Radar total (mm)</th>
<th>Sample bias $B_i = (1)/(2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>23/08/2010</td>
<td>8 hr</td>
<td>23.53</td>
<td>7.29</td>
<td>6.80</td>
<td>3.23</td>
</tr>
<tr>
<td>26/05/2011</td>
<td>9 hr</td>
<td>15.53</td>
<td>5.10</td>
<td>4.88</td>
<td>3.04</td>
</tr>
<tr>
<td>05/06/2011</td>
<td>24 hr</td>
<td>20.87</td>
<td>9.43</td>
<td>9.48</td>
<td>2.21</td>
</tr>
<tr>
<td>03/01/2011</td>
<td>13 hr</td>
<td>8.93</td>
<td>7.72</td>
<td>7.55</td>
<td>1.16</td>
</tr>
</tbody>
</table>

Bias is event-varying, separate adjustment for each event is required.
Both rainfall profiles and accumulations can be significantly improved through adjustment.

**Mean Rainrate: 23/08/2010 event**
- Mean RGs
- Radar 1km
- Corrected Radar 1km
- Bayesian Radar 1km

**Mean Rainfall Accumulation: 23/08/2010 event**
- Mean RGs
- Radar 1km
- Corrected Radar 1km
- Bayesian Radar 1km
Simulation of flow depths can be largely improved using radar rainfall estimates “locally” adjusted with the co-located raingauge measurements.

23/08/2010 event
Pipe 463.1 (Mid-stream)

Observations

Rain (mm/hr)
Flow Depth (m)

23 August 2010 (Time, GMT)
26/05/2011 event

Pipe 463.1 (Mid-stream)

Rain (mm/hr)
Flow Depth (m)

- RGs
- Radar 1km
- Corrected Radar 1km
- Bayesian Radar 1km
- Obs. 463.1 (Mid-stream)
Potential applications of gauge-based locally adjusted radar rainfall estimates

• Event reconstruction

• Calibration of urban drainage models – underway!
  • Improved calibration with not so dense networks of raingauges (this could lead to cost savings)

• Improved radar-based nowcasts – underway!
Preliminary results:

Calibration of urban drainage models using gauge-based adjusted radar rainfall estimates

- **Case Study**: Beddington Catchment, LB Croydon
- **Model**: InfoWorks CS semi-distributed model of the sewer system verified in 2012
- **Drainage area**: 64 km²
- **Number of nodes**: 10,205
- **Number of links**: 10,500
- **Pipe length**: 708 km
- **Number of subcatchments**: 5,185
- **Mean subcatchment area**: 1.2 km²
Rainfall and flow monitoring data for model verification

- **Medium term flow survey data:**
  - Carried out by TW between 28/01/11 and 13/07/11
  - 79 flow gauges
  - 18 rain gauges
  - 2 min resolution

- **Nimrod (radar) data available at 1 km – 5 min**
Testing of model for different rainfall inputs:

(3 storms were analysed – the same used for calibration)

1. Original raingauge data, applied using Thiessen Polygons

2. Original Nimrod (radar) data

3. Merged rainfall data (using Bayesian methodology)
Better calibration results could be achieved by using adjusted rainfall inputs, as these can better capture the spatial structure and accuracy of rainfall fields.

<table>
<thead>
<tr>
<th></th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>MEAN RELATIVE ERROR – PEAK FLOW RATE</td>
<td>MEAN RELATIVE ERROR - PEAK FLOW DEPTH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RG</td>
<td>30.57%</td>
<td>40.56%</td>
<td>40.40%</td>
<td>90.96%</td>
<td>76.29%</td>
<td>20.79%</td>
</tr>
<tr>
<td>NIMROD</td>
<td>28.27%</td>
<td>36.96%</td>
<td>53.59%</td>
<td>46.21%</td>
<td>24.76%</td>
<td>26.34%</td>
</tr>
<tr>
<td>MERGED</td>
<td>24.91%</td>
<td>29.75%</td>
<td>37.51%</td>
<td>32.34%</td>
<td>21.12%</td>
<td>18.93%</td>
</tr>
<tr>
<td></td>
<td>MEAN R² – FLOW RATE</td>
<td>MEAN R² – FLOW DEPTH</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>RG</td>
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<td>0.641</td>
<td>0.705</td>
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<tr>
<td>NIMROD</td>
<td>0.666</td>
<td>0.667</td>
<td>0.575</td>
<td>0.703</td>
<td>0.656</td>
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<tr>
<td>MERGED</td>
<td>0.701</td>
<td>0.703</td>
<td>0.633</td>
<td>0.748</td>
<td>0.713</td>
<td>0.718</td>
</tr>
</tbody>
</table>

**Mean Relative Error:**
- Indicator of how well the model captures the ‘magnitude’ of flow rates and depths
- The lower, the better

**R² (Coefficient of determination):**
- Indicator of how well the model captures flow rate and depth patterns
- The higher, the better
Preliminary results:

Improvement of radar-based rainfall nowcasting and associated urban runoff and flow forecasting through dynamic radar-raingauge rainfall adjustment

• Radar rainfall estimates for a large area (500 km x 500 km) are required as input for nowcasting model

• Radar estimates for large area were adjusted using colocated raingauges.

• 2 adjustment techniques were tested:
  • Kriging with external drift
  • Mean bias correction

• The Met Office nowcasting model was used to produce rainfall forecast for the different rainfall inputs
Adjustments were done at too large scales and no improvements were achieved at the local scale of urban catchments – spatial variability needs to be considered!
Adjusted radar rainfall estimates may lose their temporal correlation and may not be suitable for further rainfall nowcasting uses.
2.2. Cascade based spatial downscaling to improve spatial resolution of radar rainfall estimates

Scaling analysis

Feature curve

Level n = 8 km

Level n = 4 km

Level n = 2 km

Level n = 1 km

Rainfall Cascade Generator

downscaling

fitting
2.3. Accuracy vs. Resolution

Analysis of the relative impact of adjustment and downscaling

$U_{\text{adjusted}}$: difference in water depth estimates resulting from bias correction

$U_s$: range of water depth estimates resulting from downscaling
### Table: Water Depth Measurements

<table>
<thead>
<tr>
<th>Scale</th>
<th>Upstream</th>
<th></th>
<th>Midestream</th>
<th></th>
<th>Downstream</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Max</td>
<td>Mean</td>
<td>Max</td>
<td>Mean</td>
<td>Max</td>
</tr>
<tr>
<td><strong>23/08/2010 event</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 km - 500 m</td>
<td>37.74</td>
<td>59.68</td>
<td>13.42</td>
<td>46.10</td>
<td>10.81</td>
<td>31.52</td>
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<tr>
<td>1 km - 250 m</td>
<td>43.89</td>
<td>103.03</td>
<td>16.23</td>
<td>62.80</td>
<td>12.50</td>
<td>31.34</td>
</tr>
<tr>
<td>1 km - 125 m</td>
<td>37.59</td>
<td>62.32</td>
<td>17.34</td>
<td>52.21</td>
<td>11.63</td>
<td>20.00</td>
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<td><strong>26/05/2011 event</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 km - 500 m</td>
<td>47.66</td>
<td>67.35</td>
<td>24.04</td>
<td>56.59</td>
<td>21.61</td>
<td>32.89</td>
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<tr>
<td>1 km - 250 m</td>
<td>53.14</td>
<td>76.62</td>
<td>30.79</td>
<td>73.13</td>
<td>28.45</td>
<td>36.78</td>
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<tr>
<td>1 km - 125 m</td>
<td>64.14</td>
<td>72.34</td>
<td>28.28</td>
<td>60.35</td>
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</tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 km - 500 m</td>
<td>105.47</td>
<td>113.33</td>
<td>49.09</td>
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<td>39.78</td>
</tr>
<tr>
<td>1 km - 250 m</td>
<td>135.40</td>
<td>190.98</td>
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<td>70.27</td>
<td>41.57</td>
<td>44.85</td>
</tr>
<tr>
<td>1 km - 125 m</td>
<td>170.46</td>
<td>219.50</td>
<td>72.26</td>
<td>98.61</td>
<td>46.49</td>
<td>62.45</td>
</tr>
<tr>
<td><strong>03/01/2012 event</strong></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>1 km - 500 m</td>
<td>100.15</td>
<td>93.73</td>
<td>31.18</td>
<td>18.87</td>
<td>19.76</td>
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<td>1 km - 250 m</td>
<td>118.29</td>
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<td>37.31</td>
<td>25.74</td>
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</tr>
<tr>
<td>1 km - 125 m</td>
<td>124.20</td>
<td>102.58</td>
<td>32.54</td>
<td>17.72</td>
<td>19.95</td>
<td>13.35</td>
</tr>
</tbody>
</table>

- > 100: resolution > accuracy
- < 100: accuracy > resolution
• In most cases, gauge-based radar rainfall adjustment shows larger impact on the subsequent hydraulic outputs:

In general, **accuracy** is more important than **resolution**!

• However, it may be possible that in small areas the impact of fine-scale spatial variability of rainfall is relatively more important than the bias observed in radar estimates.

• We will continue to study the impact of bias and resolution based on more rainfall events
3. IMPROVED RAINFALL MONITORING IN URBAN AREAS

- Installation of X-band radar in London
- Testing of X-band radar rainfall estimates is underway
Installation of X-band radar in London (April 2013 – September 2013)

- Smaller wavelength makes X band radar more sensitive and able of detecting smaller particles (e.g. drizzle, light snow, cloud formation).
- Because it is closer to the ground, it may be able to provide better rainfall estimates for London.
- Complements network of C-band radars of Met Office.
- Cheaper than bigger radars.
Installation of X-band radar in London

A website for displaying real time and historical data collected with the X-band radar is under development
Future activities with X-band radar

• Comparison of X-band radar, C-band radar and raingauge rainfall estimates

• Merging of rainfall estimates from these 3 sources

• Application of X-band radar rainfall estimates to urban drainage models – using InfoWorks ICM Live
4. CONCLUSIONS AND OUTLOOK

• Good quality rainfall estimates are essential for reliably modelling and forecasting the behaviour of urban drainage systems

• Combining rainfall estimates from multiple sensors allows overcoming current problems associated to poor accuracy of radar estimates and point raingauge rainfall measurements

• Great potential for improving modelling and forecasting the behaviour of urban drainage systems

• The potential applications and limitations of these techniques and sensors will continue to be explored
Thank you for your attention

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