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A spatial-temporal rainfall generator for urban drainage design

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Introduction

Counters Creek is an urban drainage catchment in northwest London managed by Thames Water.

Increased basement flooding highlighted the need for further network improvements.

Spatially-uniform 30-year design storms create costly design requirements, while previous work by MWH highlighted the significance of spatial variability in storm events in the catchment (MWH, 2011).

Can we therefore capture this spatial variability in a series of simulated storm events?

MWH (2011). *Counters Creek spatial rainfall study: Stage (a) How important is spatial rainfall variation?* MWH Technical Note TN/EWI/CH11/186/01.00

Summary of Work

Individual storm events modeled as a number of rainfall cells described by a Gaussian function travelling across the catchment at a constant velocity following Willems (2001).

Parameter estimates for the model were obtained from radar rainfall data from the Greater London region for 45 storm events over the period 2000 to 2011 identified by MWH (2011) as hydraulically significant.

Distributions were fitted to each parameter estimate series, allowing the simulation tool to sample from these distributions in order to build the stochastic, spatially-varied storm events.

Willems, P. (2001). A spatial rainfall generator for small spatial scales. *Journal of Hydrology*. 252, 126-144

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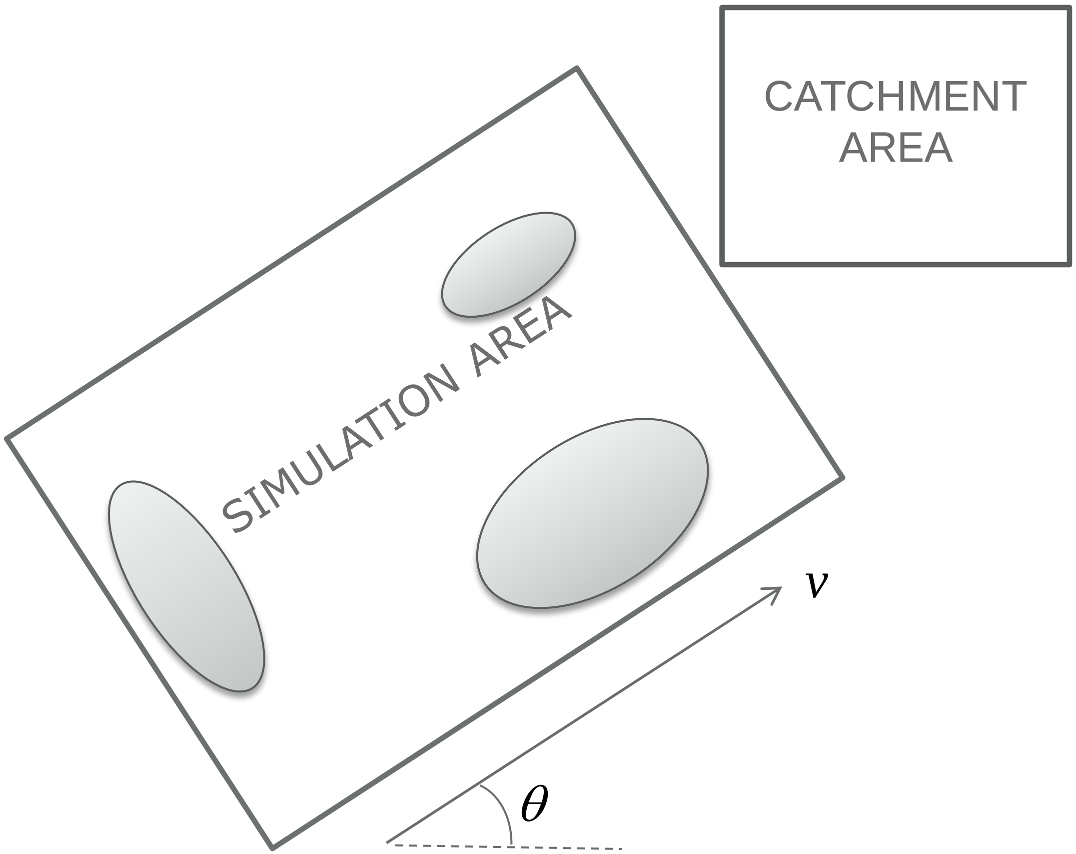
Model Conceptualisation



Storm modeled as an invariant area which moves across the catchment at constant velocity for the duration, d, of the storm.

Rainfall cells distributed uniformly at rate λ throughout the simulation area.

Each rainfall cell modeled as an ellipse, with one axis following direction of motion, and with intensity along each axis given by:

$$f(u_i) = \frac{r_{max}}{\sqrt{2\pi s_i{}^2}} \exp\left(-\frac{u_i^2}{2s_i^2}\right)$$

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Parameter Estimation and Distribution Fitting

Seven parameters requiring distributions for sampling: d, λ, v, θ, r_{max}, s_1 and s_2.

Rainfall radar data at $1km^2$ resolution and 5 minute intervals was obtained for Greater London for 45 storm events in the period 2000 to 2011 and within each storm, rainfall cells were identified within the radar data set using a hierarchical threshold method following Peak & Tag (1994).

- d and λ estimated by observed storm duration and the number of identified rainfall cells per time step respectively.
- v and θ estimated using spatial correlations of the whole radar dataset to determine prevailing speed and direction.
- r_{max}, s_1 and s_2.estimated using the Gaussian equation with the 'cut-off' intensity from the hierarchical thresholding method along with the peak intensity.

Peak, J.E. & Tag P.M. (1994). Segmentation of Satellite Imagery Using Hierarchical Thresholding and Neural Networks. *Journal of Applied Meteorology*. 33 (5), 605-616

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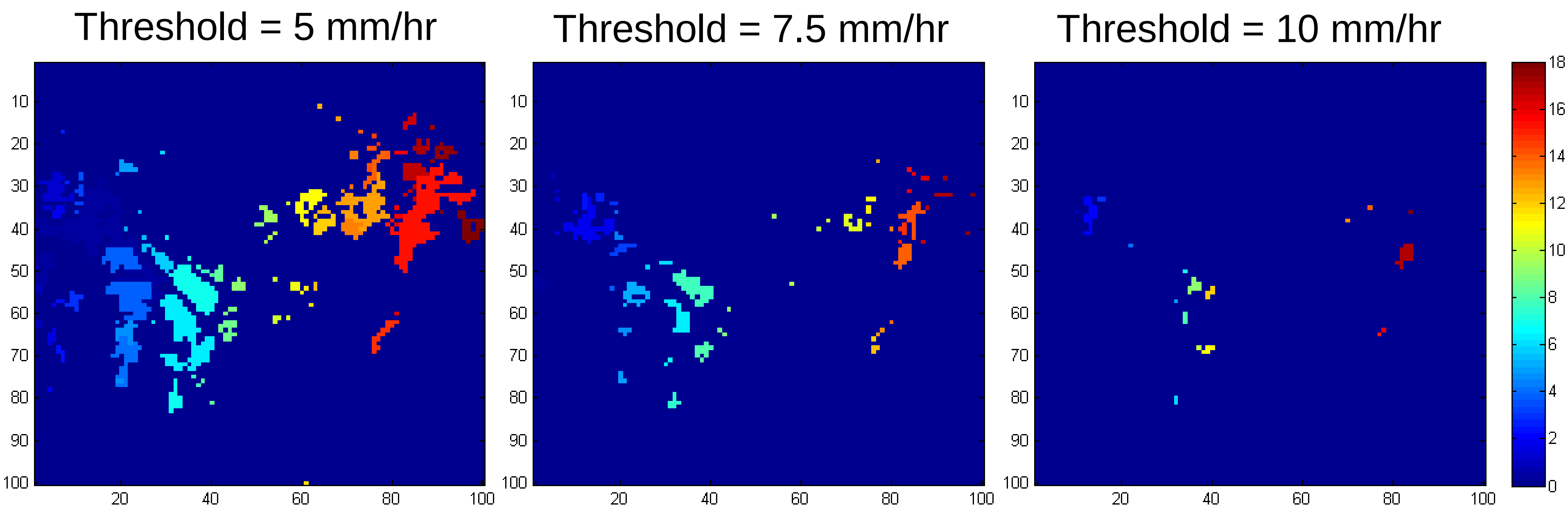
Rainfall cell identification using hierarchical threshold method



Parameter Estimation and Distribution Fitting

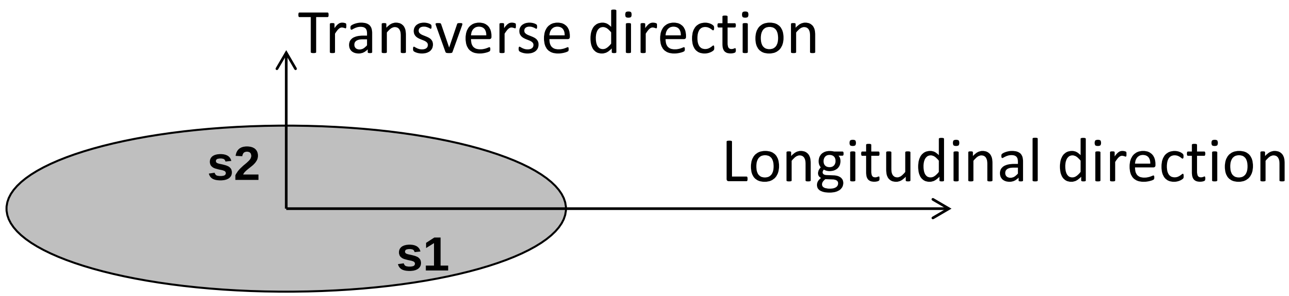
Parameter Set	Fitted Distribution	Distribution Parameters	Standard Error
Storm Duration (d)	Gamma	a (-) = 2.44 b (hrs) = 17.92	SE_a = 0.53 SE_b = 4.23
Number of Cells Per Square Kilometre (λ)	Normal	μ (km^{-2}) = 0.0099 σ (km^{-2}) = 0.0032	SE_μ = 0.00052 SE_σ = 0.00037
Velocity Magnitude (v)	Log Normal	μ (km/hr) = 78.30 σ (km/hr) = 23.64	SE_μ = 0.054 SE_σ = 0.039
Velocity Direction (θ)	Log Normal	μ (rads) = 0.51 σ (rads) = 1.16	SE_μ = 0.150 SE_σ = 0.108
Cell Spread in Direction of Motion (s_1)	Log Normal	μ = 0.70 σ = 1.06 (mean = 3.52km; var = 25.63 km^2)	SE_μ =0.0032 SE_σ = 0.0023
Cell Spread in Direction Perpendicular to Motion (s_2)	Log Normal	μ = 0.70 σ = 1.00 (mean = 3.34 km; var = 19.17 km^2)	SE_μ = 0.0030 SE_σ = 0.0021
Maximum Intensity in Cell (r_{max})	Generalised Pareto	k = 0.59 σ = 1.04 θ = 0.2 mm (mean = 2.71 mm)	SE_k =0.0023 SE_σ =0.0027 SE_θ =0

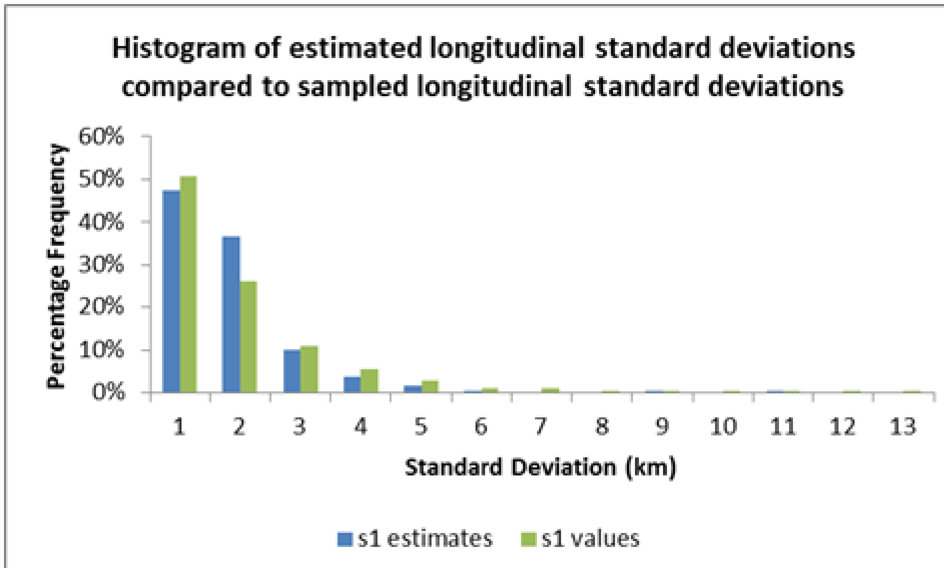
Validation

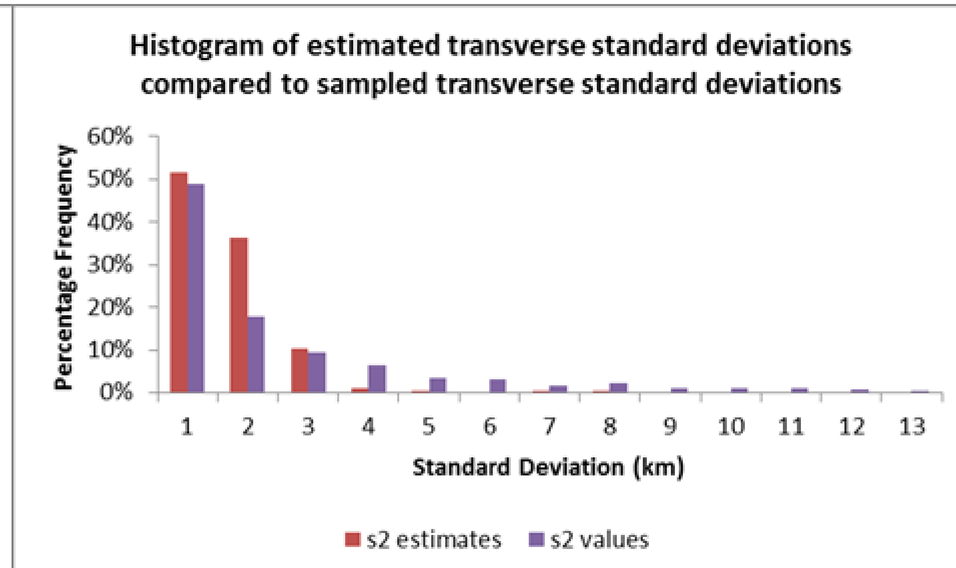
- Rainfall cell representation was analysed using the values of velocity (v and θ), duration (d) and cell density (λ) parameters from a specific observed storm events and sampling r_{max}, s_1, and s_2. Comparison with the observed storm events showed underestimation of maximum intensity and standard deviation.
  Accounted for by incorporating dependency between large rainfall intensities.

- Autocorrelation charts showed lack of persistence of rainfall intensity in simulated events.
  Lack of autocorrelation at higher lags was addressed by using Weibull distribution for storm velocity as per Willems (2001)

The distribution of rainfall cell extents can be well re-produced

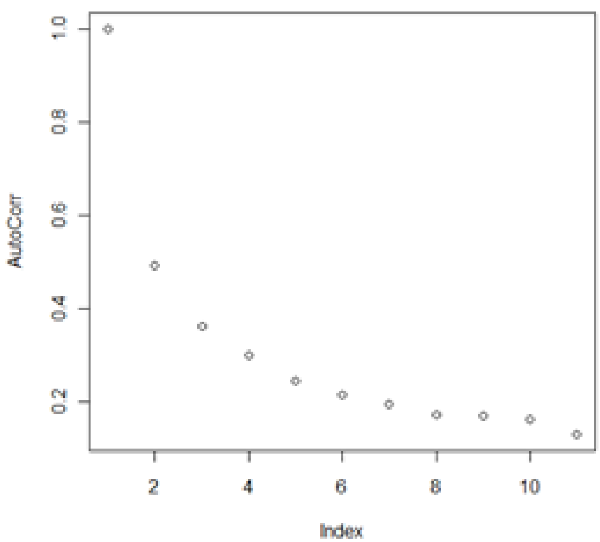




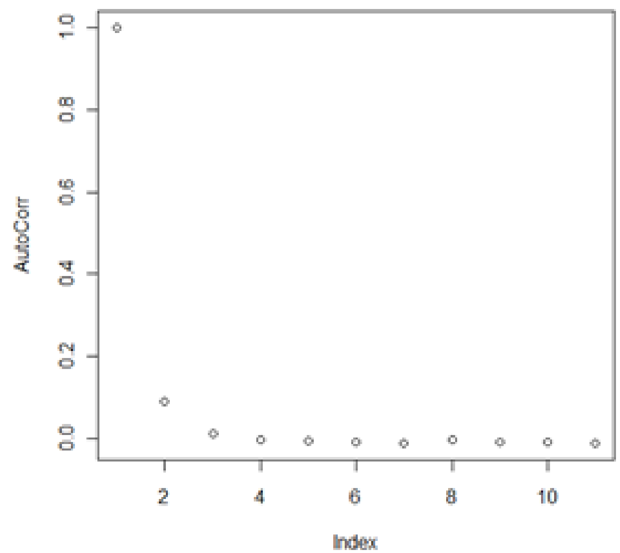


Autocorrelation (5-min, 10 lags) decreases significantly using log-Normal distributed velocity

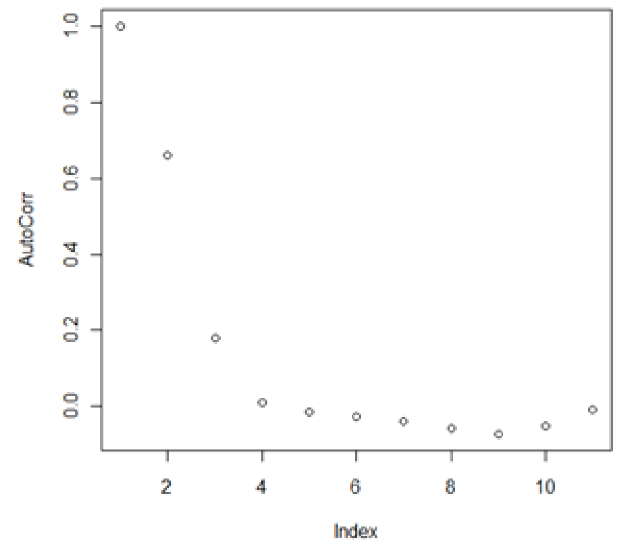
Historical event No. 31



Simulated event using Log-Normal dist.



Simulated event using Weibull dist.



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Discussion & Conclusions

Proof of concept of generating a wide variety of spatially distributed storms which emulate the observed variety of spatial storm structures.

Highlights areas for further analysis:

- Cell tracking algorithm would allow estimates of rainfall cell velocity as well as total storm velocity;
- The distributions of maximum intensity varied from storm to storm, likely to be representative of the underlying processes of the storm event;
- Incorporation of cell growth and decay throughout storm lifetime.
- Cell clustering would add a further layer of accuracy, as per Wheater et al (2000).
- Much of the uncertainty in the analysis came from uncertainties inherent in radar rainfall data analysis, in particular dealing with noise

Wheater, H.S., Isham, V.S., Cox, D.R., Chandler, R.E., Kakou, A., Northrop, P.J., Oh, L., Onof, C. & Rodriguez-Iturbe, I. (2000). Spatial-temporal rainfall fields: Modelling and statistical aspects. *Hydrological Earth Systems Sciences.* 4(4), 581-601.

If you have any question about this work, please feel free to contact:

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THANK YOU!