

Sampling design optimisation for rainfall prediction using a non-stationary geostatistical model

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Rainfall prediction and optimisation of rain-gauge network

The accuracy of spatial predictions of rainfall by merging radar and rain-gauge data is partly determined by the sampling design of the rain gauge network. Optimising the locations of the rain gauges may increase the accuracy of the predictions. In this study, we optimised the sampling pattern of rain gauges using an extension of the Kriging with External Drift (KED) model for prediction of rainfall fields. The model incorporates both non-stationarity in the mean and in the variance. The space-time averaged KED variance was minimised by Spatial Simulated Annealing (SSA). The model was tested using a case study near Manchester in the United Kingdom (Fig.1) for a one-month period at daily scale.

Material and methods

Data

185 daily rainfall measured by gauges from the Environmental Agency (EA)
Radar images from NIMROD at 1km resolution
Digital Elevation Model (DEM)

Methodology

Kriging with an external drift with non-stationary variance

$$Z(x) = \sum_{k=0}^K \beta_k f_k(x) + \sum_{l=0}^L \kappa_l g_l(x) \cdot \varepsilon(x)$$

Covariates f_k for the mean

Covariates g_l for the standard deviation

Parameter estimation

Restricted Maximum Likelihood Estimation (REML)

Sampling design optimisation

Spatial Simulated Annealing (SSA)

Minimising the space-time averaged kriging variance:

$$\frac{1}{T} \int_{t=0}^T \frac{1}{|A|} \int_{x \in A} \text{Var}(Z(x) - \hat{Z}(x)) dx dt$$

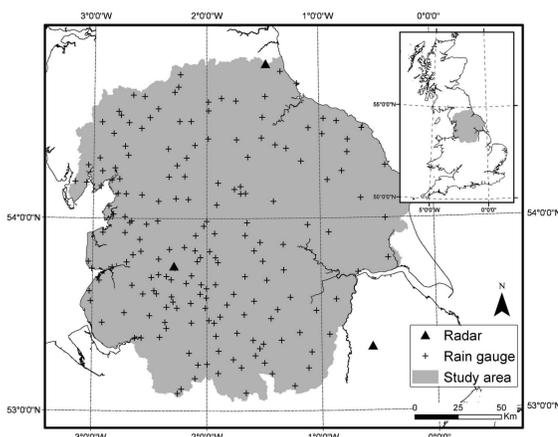


Figure 1: Study area North-East of the city of Manchester (United Kingdom).

Results & Discussion

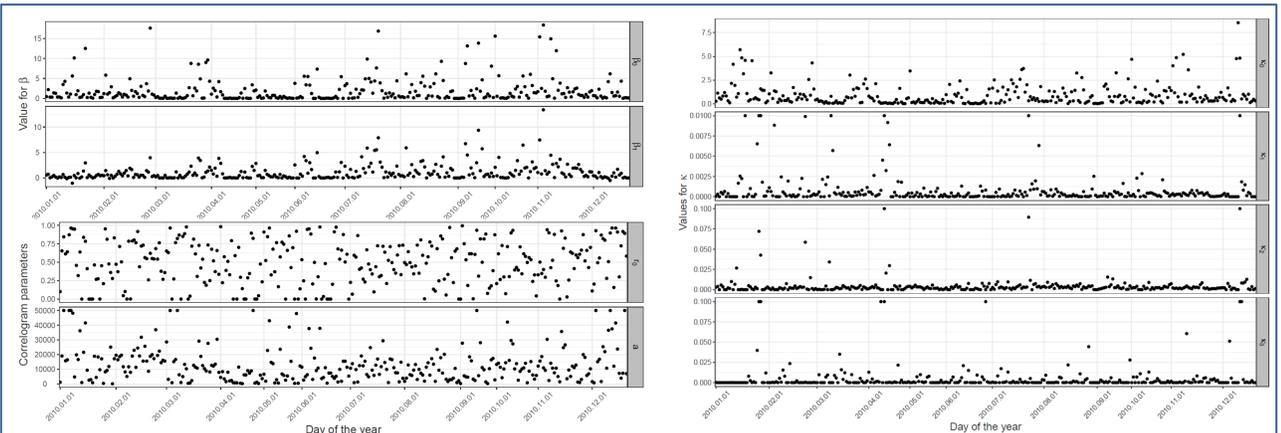


Figure 2: Spatial correlogram parameters (bottom left), coefficients for the covariates associated to the mean (upper left) and standard deviation (right) per day for the year 2010.

The model parameters are estimated by REML for each day separately. In Fig.2 (bottom left), r_0 is the nugget, a is the range. In Fig.2 (upper left) β_0 is the intercept, β_1 is the coefficient for the radar image. In Fig.2 (right) κ_0 is the intercept, κ_1 is the coefficient for the digital elevation model \times radar image, κ_2 is the coefficient distance from the radar \times radar image and κ_3 is the coefficient for the radar beam blockage \times radar image.

Figure 3: Original (left) and optimised (right) maps of the rain-gauge network with associated density. The rain-gauges move to areas of high uncertainty of radar imagery to minimise the space-time rainfall error prediction variance.

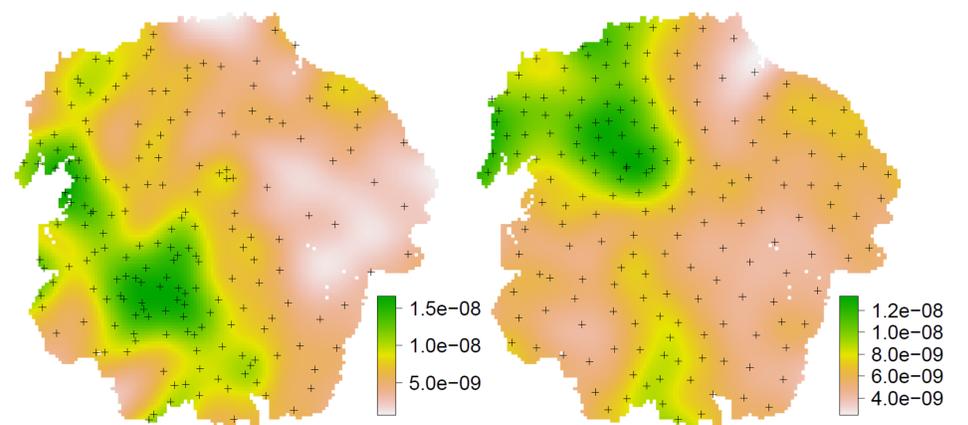


Fig. 3 shows that density of rain-gauge increase in areas of high uncertainty (far away from the radar, areas of beam blockage, mountainous areas), but a few stations are kept in areas of low radar imagery uncertainty.

After optimisation, the reduction of the rainfall prediction error variance is about 5%.

Conclusion

- 1. Some decrease of rainfall prediction error variance is obtained by optimisation of rain-gauge network
- 2. Optimised network is a compromise between uniform sampling and more intensive sampling in areas where radar imagery is inaccurate

Further reading

- Wadoux, A, Brus, DJ, Rico-Ramirez, MA, and Heuvelink, GBM, Sampling design optimisation for rainfall prediction using a non-stationary geostatistical model. 2017; Advances in Water Resources (in Press)
- Brus DJ, Heuvelink GBM. Optimization of sample patterns for universal kriging of environmental variables. Geoderma 2007;138(1):86–95.
- Lark R. Kriging a soil variable with a simple nonstationary variance model. Journal of Agricultural, Biological, and Environmental Statistics 2009;14(3):301–21.



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