High-resolution rainfall field re-construction based upon Kriging and local singularity analysis

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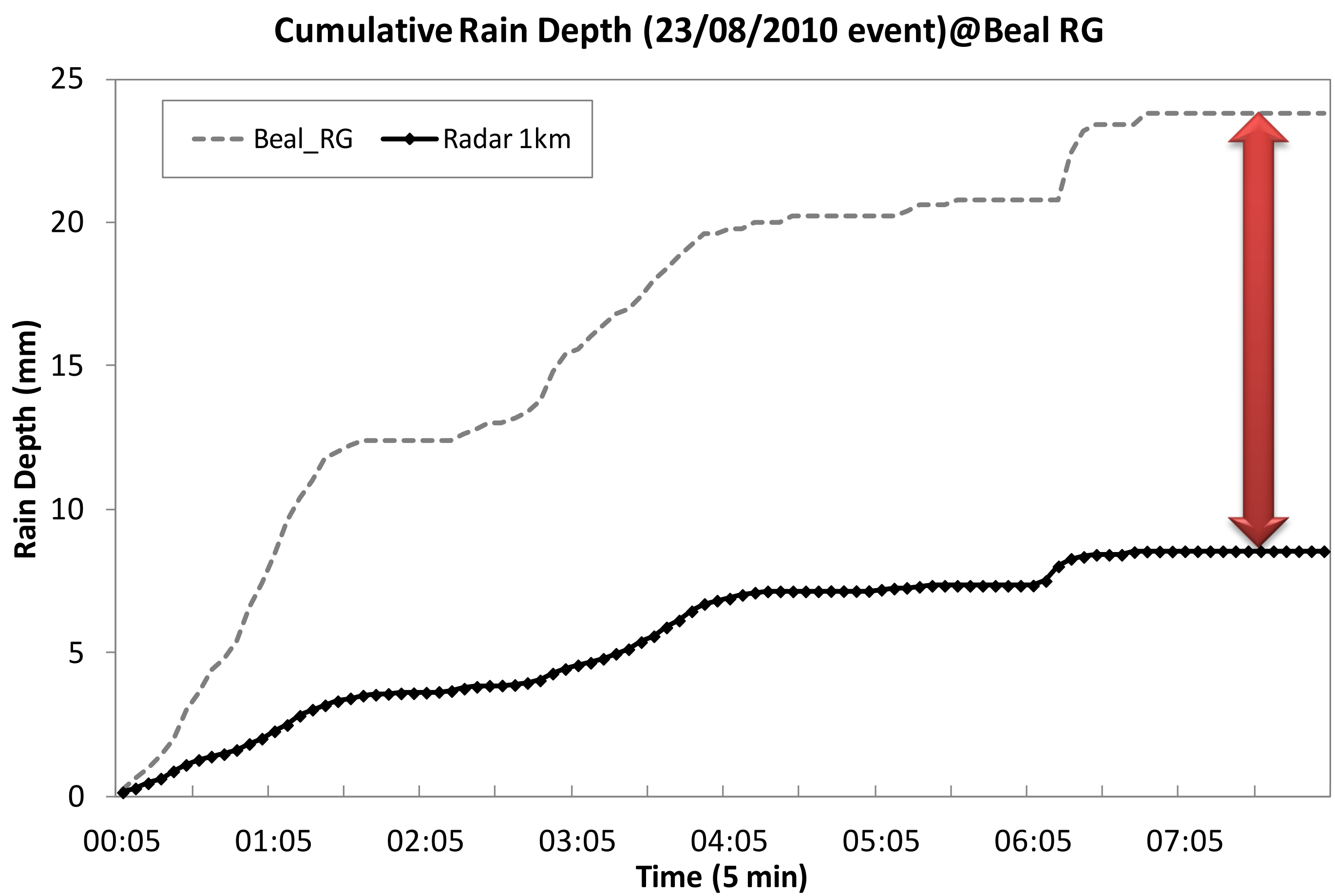
Hydrofractals '13, Kos Island (Greece), 17th-19th October 2013

Contents

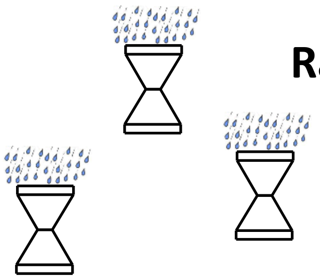
1. INTRODUCTION

Why we need to adjust radar rainfall data?

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

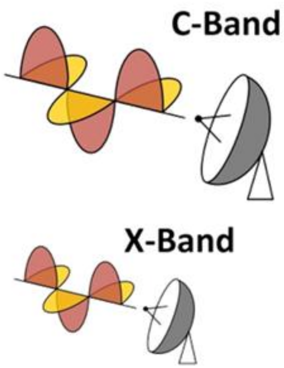


Sensors commonly used for estimation of rainfall at catchment scales



Raingauge

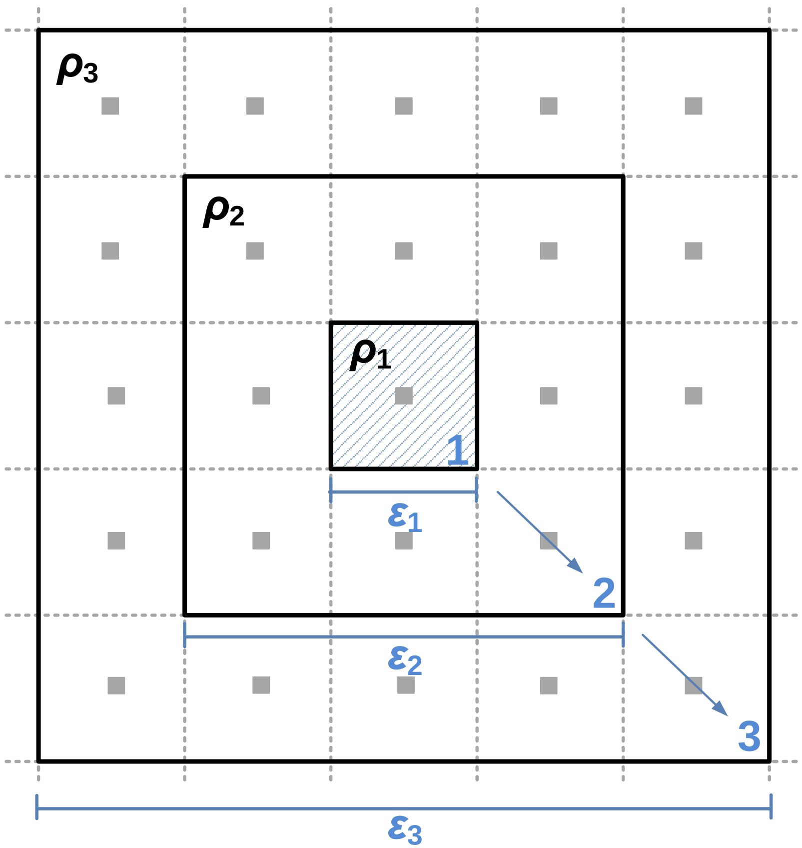
Weather Radar



	RAINGAUGE	RADAR
Accuracy		
Coverage, spatial characterisation of rainfall field		

2. LOCAL SINGULARITY ANALYSIS

Local singularity analysis decomposes a geo-value into a singular and a non-singular components



Mass density

The “singularity” component, of which the value varies at different scales according to local singularity exponent, termed $\alpha(x)$

$$\boxed{\rho(x)} = \boxed{c(x)}\boxed{\varepsilon^{\alpha(x)-E}}$$

Non-singularity component: The Background magnitude that does not change as scale varies

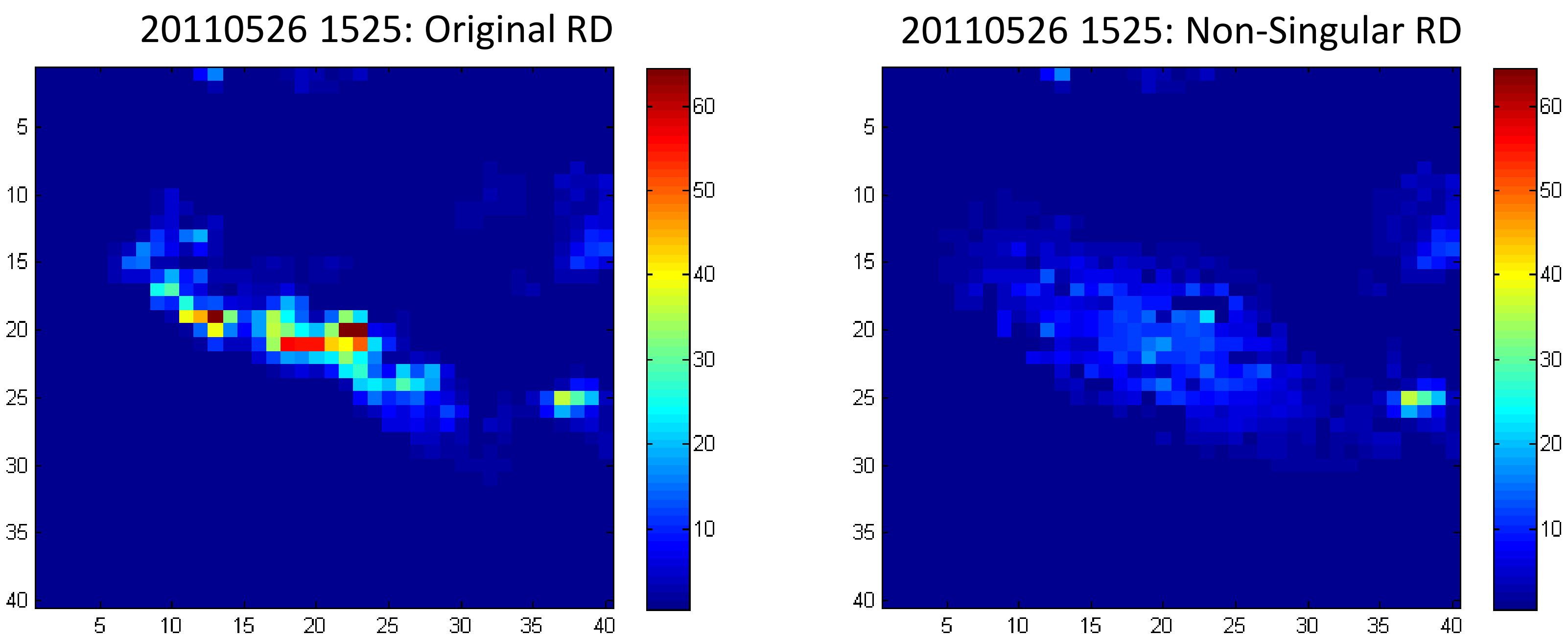
$\alpha = 2$, no singularity exists

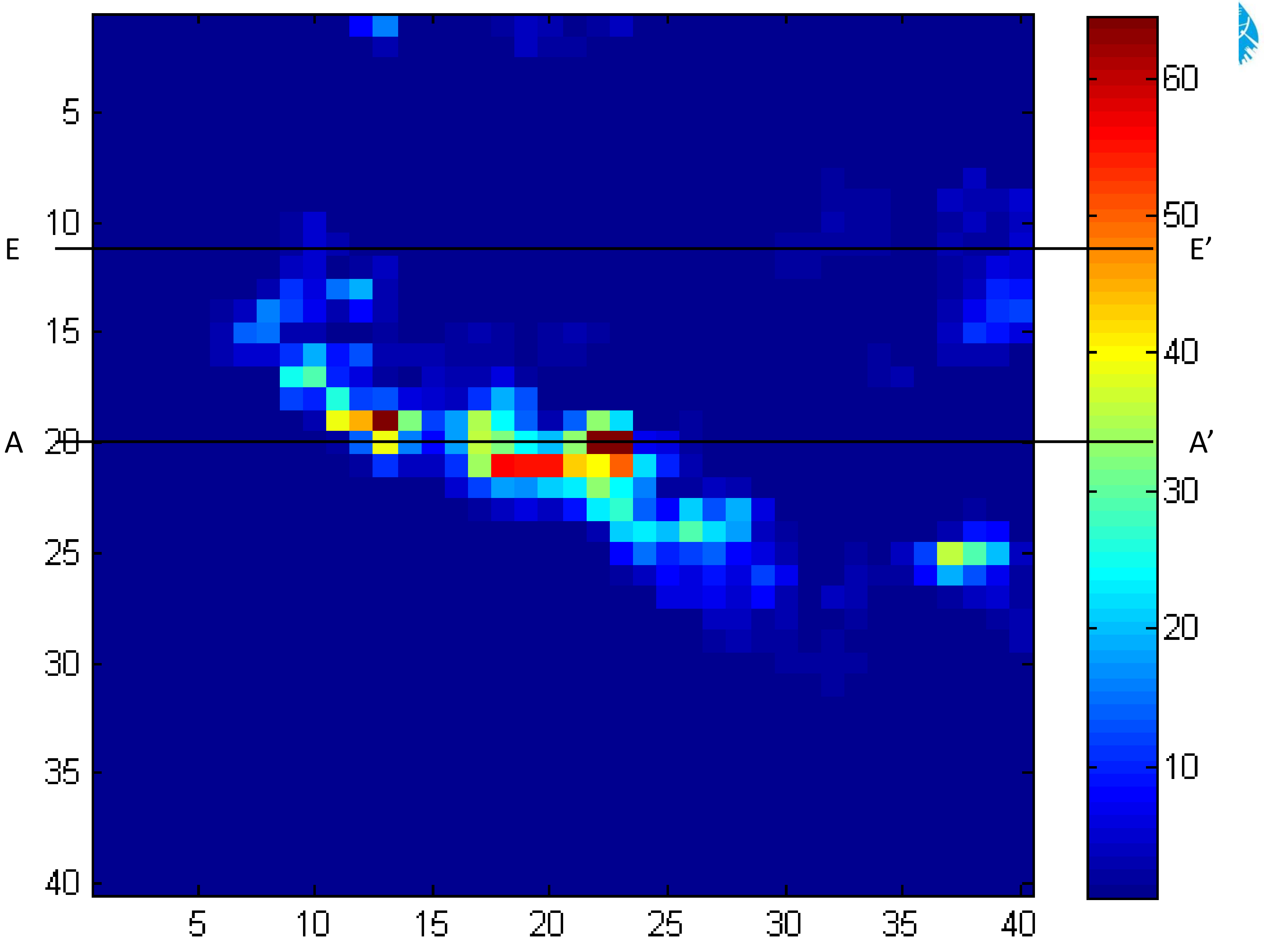
$\alpha \neq 2$, singularity exists

$\alpha > 2$, local depletion

$\alpha < 2$, local enrichment

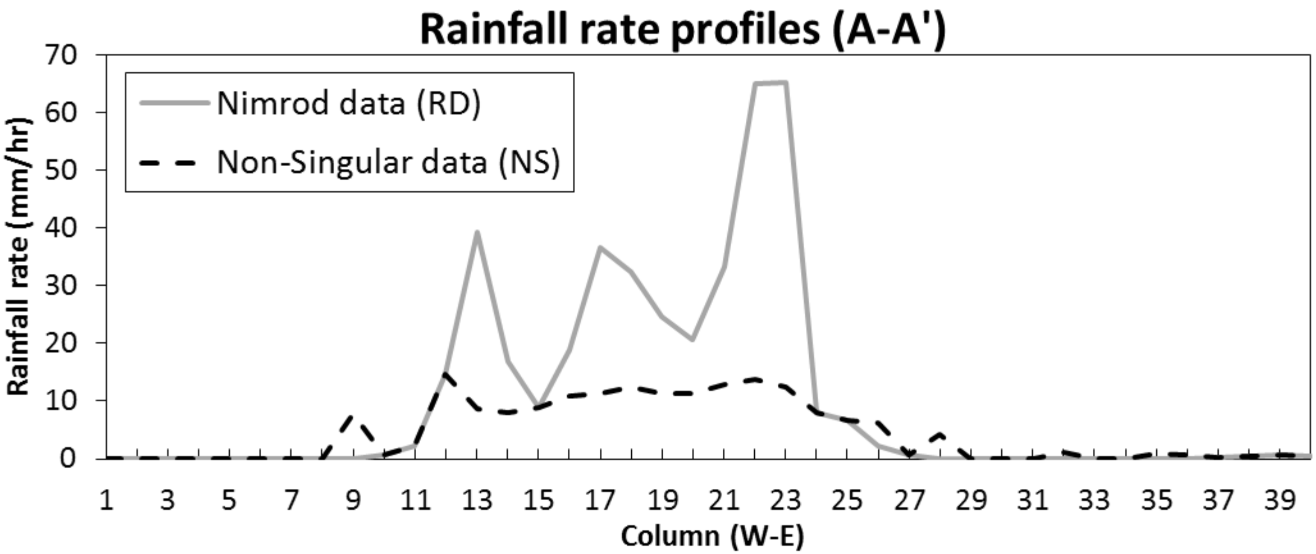
As compared to the original radar (RD) field, the Non-Singular (NS) one is smoother and more symmetric

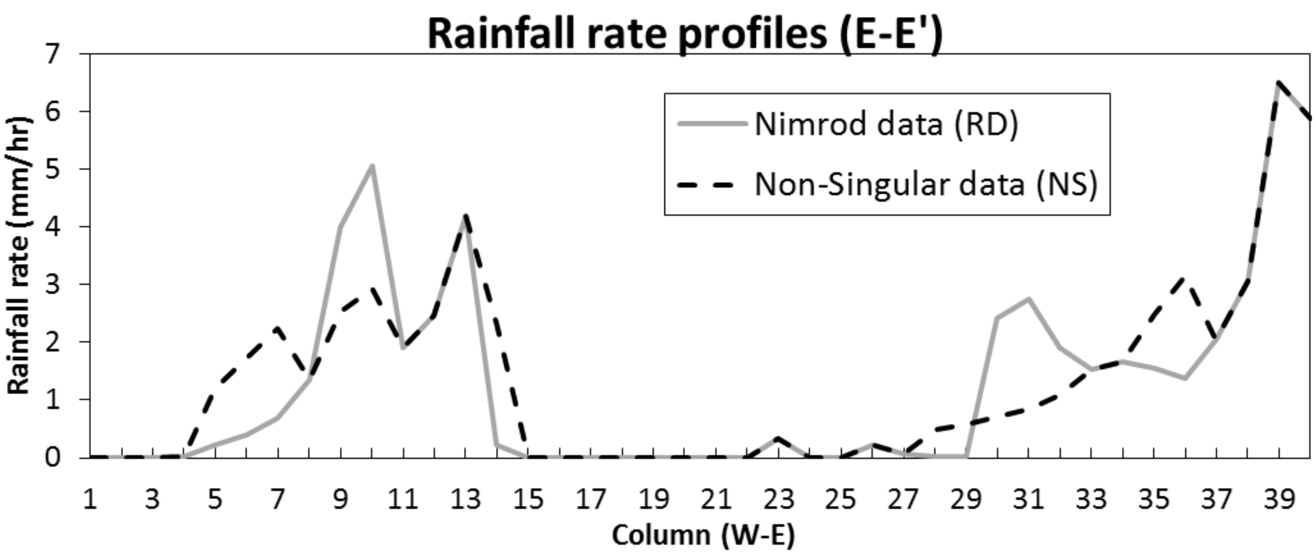




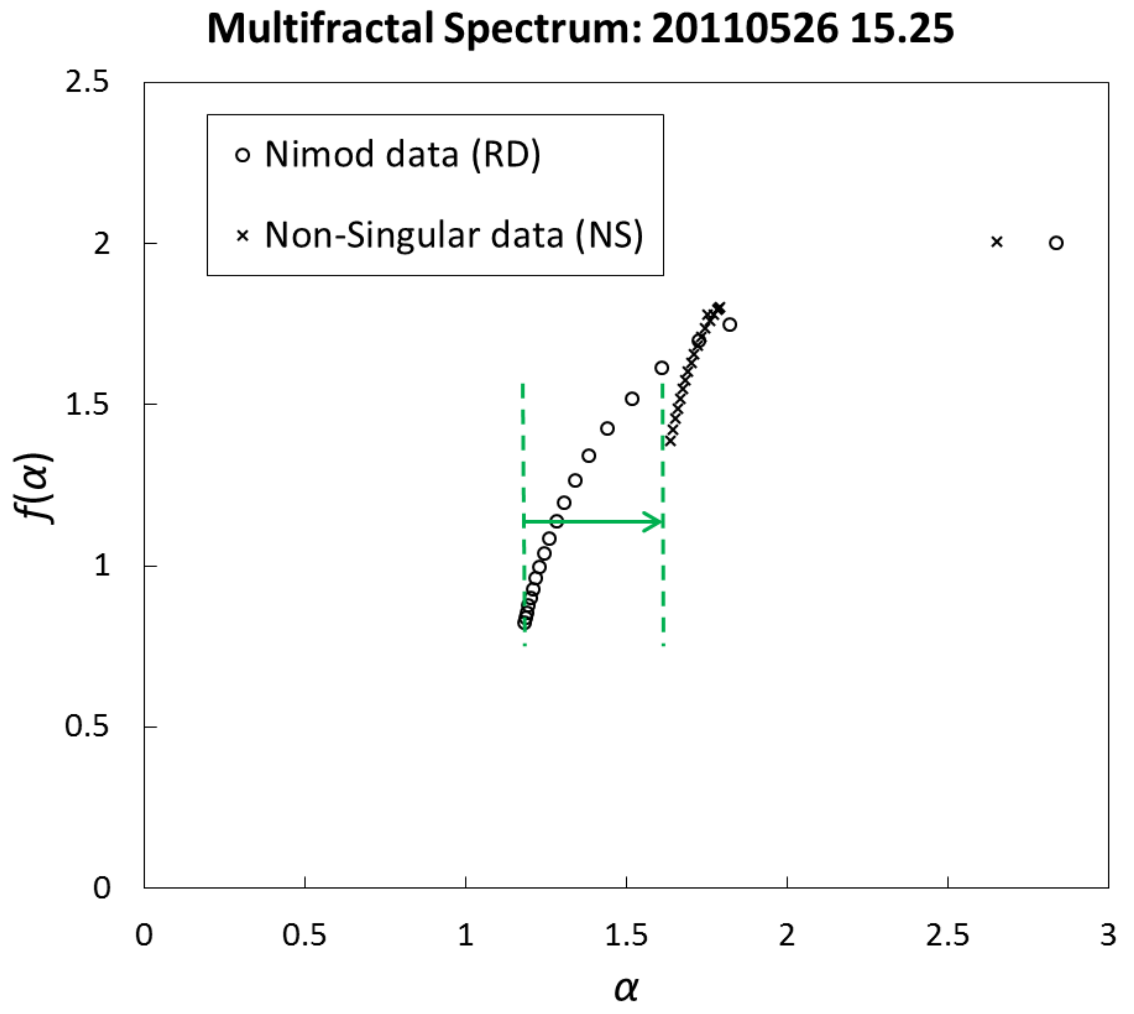
E
E'
A
A'
5
10
15
20
25
30
35
40
60
50
40
30
20
10

The degree of “smoothing” is in particular strong at the locations where more local extreme magnitudes are seen



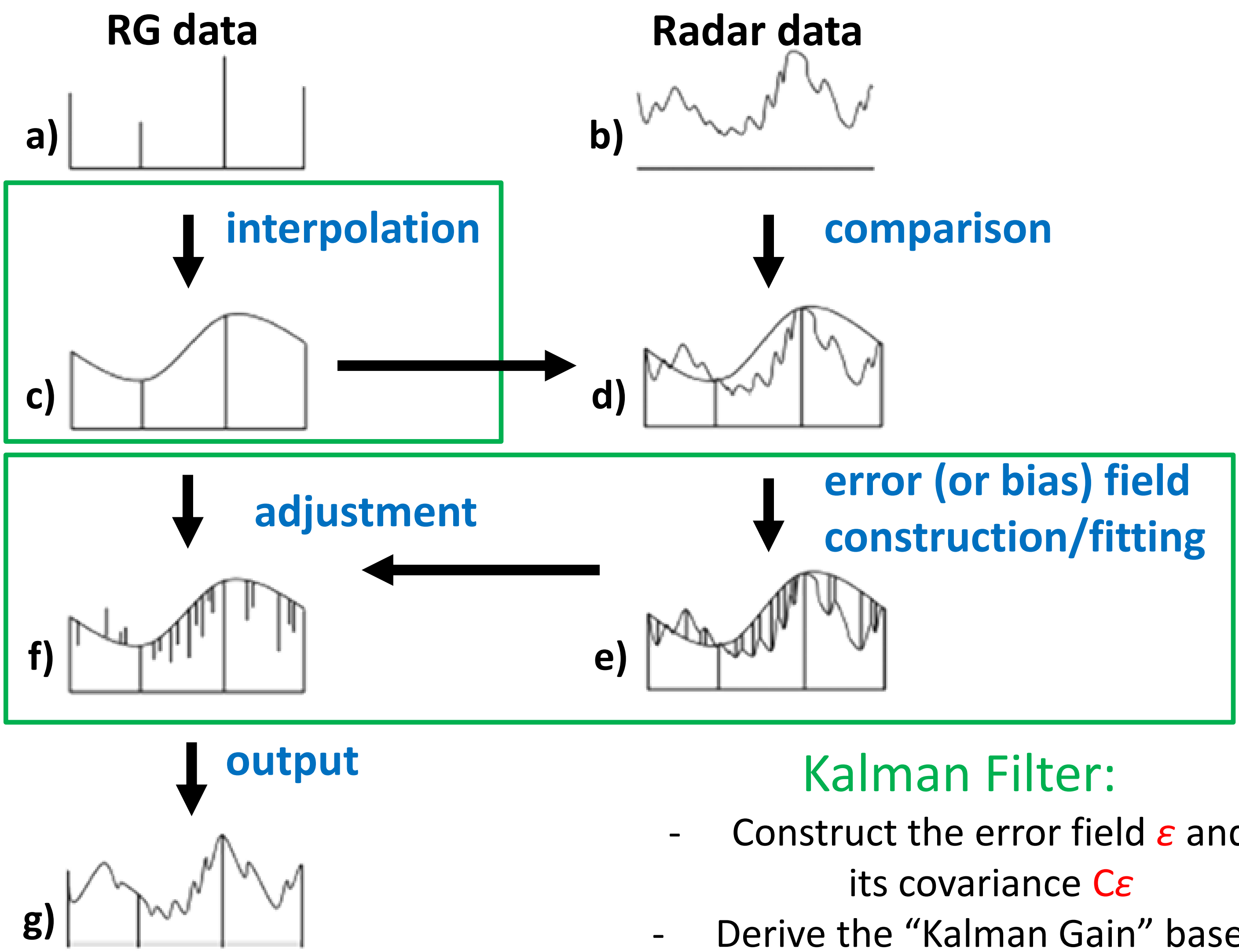


The multifractal spectrum of a Non-Singular field is narrower and the α values are less diverse (concentrating around 2, i.e. non singular)



3. BAYESIAN DATA MERGING AND ITS INTEGRATION WITH LOCAL SINGULARITY ANALYSIS

Principle of radar-raingauge data merging technique



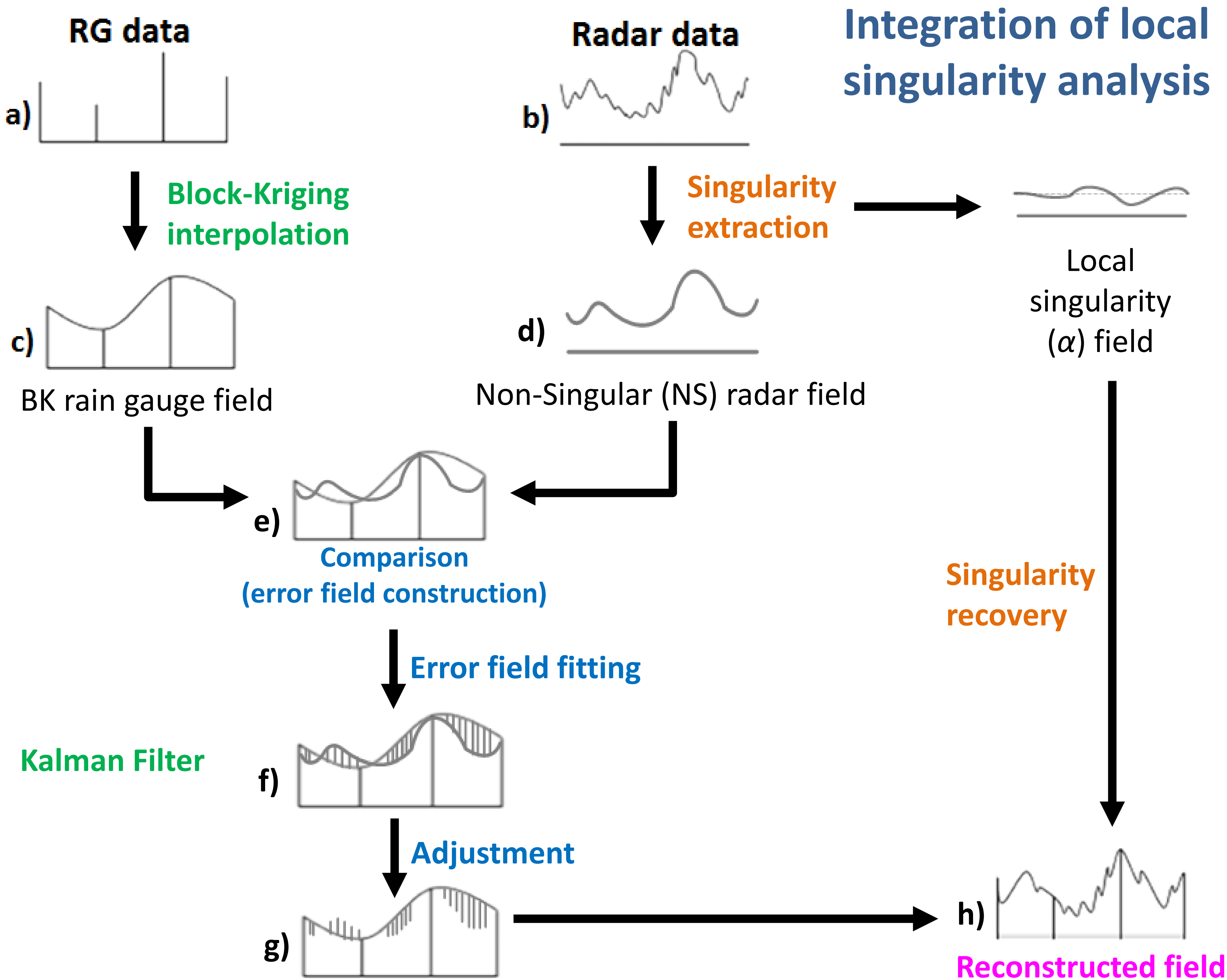
Block-Kriging Interpolation:

- RG field y^G
- estimation error covariance $C\varepsilon_G$

Kalman Filter:

- Construct the error field ε and its covariance $C\varepsilon$
- Derive the “Kalman Gain” based upon $C\varepsilon_G$ and $C\varepsilon$

(Todini, 2001; Ehret et al., 2008)

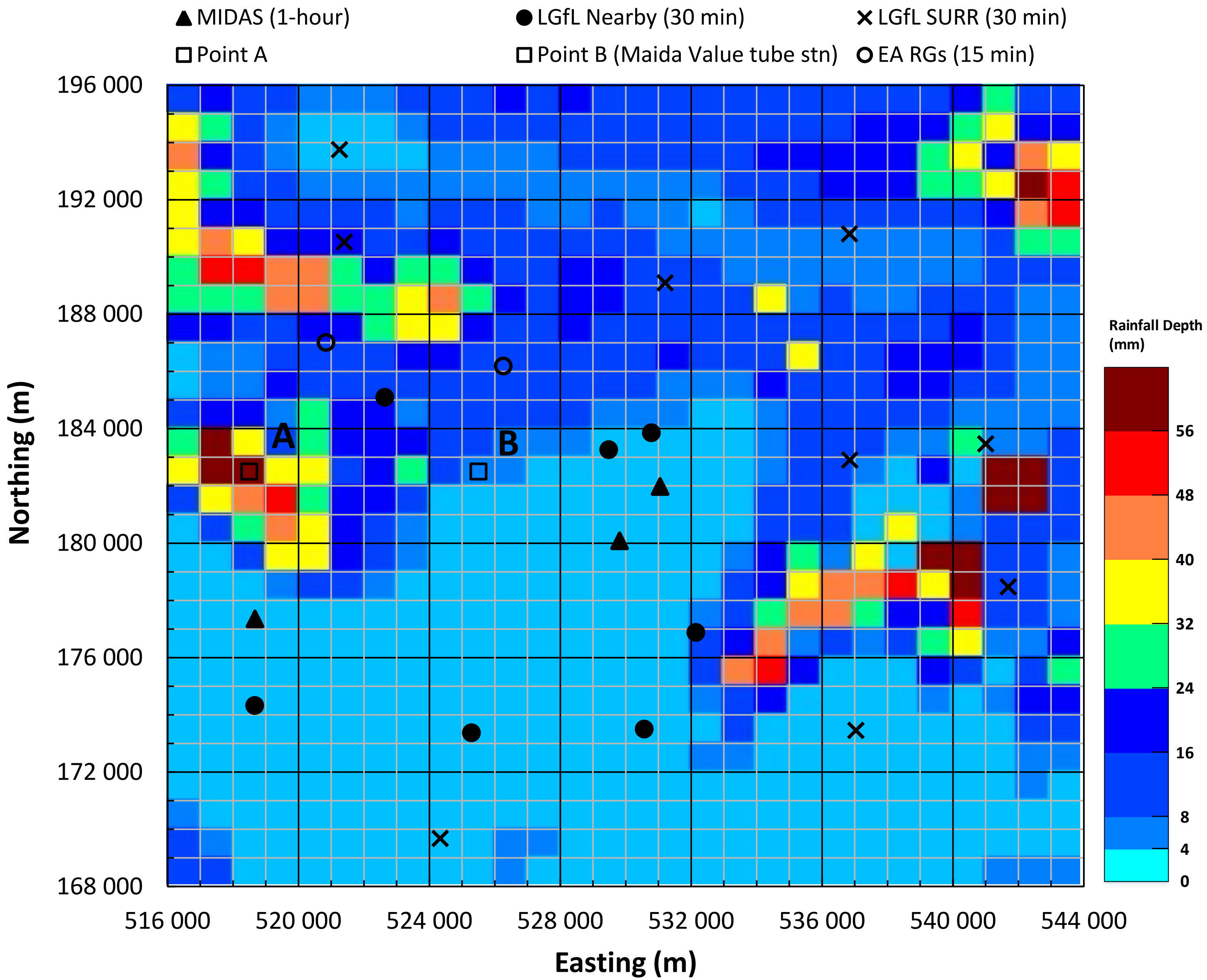

Integration of local singularity analysis
RG data
Radar data
a)
b)
Block-Kriging interpolation
Singularity extraction
Local singularity (α) field
c)
d)
BK rain gauge field
Non-Singular (NS) radar field
e)
Comparison (error field construction)
Singularity recovery
Error field fitting
Kalman Filter
f)
Adjustment
g)
h)
Reconstructed field

Reconstruction of a 2009 summer storm crossing Central London area

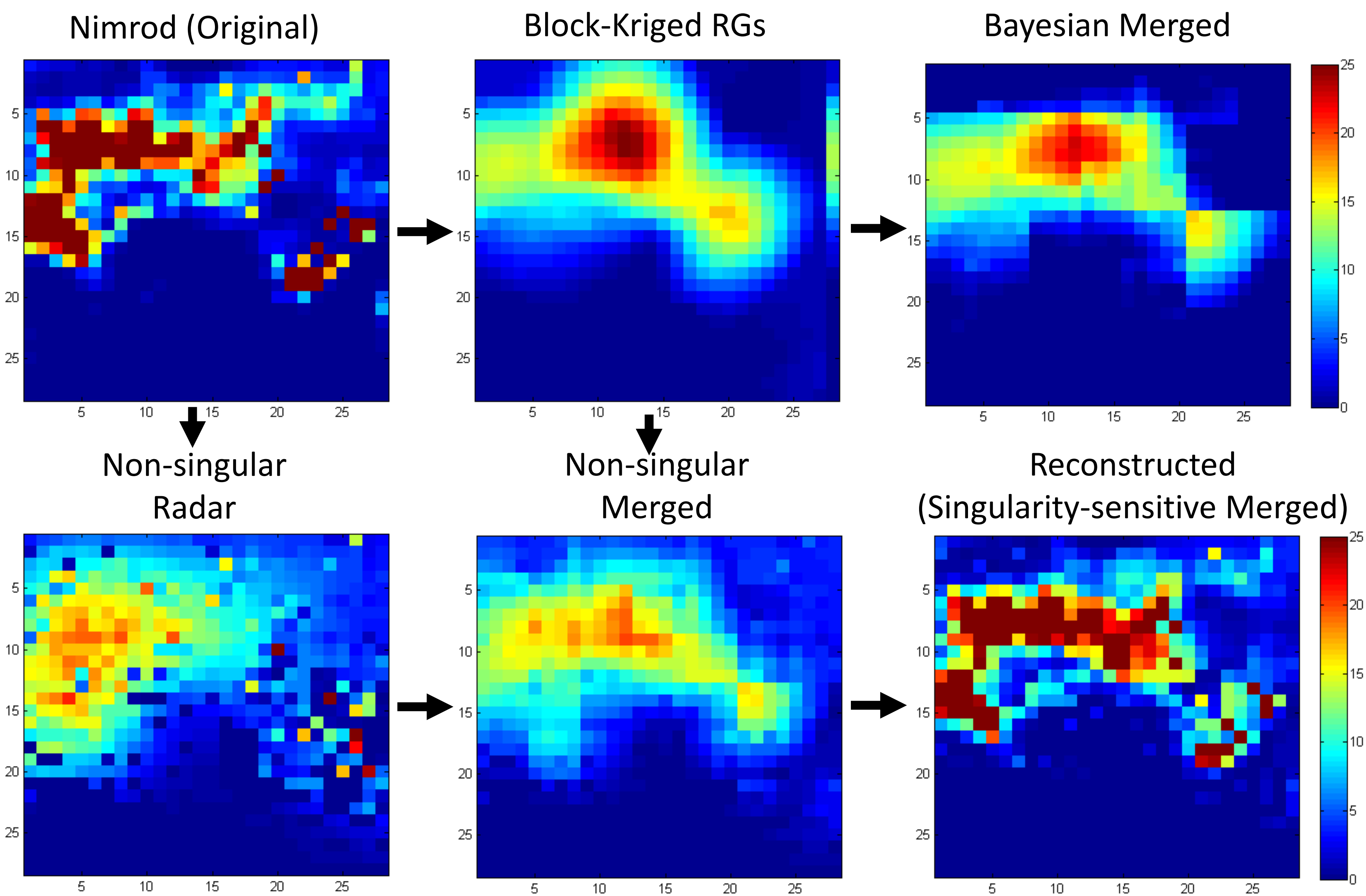
PRELIMINARY RESULTS

- *This storm led to flooding in North-West London*
- *The water company of the area wants to reconstruct this storm in order to improve the design of the sewer system (they are interested in appropriately estimating the return period of the storm)*
- *Original radar QPEs underestimate rainfall depths: when inputting the radar QPEs into the hydraulic model of the area, no flooding is observed.*
- *The Bayesian merging led to smoothening of the convective cells initially observed in the radar images (although the radar estimates were inaccurate, the shape of the convective cells was properly captured by it)*
- *Local Singularity Analysis was applied with the aim of better preserving the intense precipitation areas during the Bayesian merging*

Deployment of rain gauges, backgrounded by radar rainfall accumulations over the event period

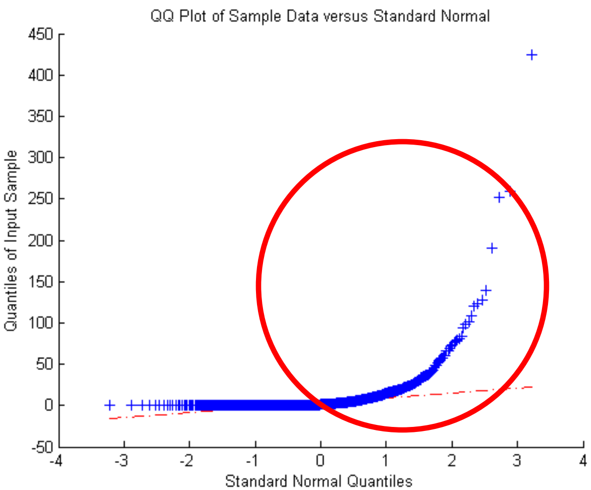


Images at each step of the Bayesian data merging with/without local singularity analysis

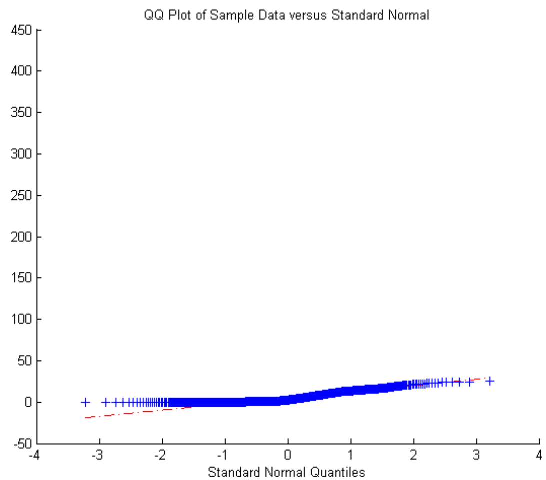


Quantile-quantile plots at each step of the Bayesian data merging with/without local singularity analysis

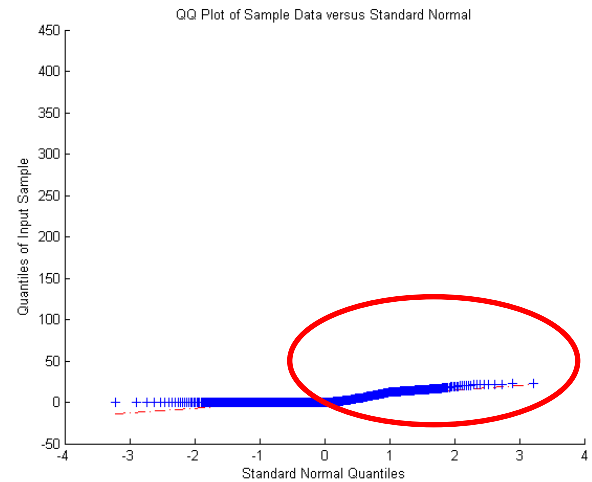
Nimrod (Original)



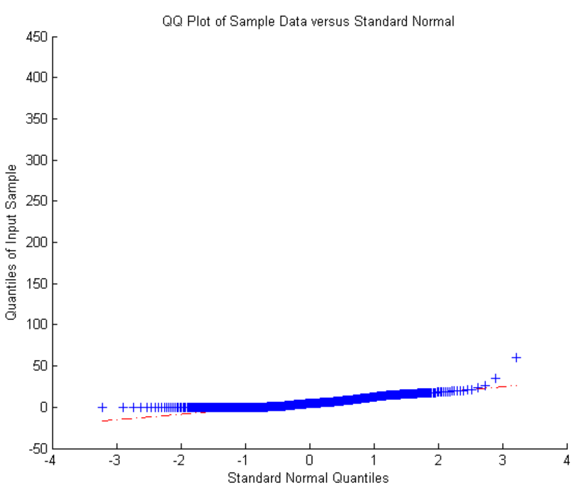
Block-Kriged RGs



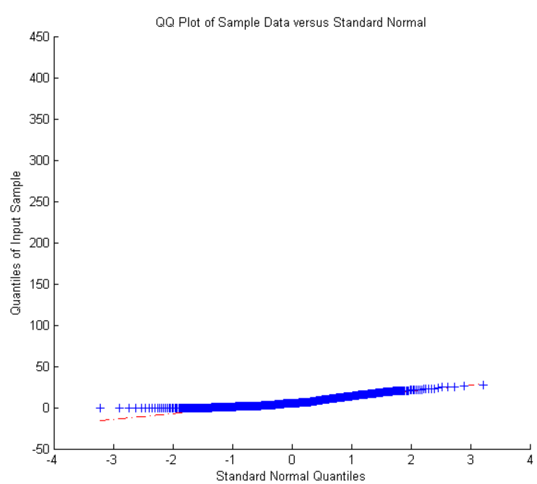
Merged



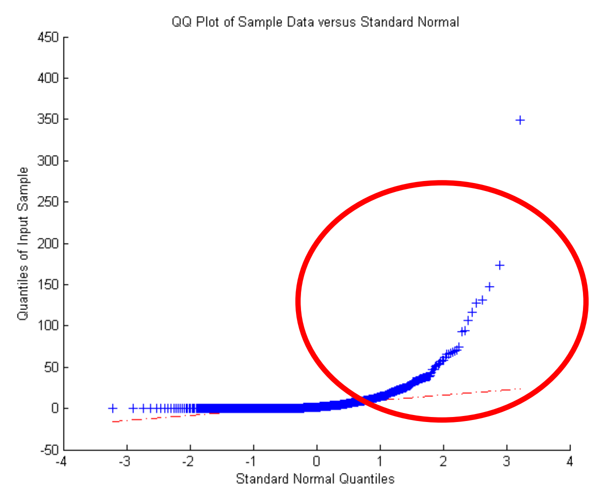
Non-singular Radar



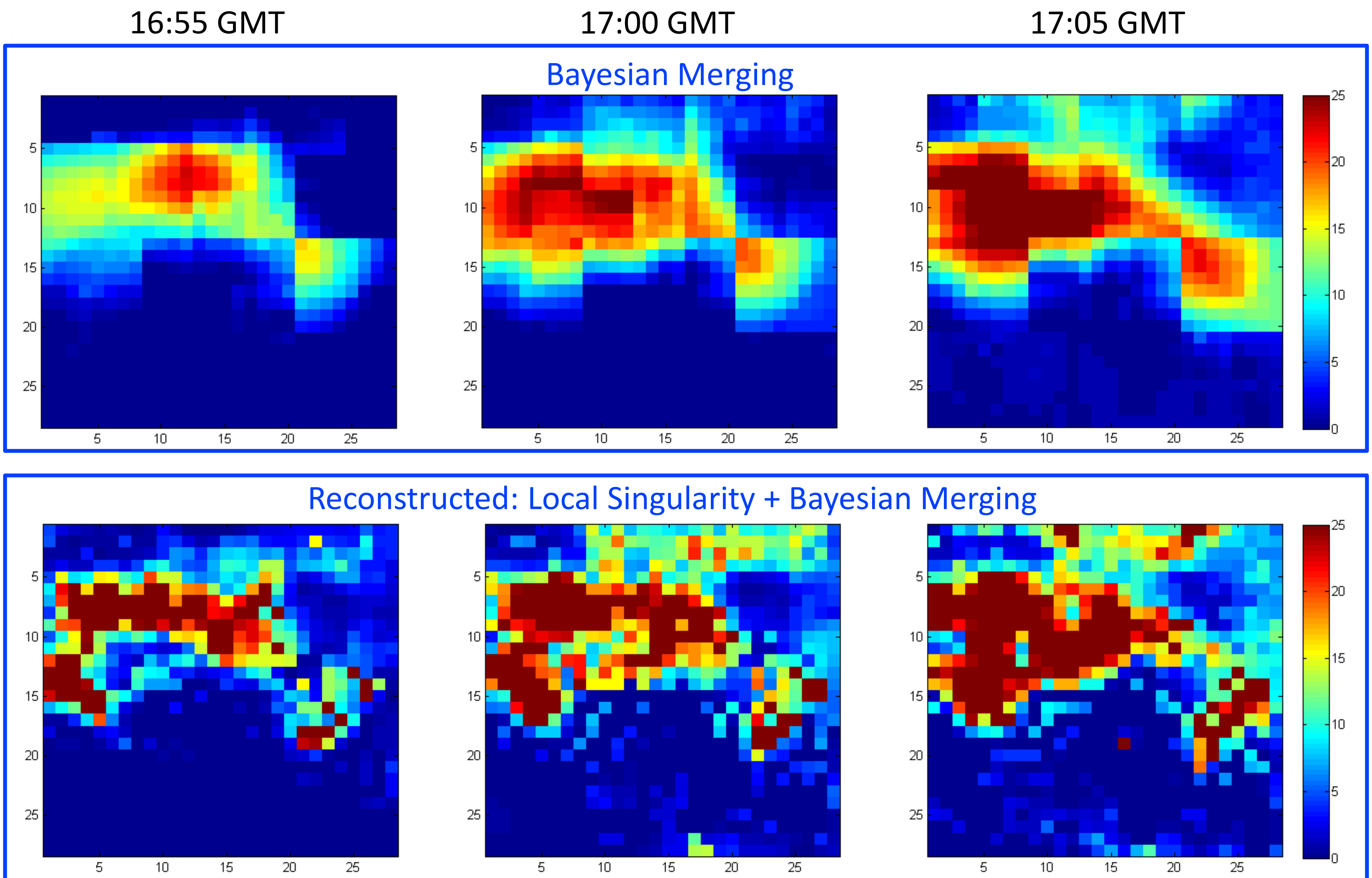
Non-singular Merged



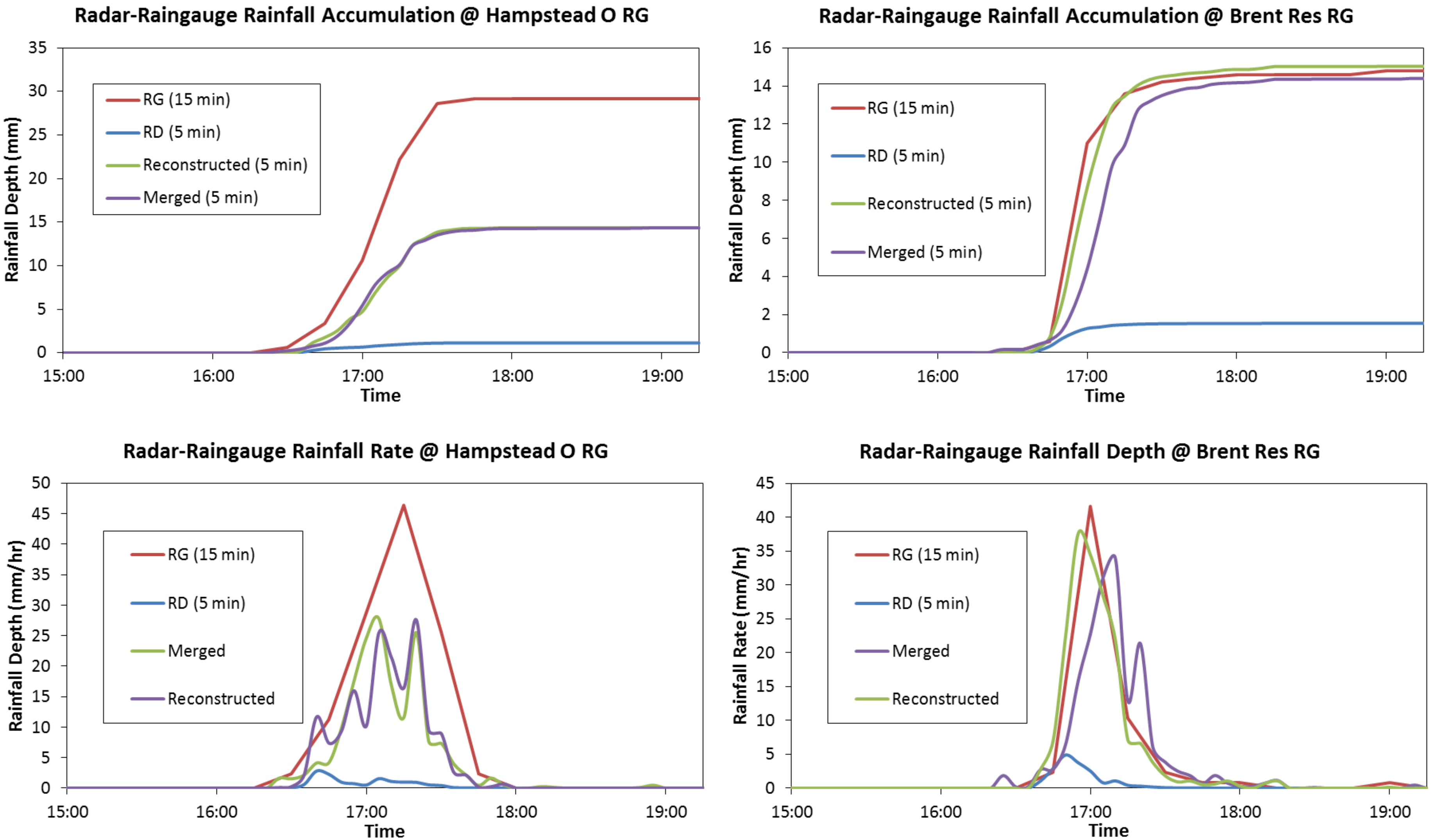
Reconstructed



Merged radar rainfall estimates with local singularity analysis are visually more realistic and show better temporal continuity



Comparison of the merged radar rainfall accumulations and rates against independent EA raingauge records



Conclusions & on-going research

- Local singularity analysis enables the decomposition of a geo-datum into 2 components: a local singularity exponent and a non-singular value, where the latter is of better normality than the original geo-datum. This facilitates the merging process since the existing merging techniques are developed mostly based upon the 1st and/or 2nd (statistical) moment approximation.
- It can be observed that local singularity analysis enables a visually more realistic and less smooth merged rainfall field; this is because the proposed methodology can recover the valuable singularity information that were smoothed off in the conventional merging process.
- In our case study, both the original and the "singularity-sensitive" Bayesian data merging techniques were found to effectively reduce the cumulative radar rainfall bias (as compared to the raingauge records), but the latter can better capture the local peaks in instantaneous rainfall rate profiles.
- The proposed methodology is now being used to re-construct a number of storm events observed in Edinburgh (UK) during the Summer of 2011 and for which high density raingauge rainfall and sewer flow data are available.

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THANK YOU FOR YOUR ATTENTION

Appendix

The impact of local singularity analysis on radar-raingauge error (or bias) field construction

Obtaining merged estimates using Kalman filter

$$y^{Merged} = y^{RD} + \boldsymbol{K}\,(y^{G} - y^{RD})$$

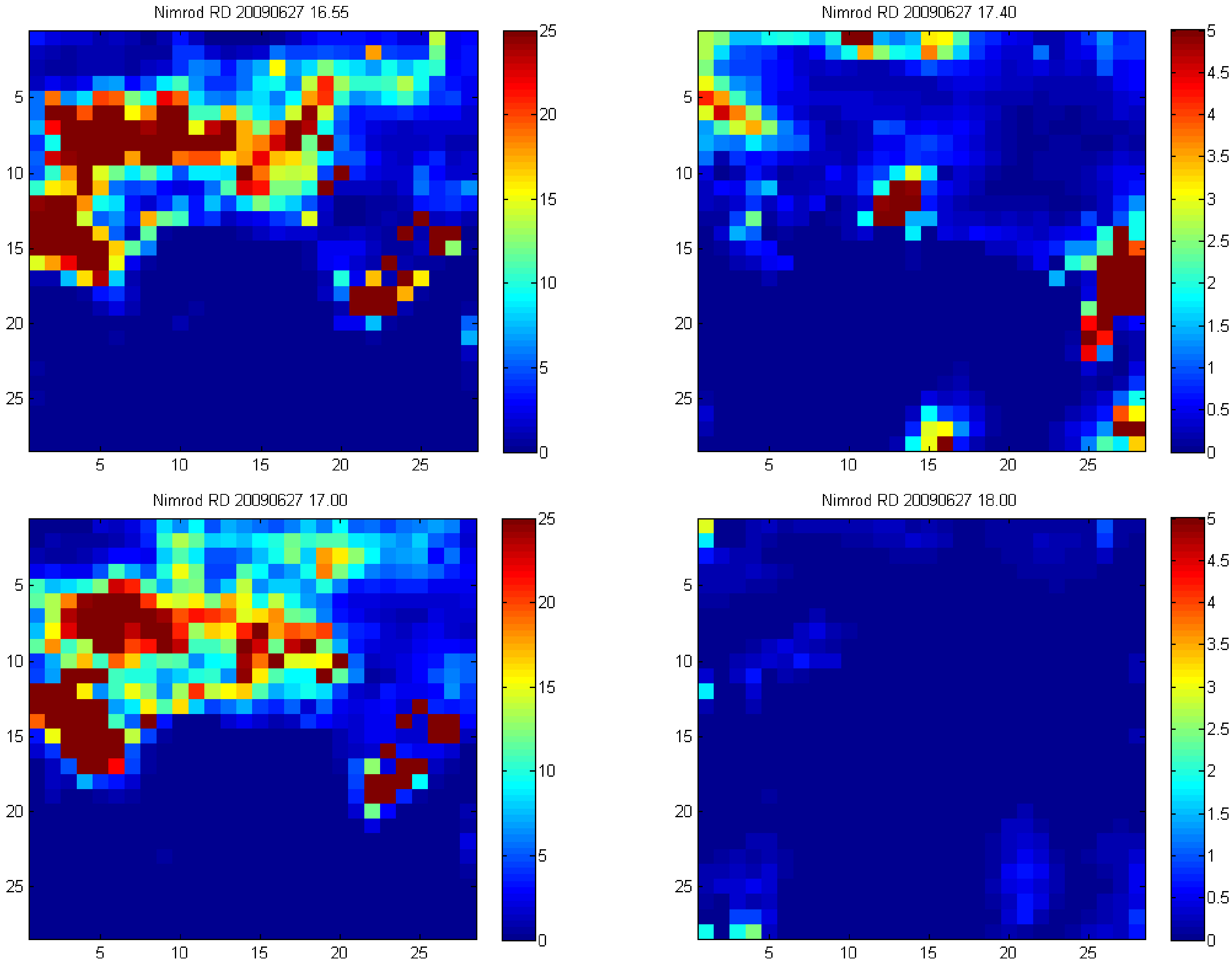
$$\boldsymbol{K} = C\varepsilon\,(C\varepsilon + C\varepsilon_{G})^{-1}$$

Kalman Gain is the function of the covariances of estimation errors (uncertainty) of BK interpolation (y^G) and RD-BK bias ($y^G - y^{RD}$).

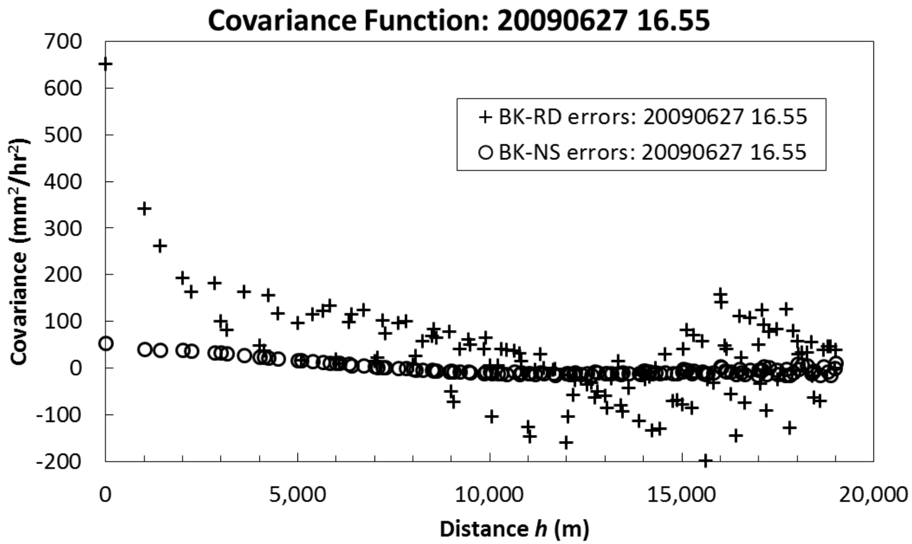
If $\boldsymbol{C\varepsilon} \gg C\varepsilon_G$, the BK-RG estimates ($y^G$) are trusted more than RD estimates (y^{RD});
If $\boldsymbol{C\varepsilon} \ll C\varepsilon_G$, the RD estimates ($y^{RD}$) are trusted more than BK-RG estimates (y^G).

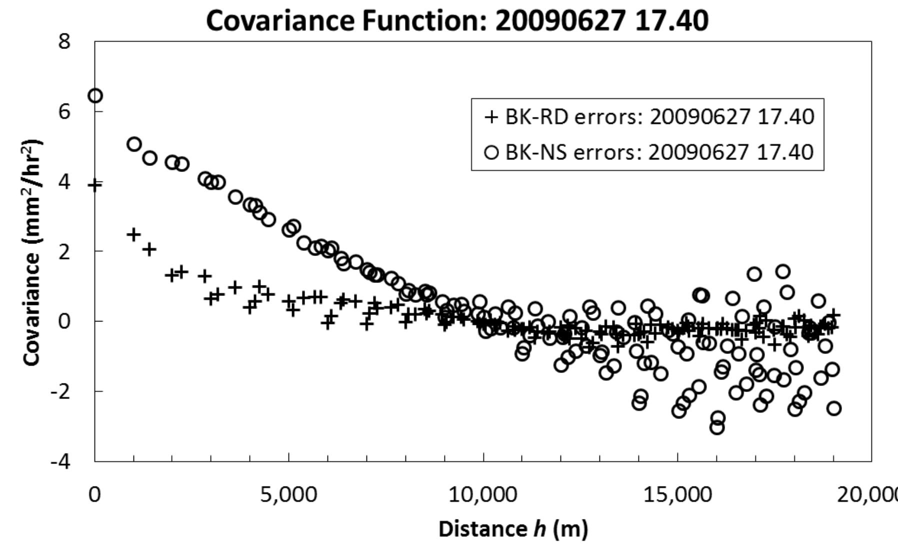
The magnitude of $\boldsymbol{C\varepsilon}$ and its estimation will largely affect the quality of data merging!

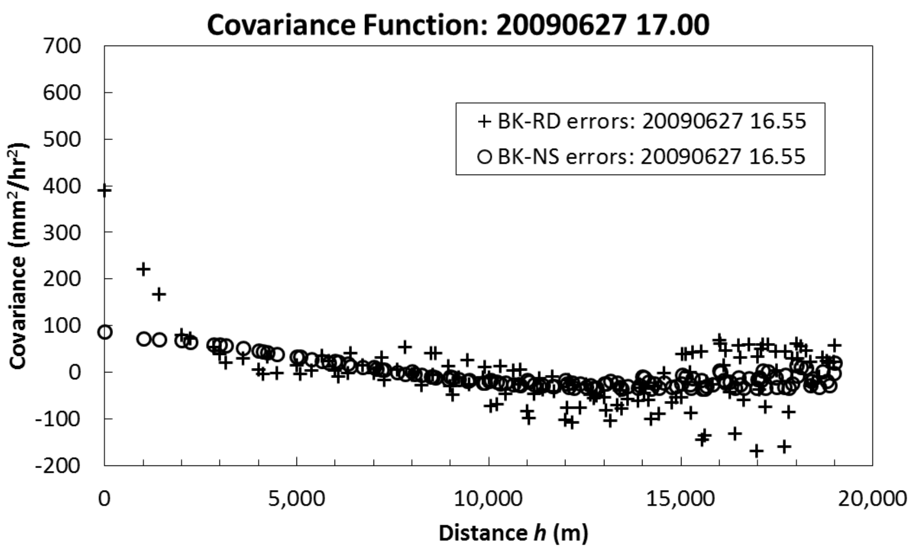
Radar data at 4 different time steps are used to assess the impact of singularity extraction on covariance of radar-raingauge errors (bias)

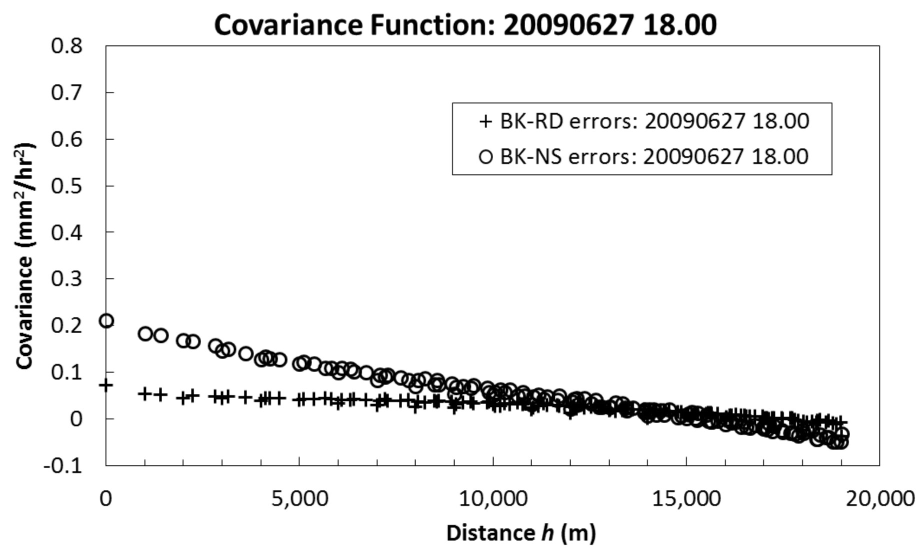


Magnitude of the covariance of BK-RD errors can be largely decreased in “extreme” cases.



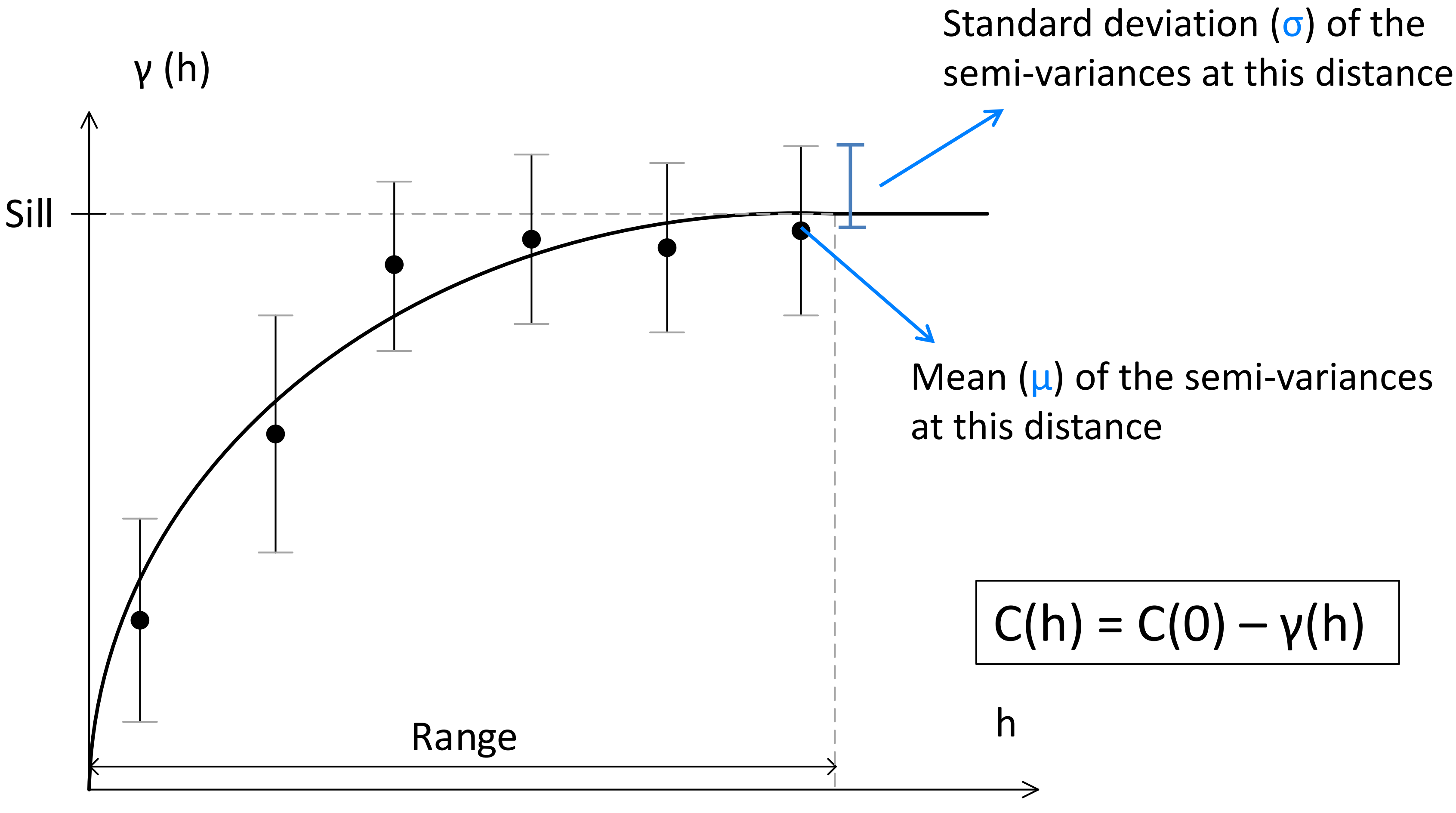






Coefficient of Variation (CV) of variogram/covariance estimation

Coefficient of Variation (CV) = σ / μ



$$C(h) = C(0) - \gamma(h)$$

The estimation uncertainty of variogram estimation of radar-raingauge errors can be reduced in “extreme” cases.