Probabilistic nowcasting for short-term flow prediction in urban areas

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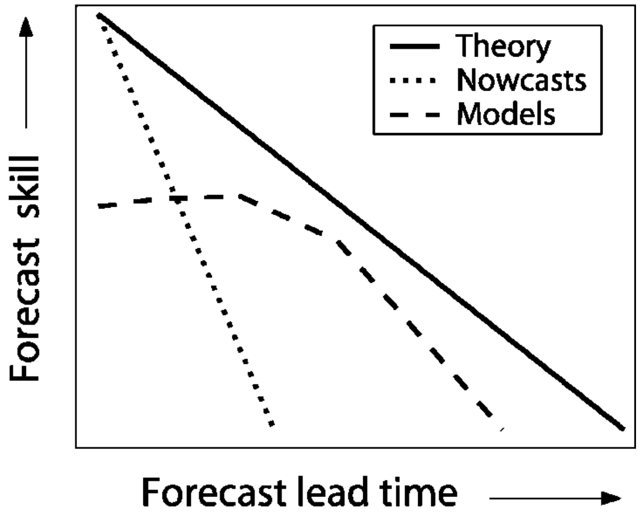
Outline

- Precipitation forecasting
- Uncertainties in radar-based forecasting methods
- Quantifying errors in radar rainfall measurements
- Radar rainfall ensembles and applications in urban hydrology
- Probabilistic radar-based forecasts and applications in urban hydrology
- Concluding comments

Precipitation Forecasting

• **Radar advection-based methods (radar nowcasting)**. Start with high initial skill, which decreases with forecasting lead time as growth/decays processes are not resolved.

• **Numerical Weather Models** (**NWP**) take into account growth/decay processes, but they have a lower initial skill at the beginning of the forecast. However, the skill remains more or less constant with forecasting lead time.

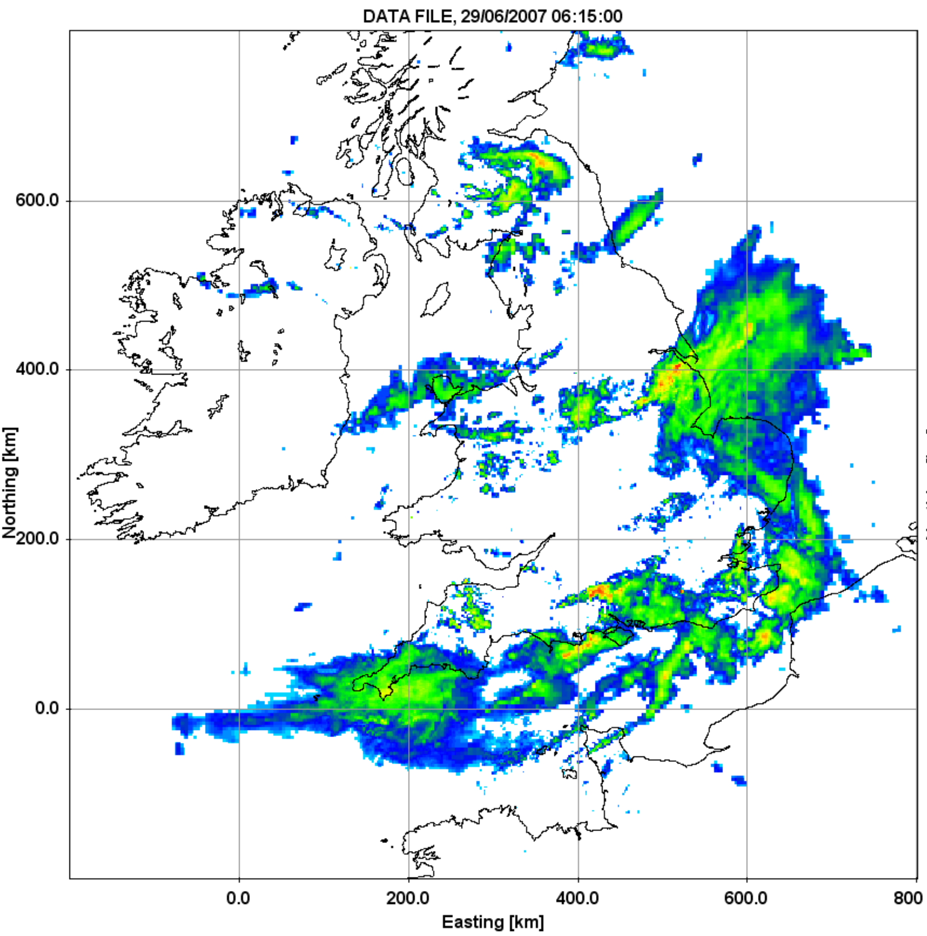


Austin, et al., (1987); Golding, (1998); Lin et al., (2005)

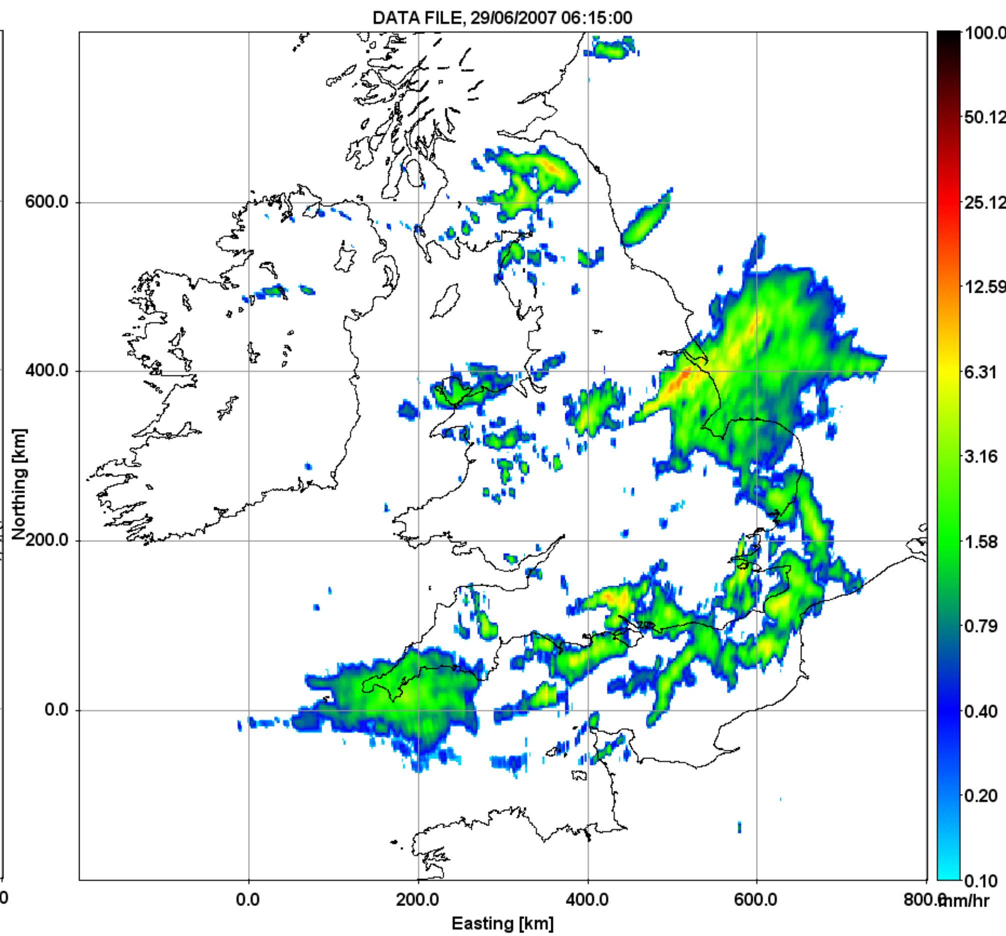
Nowcasting Methods:

- Tracking radar echoes by correlation (TREC, COTREC)
- Tracking of rain cell centroids
- Use of NWP advection techniques
- VET, Optical flow techniques
- Blending techniques (Nowcasting+NWP forecasts): STEPS (Short-term ensemble prediction system)

Nowcasting (deterministic forecast using STEPS with now NPW blending)

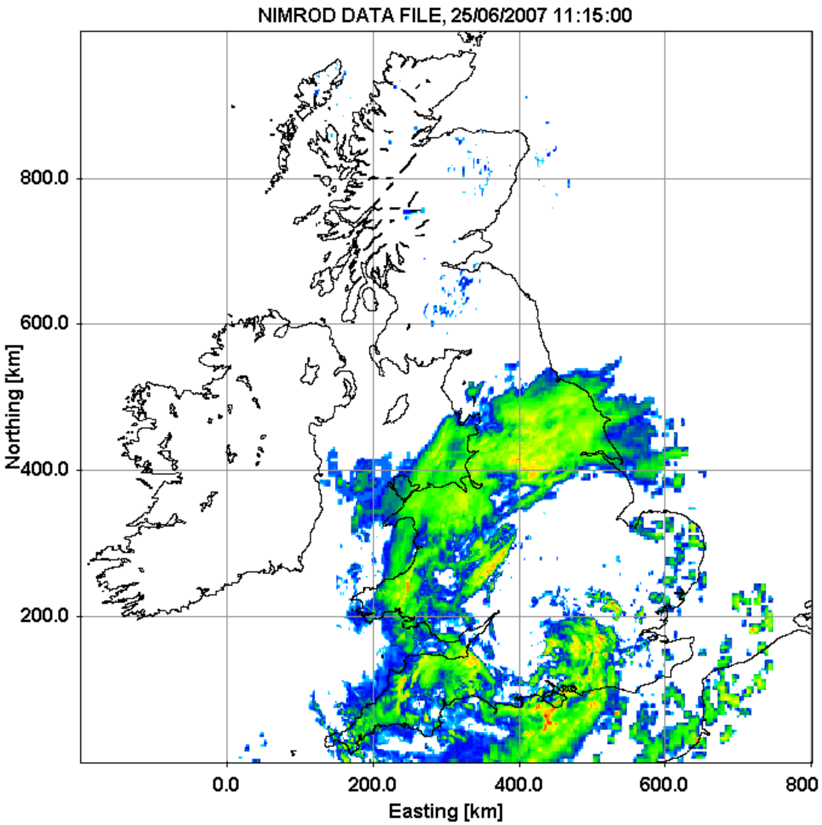


Radar

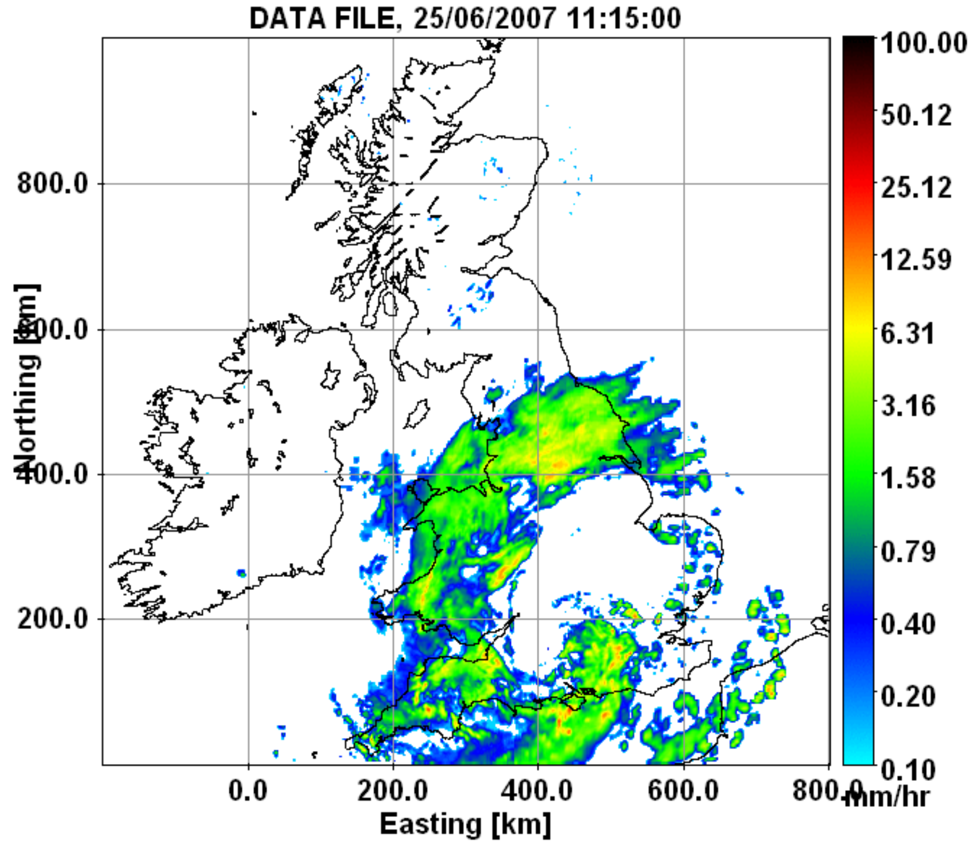


Nowcasting

Nowcasting (deterministic forecast using STEPS with now NPW blending)



Radar



Nowcasting

Uncertainties in nowcasting methods

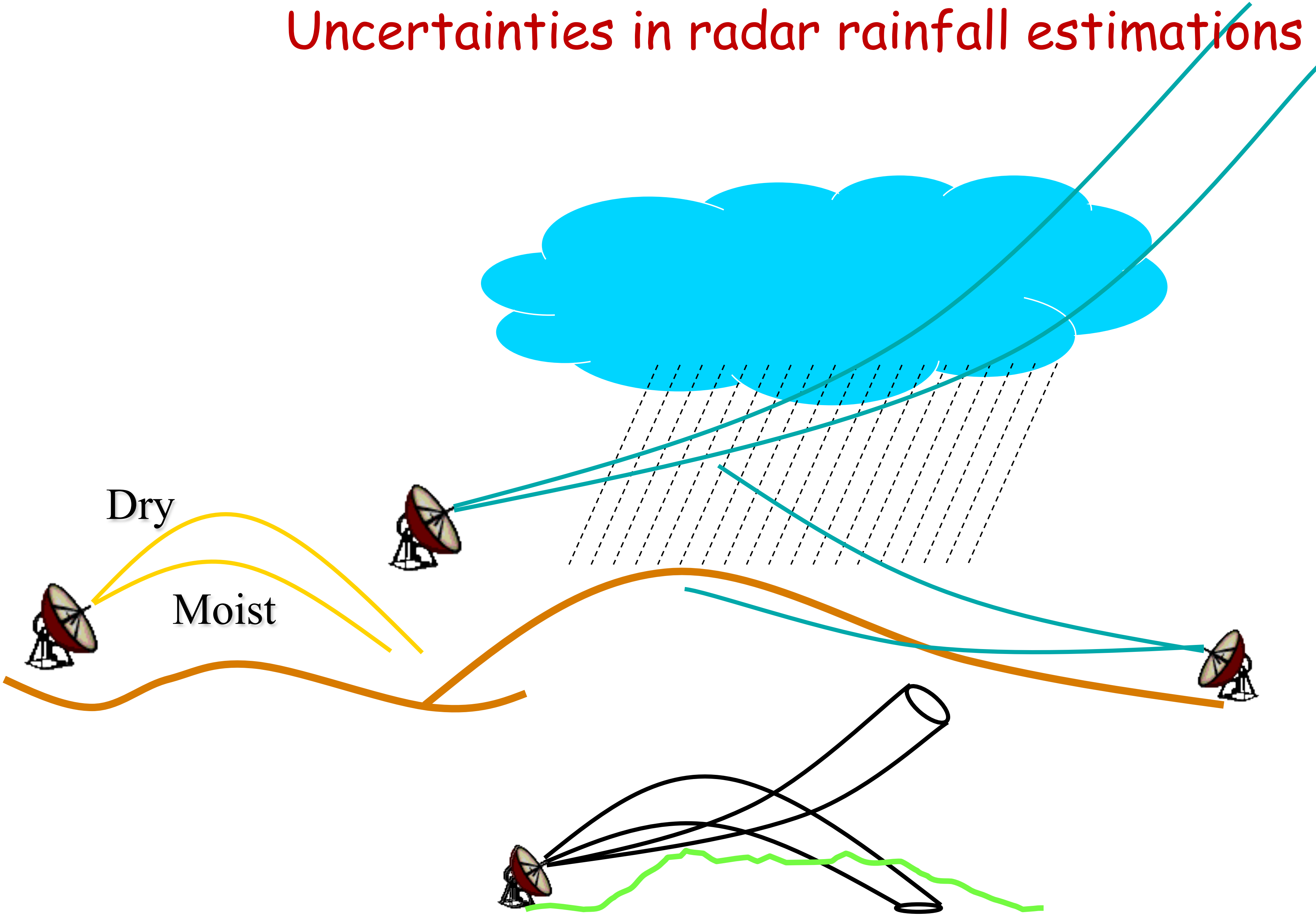
Can be broadly classified in (after Foresti & Seed, 2014):

- **Uncertainties in radar rainfall estimations**
- Uncertainties in the nowcasting model (e.g. TREC, COTREC, VET, tracking rain cell centroids, OFC)
- Uncertainties due to the temporal variation of the diagnosed velocity field during the forecast. Worst after 2-3 hr.
- Uncertainties in the temporal evolution of rainfall. Growths & decays rainfall processes not modelled.

Uncertainties in radar rainfall estimations

1. Radar beam overshooting the shallow precipitation at long ranges. Radar beam is at several kilometers above the ground at long ranges.
2. Low level evaporation of precipitation beneath the radar beam
3. Orographic enhancement above hills which goes undetected beneath
4. Vertical profile of reflectivity. There is a variation of reflectivity in the vertical. Uncertainty in the extrapolation of the reflectivity measured aloft to the ground.
5. Overestimation of precipitation in the melting layer (bright band). If the radar beam intercepts the ML, the result is an increase of power reflected back to the radar. Errors can be up to a factor of 5 in the bright band.
6. Changes in the Drop Size Distribution *N(D)*. This affects the *Z-R* relationship.
7. Partial beam blocking. Hills close to the radar block the beam path. This blocking can be total or partial.
8. Representativeness errors. Radar scans with a given spatial and temporal resolution
9. Attenuation by hydrometeors and atmospheric gases. Affects higher frequencies (e.g. C-band=5GHz or X-band = 10GHz).
10. Clutter (ground, sea, wind farms). Non-meteorological echoes that have to be identified and removed.
11. Anomalous propagation of the radar beam due to changes in the atmospheric conditions. The path of the beam departs from standard propagation and in some cases it is bent towards the earth surface producing ground echoes.
12. Radar miscalibration. This can bias the rainfall estimation.

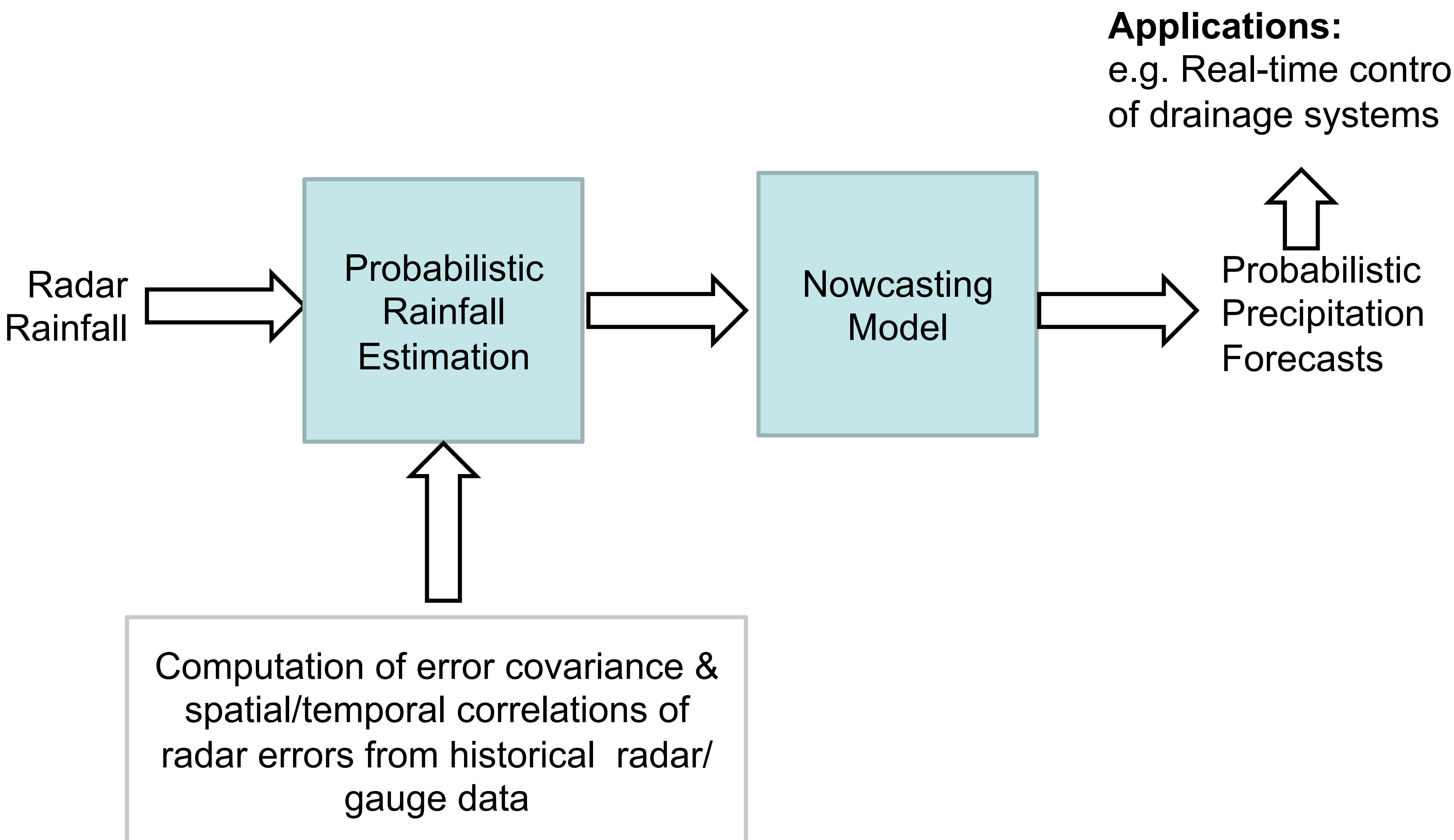
Uncertainties in radar rainfall estimations



Quantifying Radar Residual Errors

- However, despite significant progress to correct and adjust radar rainfall estimates, residual errors often remain
- So, what can we do about it? -> The use of probabilistic approaches to characterise the radar rainfall error:
  - Evaluation of individual sources of error
  - Computation of error covariance
- Several approaches available e.g. Ciach et al (2007), Germann et al (2009), Villarini et al. (2014), etc.

Quantifying the uncertainty in rainfall measurement in Nowcasting



Computation of Error Covariance (Germann et al, 2009)

$$\hat{\varepsilon}_{t,xk} = 10\log\left(G_{t,xk} / R_{t,xk}\right)$$

$$\mu_k \equiv \mathrm{E}\left\{\varepsilon_{xk}\right\}$$

$$\mathbf{C}_{kk} \equiv \mathrm{Var}\left\{\varepsilon_{xk}\right\}$$

$$\mathbf{C}_{kl} \equiv \mathrm{Cov}\left\{\varepsilon_{xk}, \varepsilon_{xl}\right\}$$

How to generate the perturbations?

$$\boldsymbol{\delta}_{t,i} = \boldsymbol{\mu} + \mathbf{L}\mathbf{y}_{t,i} \qquad \mathbf{y}_{t,i} = N\left(\mathbf{0}, \mathbf{I}\right)$$

$$\mathbf{C} \equiv \mathbf{L}\mathbf{L}^T$$

Taking into account the temporal correlation of the error:

$$\boldsymbol{\delta}'_{t,i} = \mathbf{L}\mathbf{y}_{t,i} - a_1\boldsymbol{\delta}'_{t-1,i} - a_2\boldsymbol{\delta}'_{t-2,i}$$

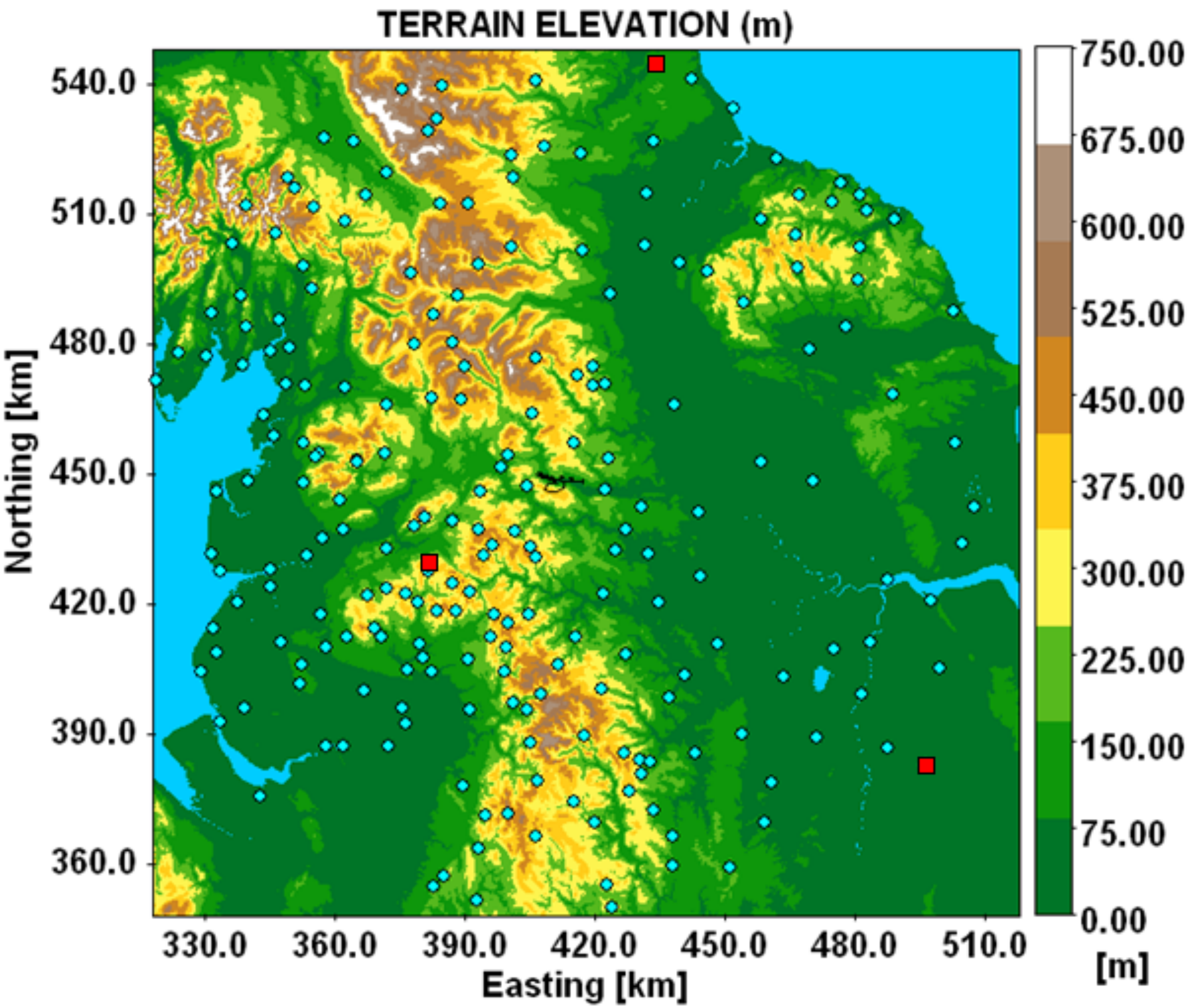
$$\boldsymbol{\delta}_{t,i} = \boldsymbol{\mu} + v\boldsymbol{\delta}'_{t,i}$$

Finally, the perturbations are generated using:

$$10\log\left\lfloor \boldsymbol{\Phi}_{t,i} \right\rfloor = 10\log\left\lfloor \mathbf{R}_{t,i} \right\rfloor + \boldsymbol{\delta}_{t,i}$$

Germann *et al*. (2009), QJRMS

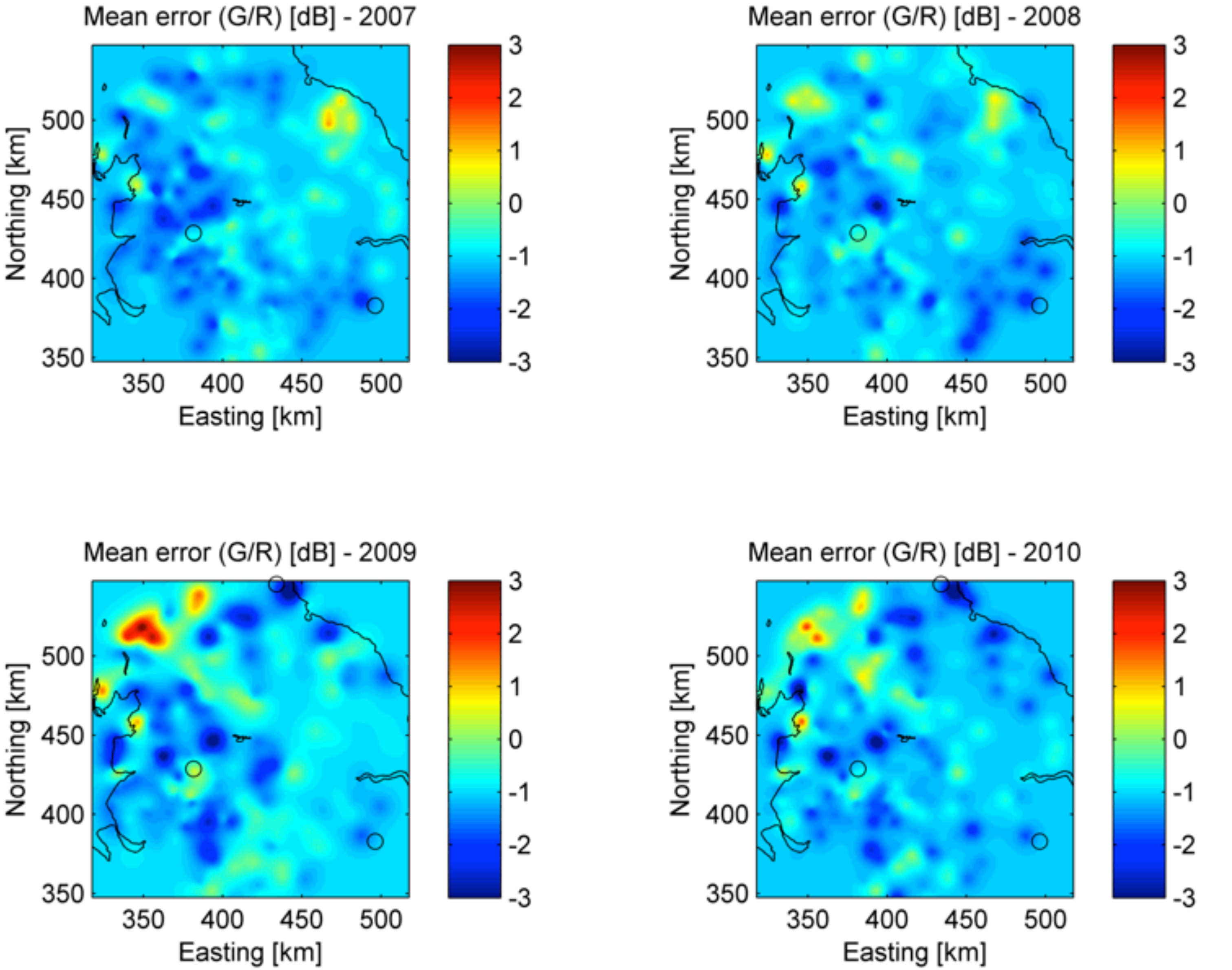
Study Area



- >200 tbr EA raingauges
- UKMO radars @ 1km/ 5min
- Urban catchment:
  - 15 flow monitors,
  - 7 depth monitors
  - 4-6 raingauges

Data sets: 2007-2009

Mean error (G/R) in dB

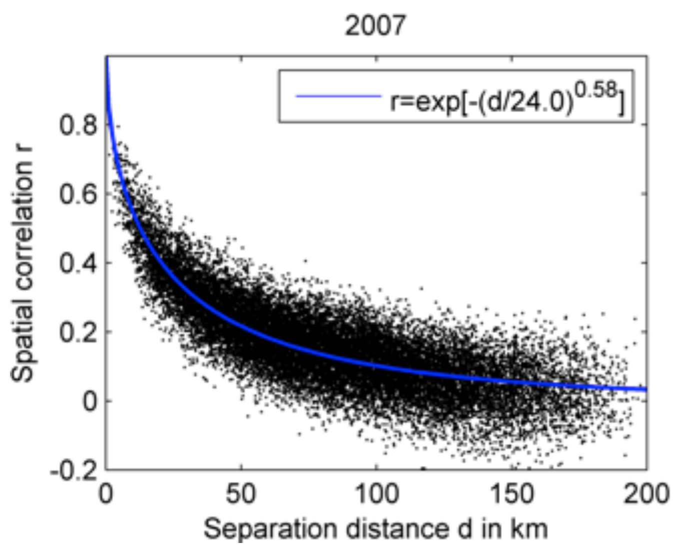


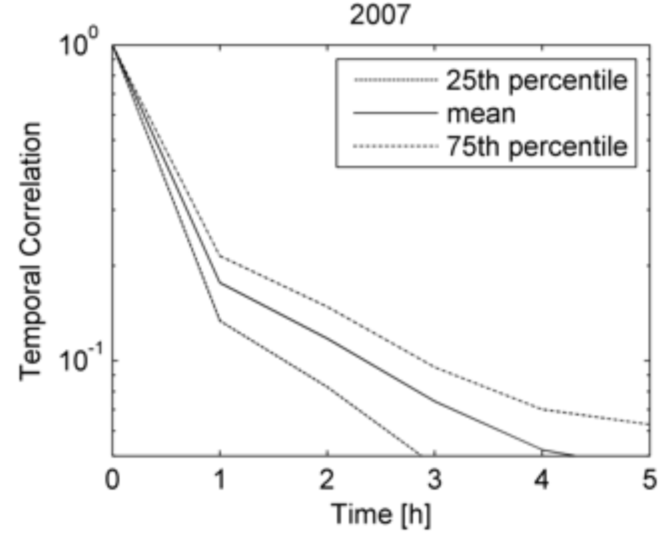
Spatial and temporal correlations of the radar residual errors

Spatial correlation

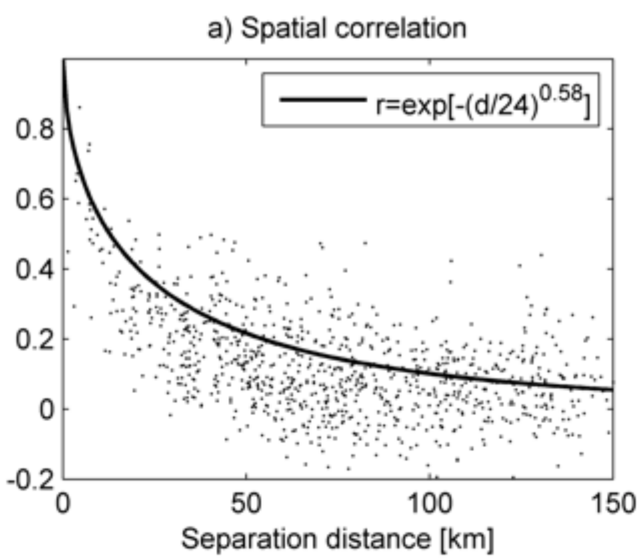
Temporal correlation

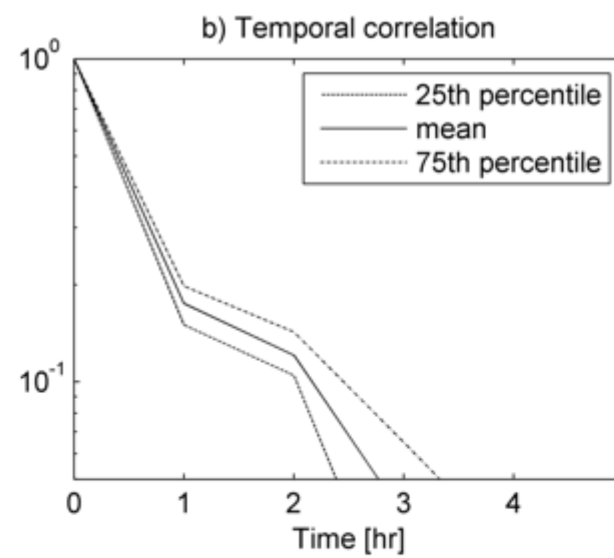
Measured



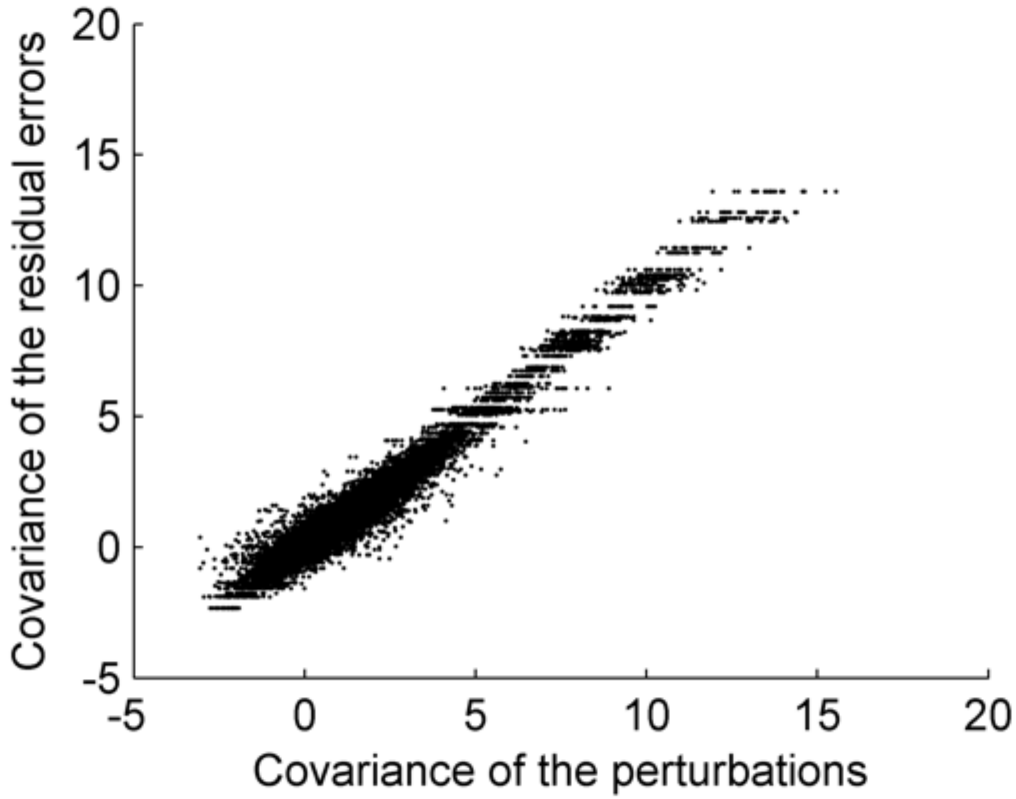


Simulated (perturbations)

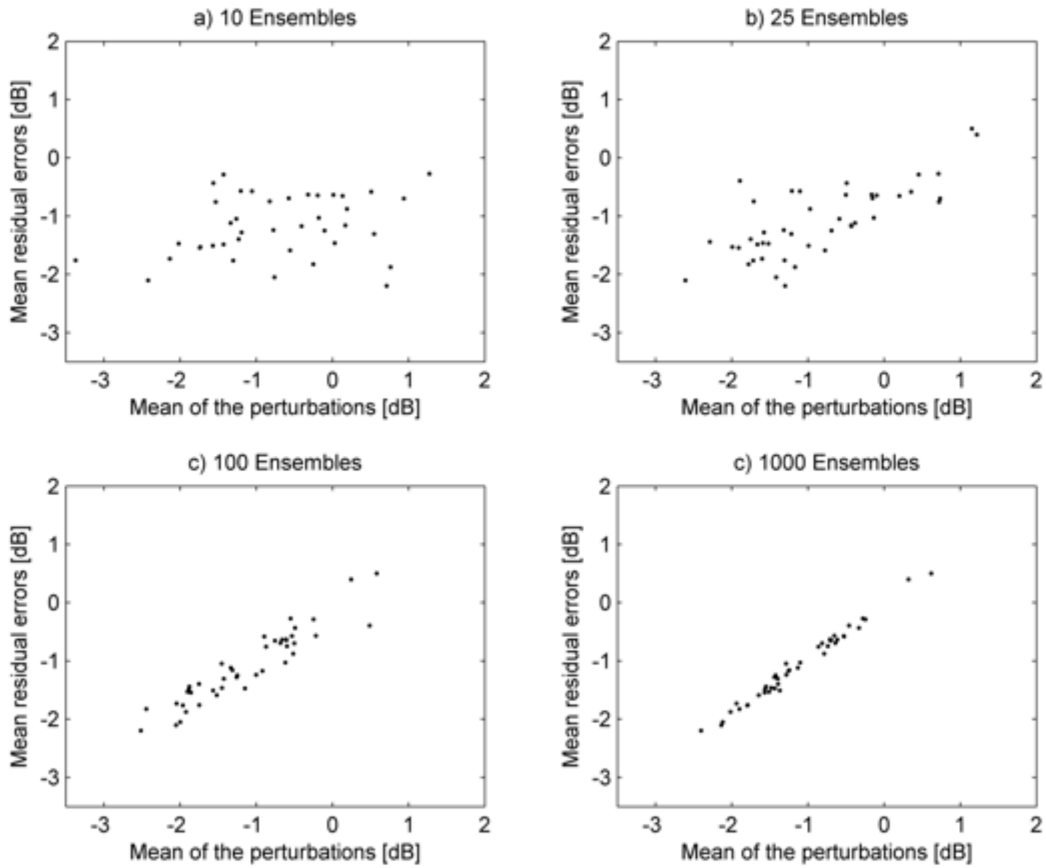




Covariances of the perturbations & residual errors

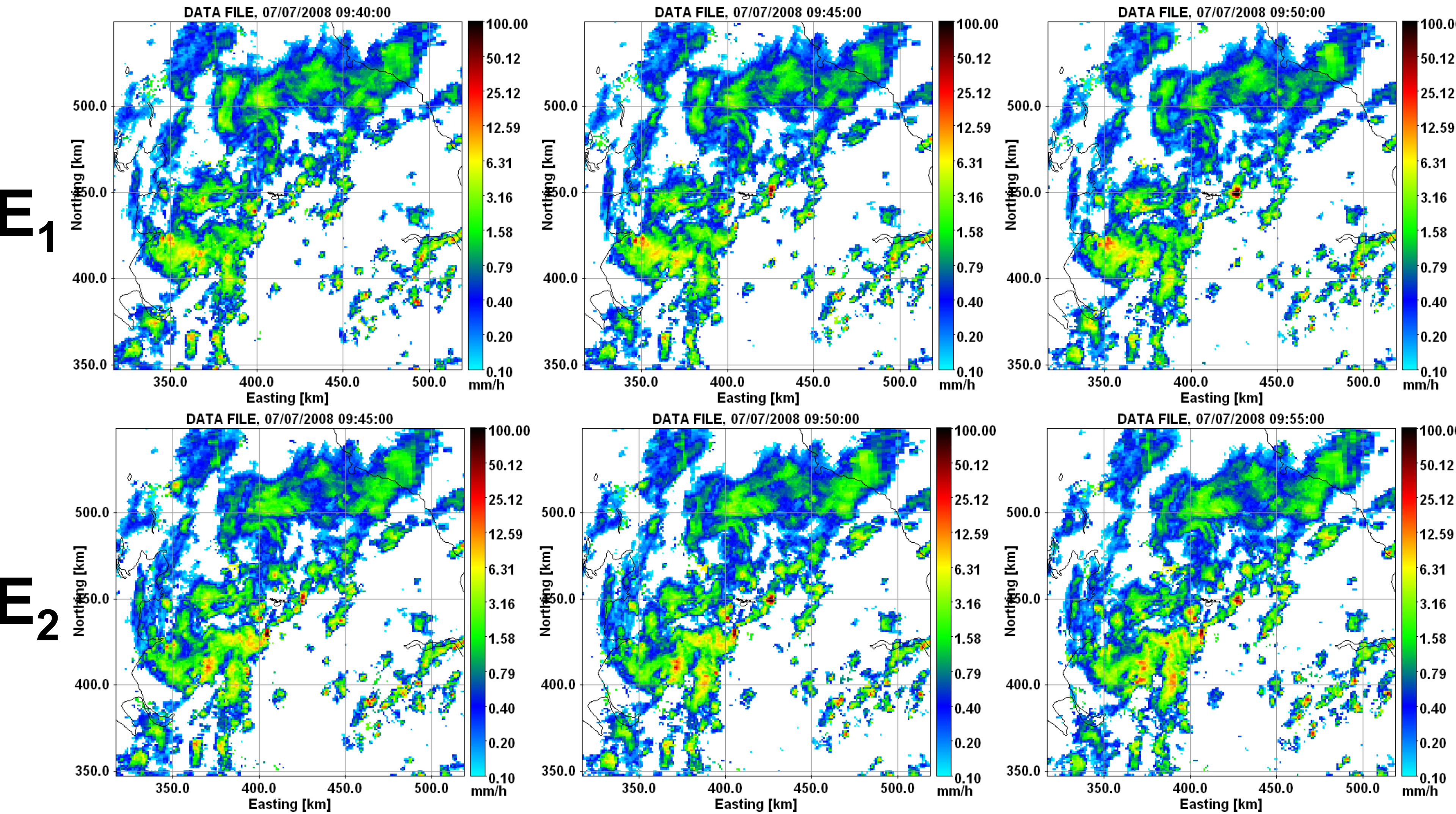


How many ensembles?

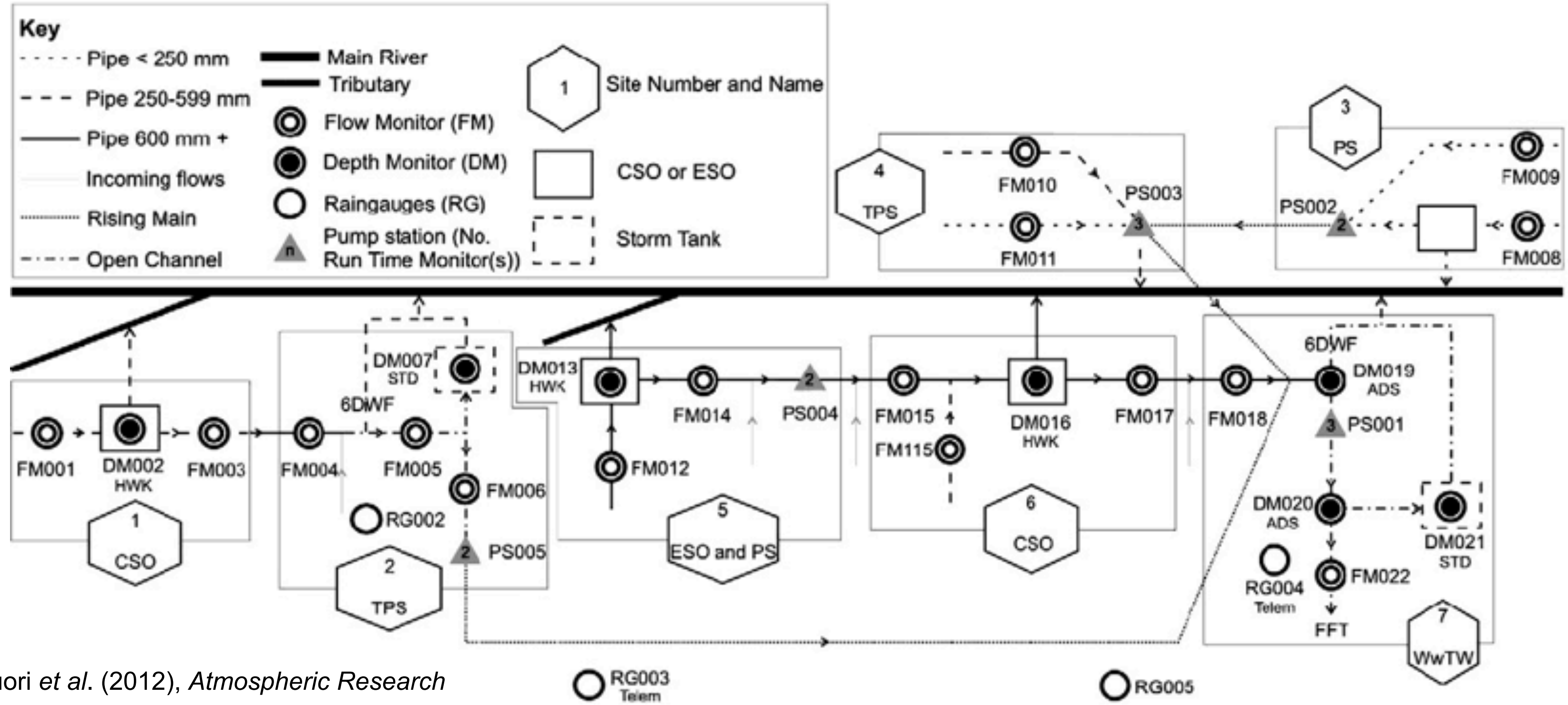


Example of radar ensembles ($\Phi_{t,i}$)

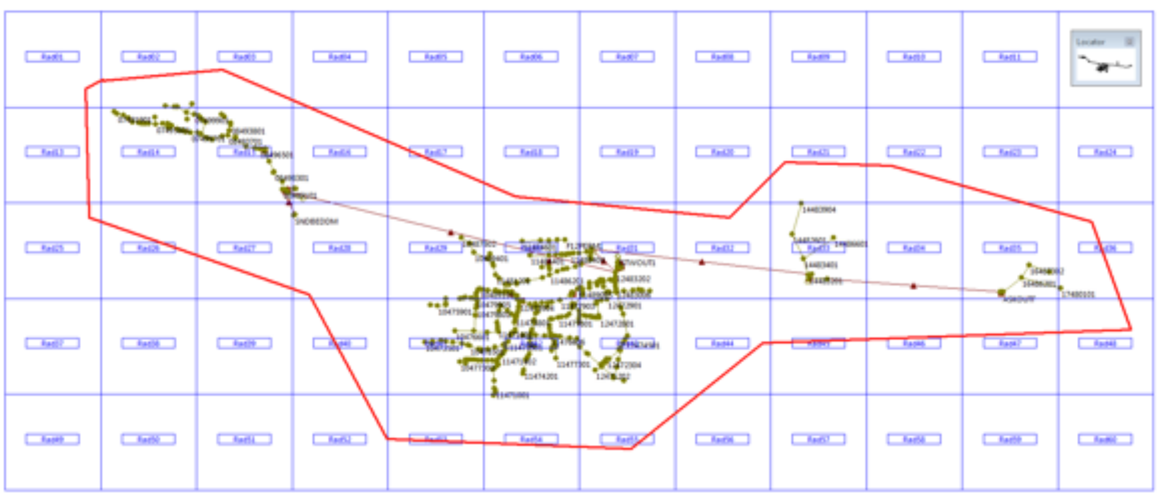
time →



Testing radar rainfall ensembles in urban catchment



Liguori *et al*. (2012), *Atmospheric Research*



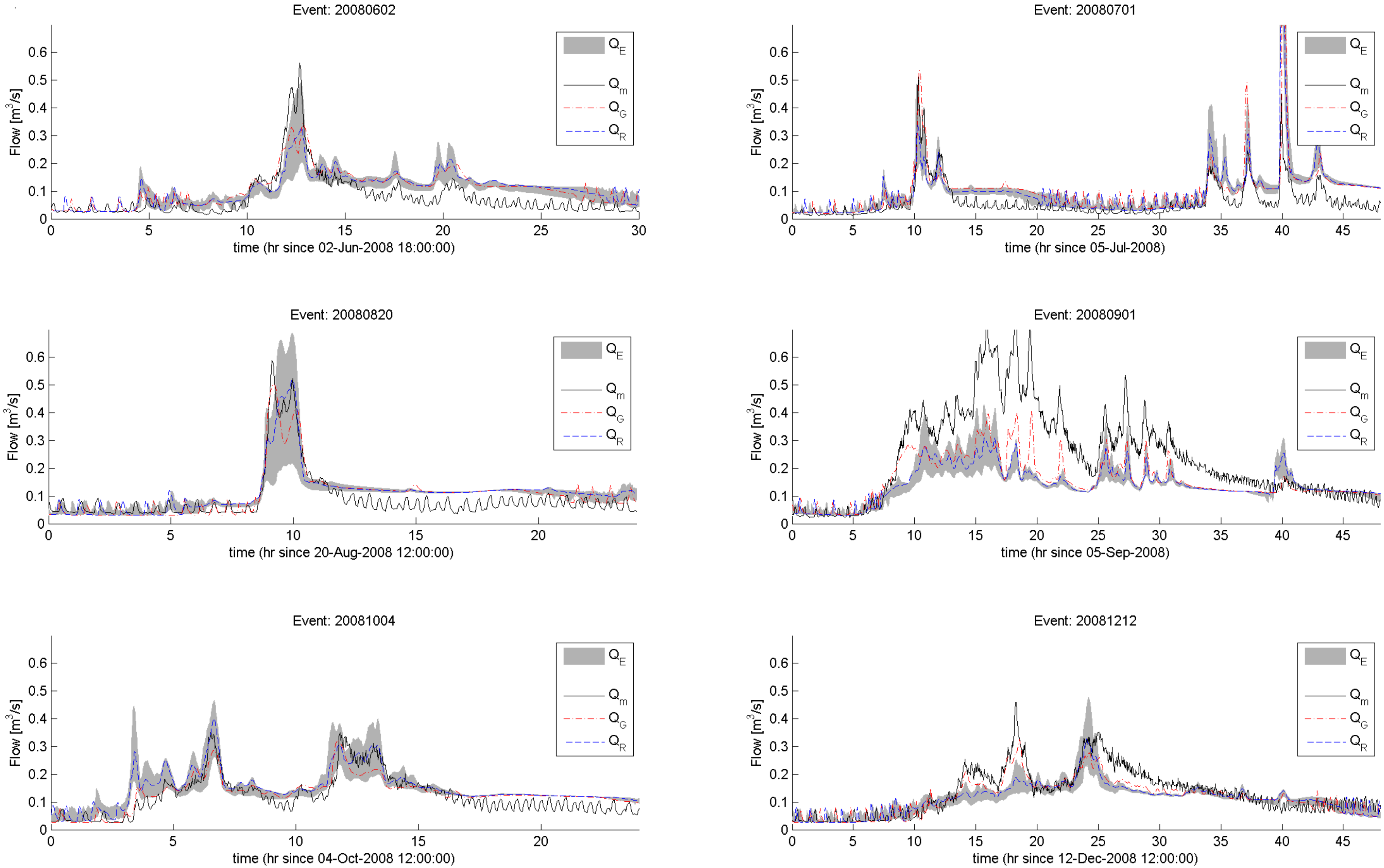
Urban catchment:

- Area ~11km^2 (0.71km^2 impermeable, 10.35km^2 pervious)
- 432 inlet points/pipe connections
- 444 sewer conduits
- 13 pumps
- 134 sub-catchments
- 60km of sewers

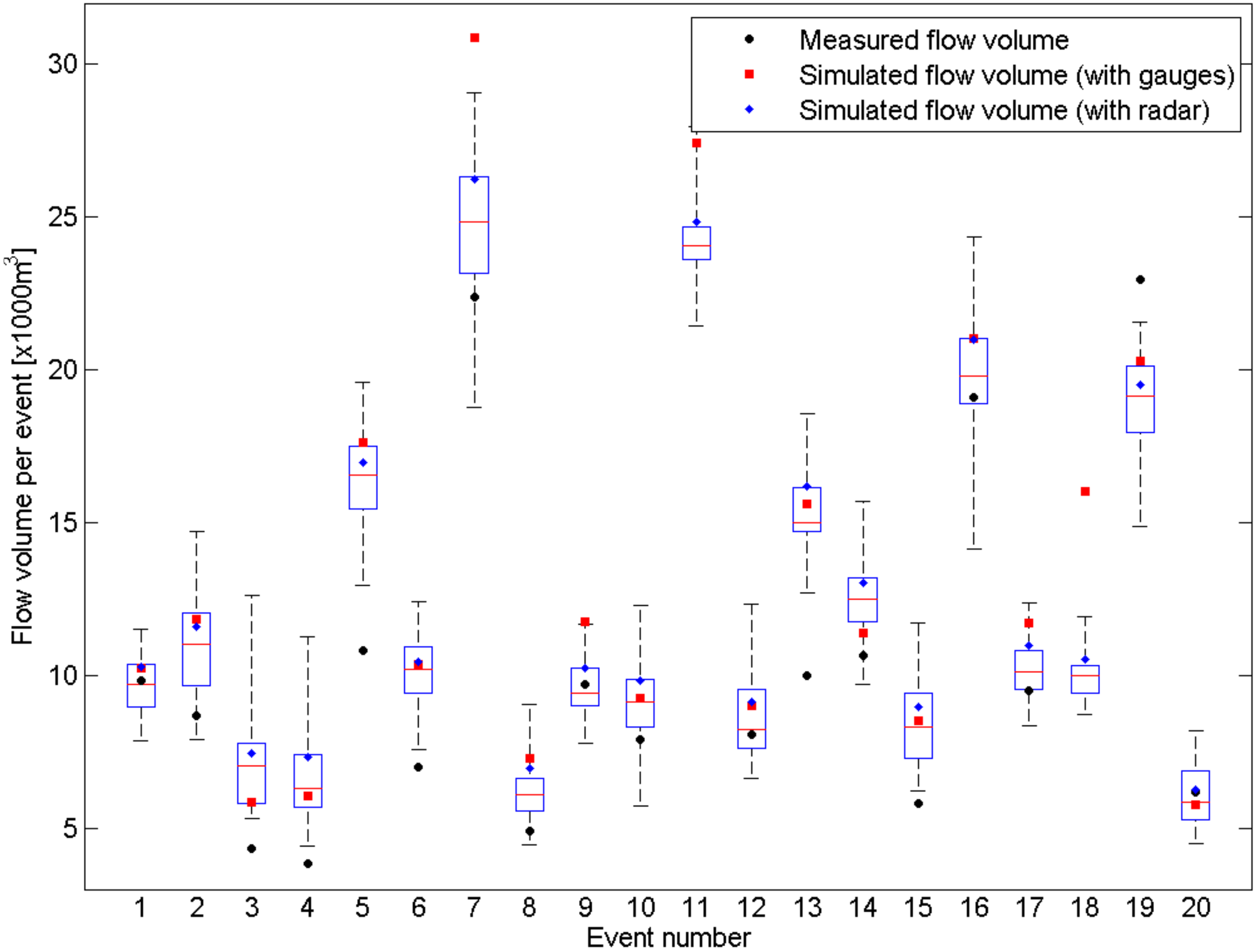
Summary of analysed events

Event	Date	Rain depth (mm)	Duration (hr)	Peak flow (litres/s)	Flow volume ($1000m^3$)	Storm Type
1	20080501 0100	10.2	8	558	9.8	S
2	20080602 2200	18.1	20	562	8.6	S
3	20080626 1200	13.3	10	289	4.3	C
4	20080701 1900	6.1	7	294	3.8	C
5	20080705 0700	25.5	37	511	10.8	C
6	20080707 0900	10.4	8	511	7.0	C
7	20080709 1500	37.1	62	482	22.4	C
8	20080729 0400	11.0	4	588	4.9	C
9	20080812 0600	19.2	22	425	9.7	C
10	20080820 1600	9.5	7	590	7.9	C
11	20080905 0500	57.3	36	758	42.1	C
12	20080901 1800	13.1	29	817	8.1	C
13	20080903 0000	10.9	38	268	10.0	C
14	20081004 1200	18.8	16	359	10.6	S
15	20081014 0500	12.1	15	279	5.8	S
16	20081108 0000	30.9	48	578	19.1	S
17	20081202 0000	12.7	31	203	9.5	S
18	20081204 0000	20.3	25	187	16.0	S
19	20081212 1200	28.5	32	460	22.9	S
20	20081219 1200	10.7	10	339	6.2	S

Ensemble flow simulations



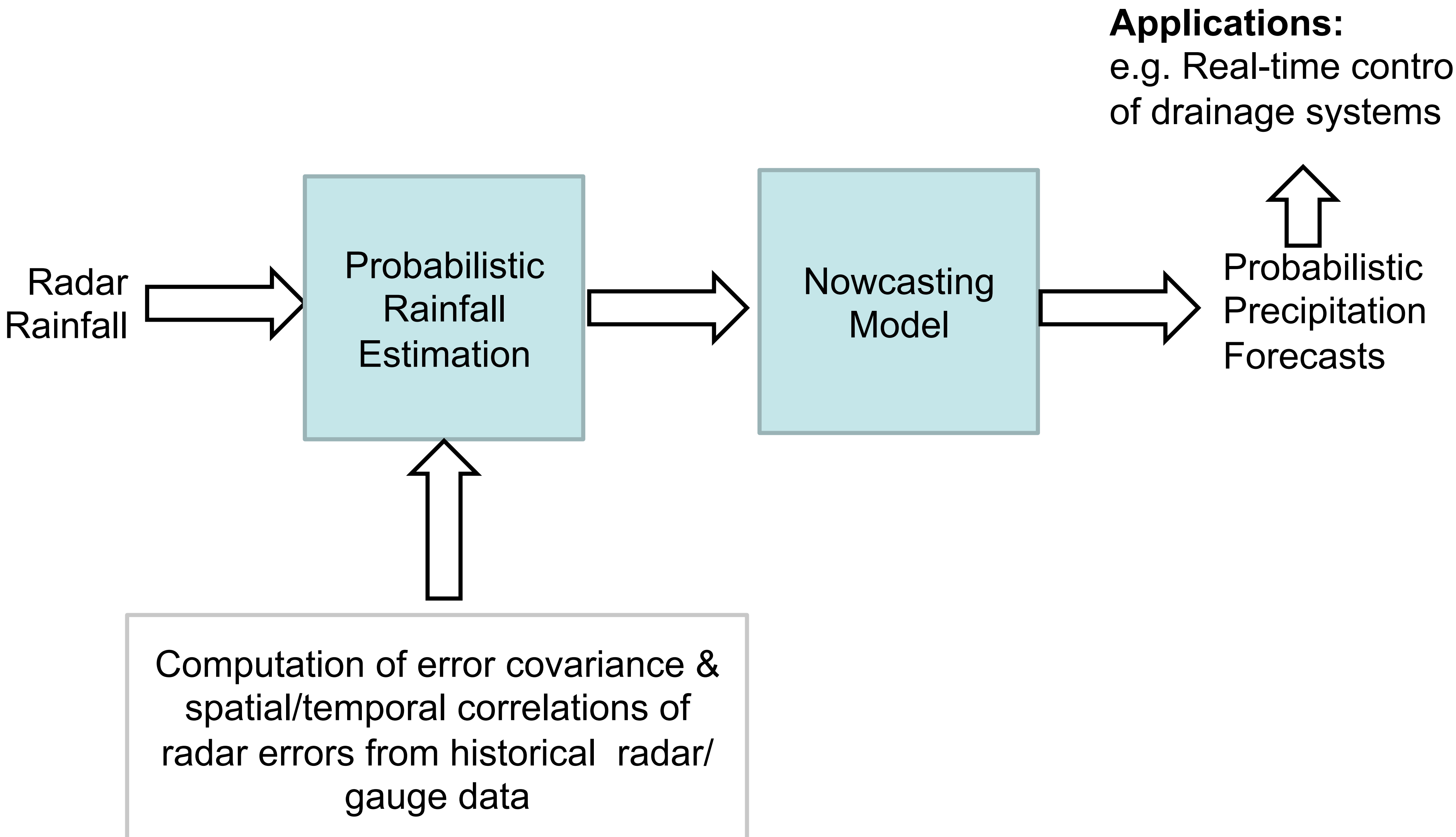
Summary of measured & simulated flow volumes per event



The radar ensembles are able to capture the total flow volumes for 11 out of 20 events (55%).

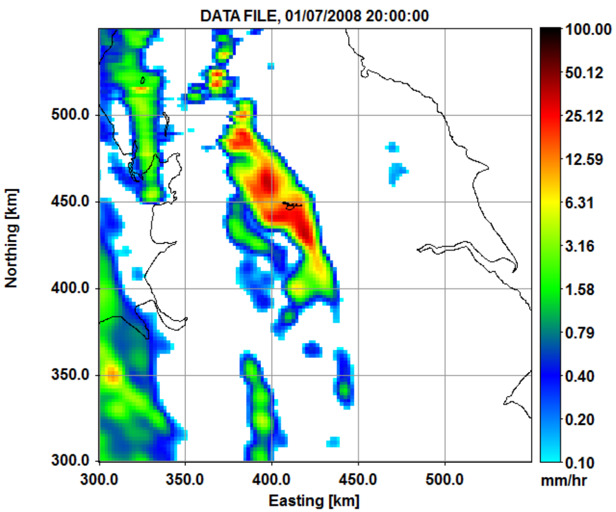
There are 4 events where neither the raingauges nor the radar ensembles were able to capture the measured flow volume

Quantifying the uncertainty in rainfall measurement in Nowcasting

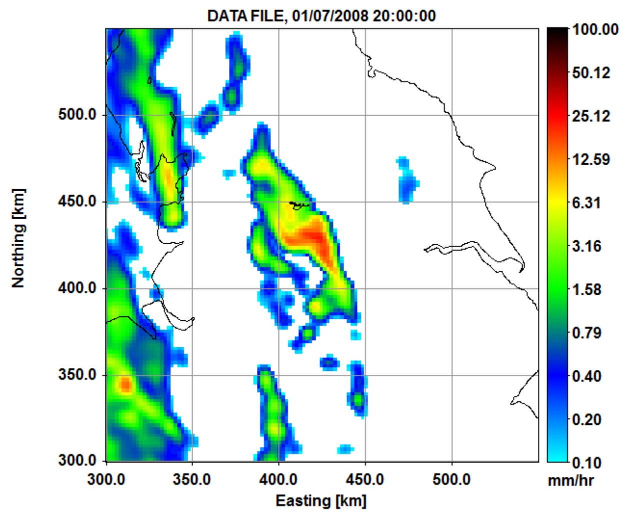


Probabilistic Nowcasting (t+1h) - Event 20080701

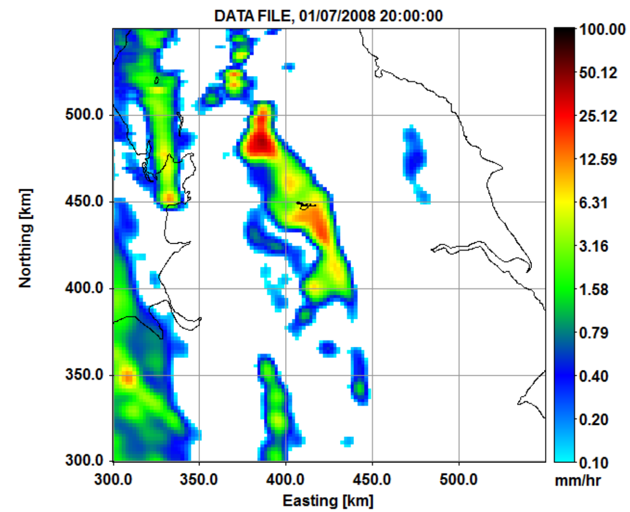
Det



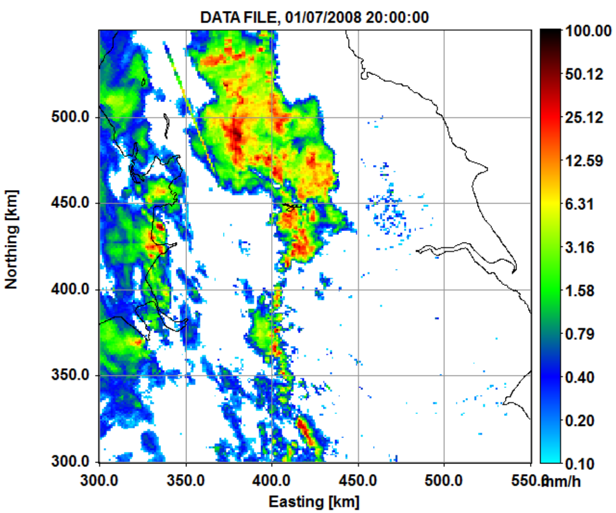
E_2



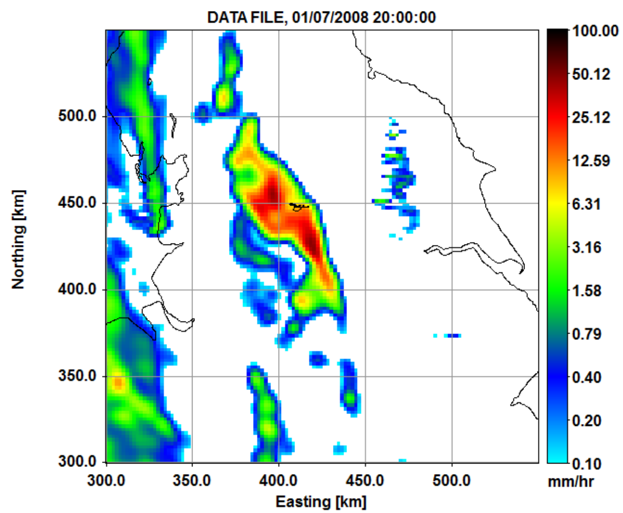
E_3



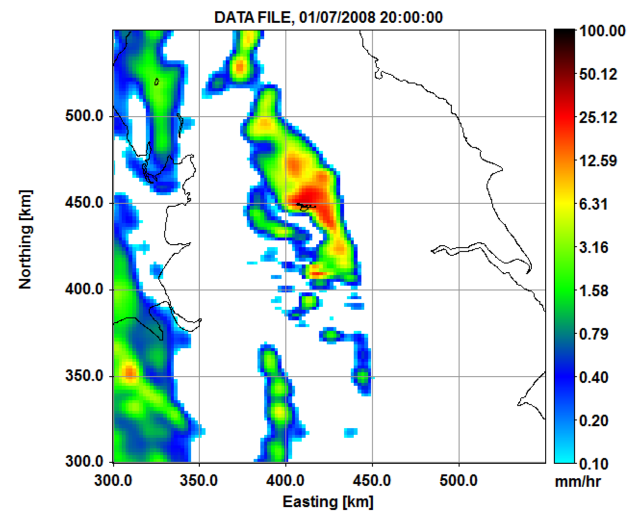
Radar



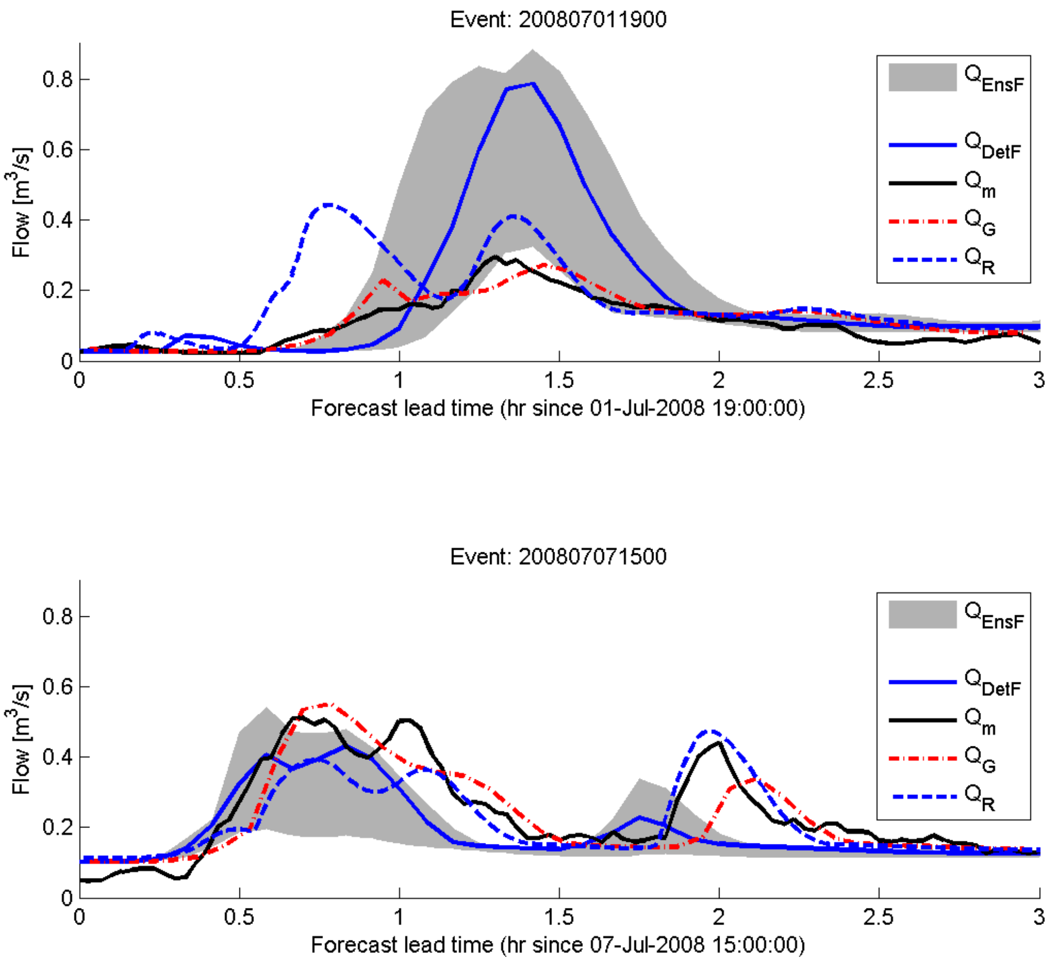
E_{12}



E_{18}

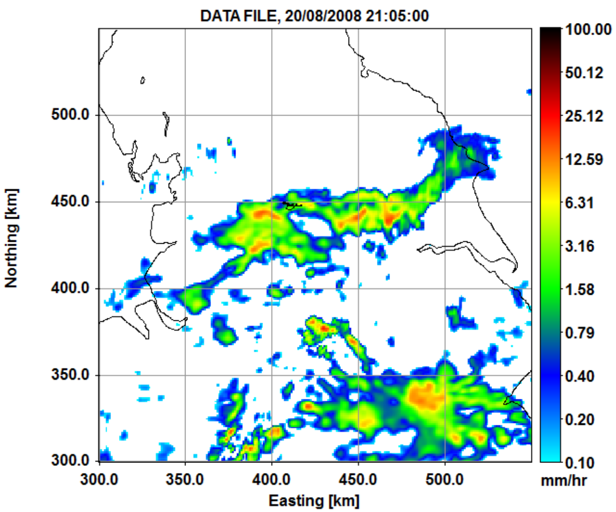


Ensemble flow forecasts

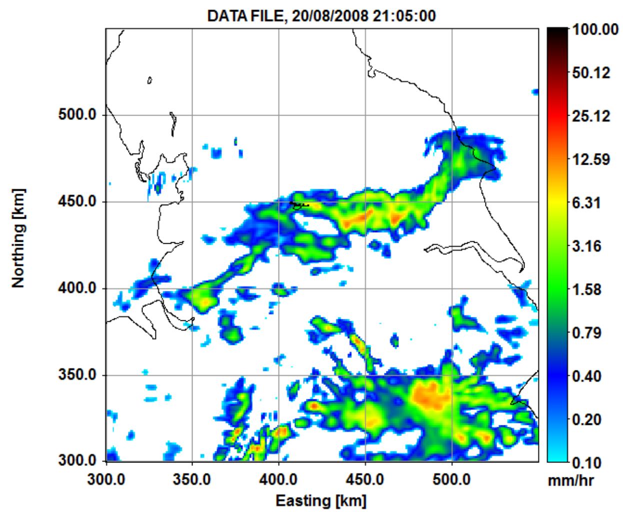


Probabilistic Nowcasting (t+1h) - Event 20080820

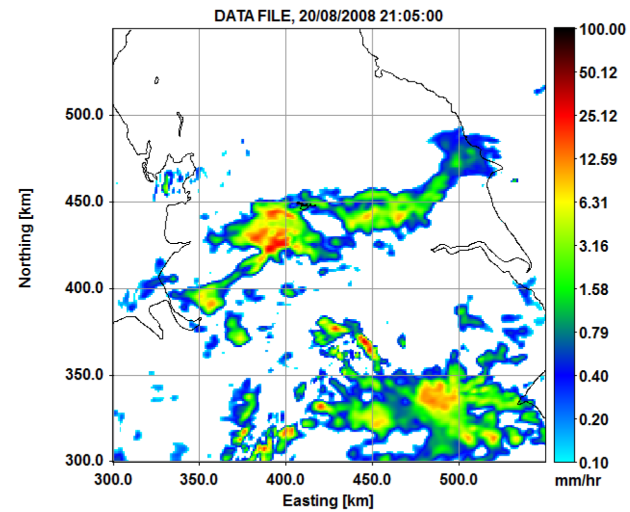
Det



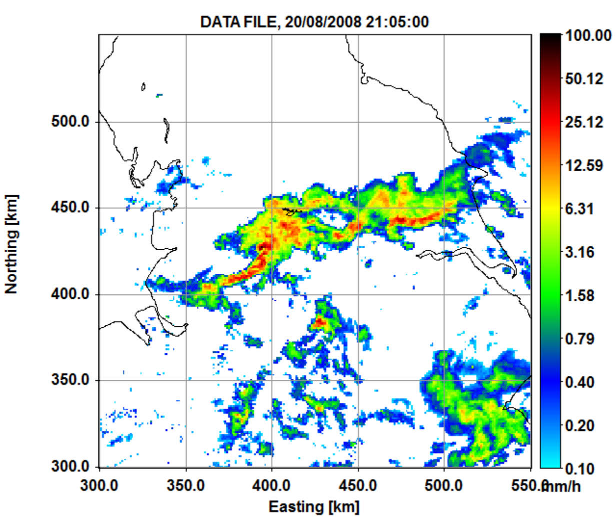
E_2



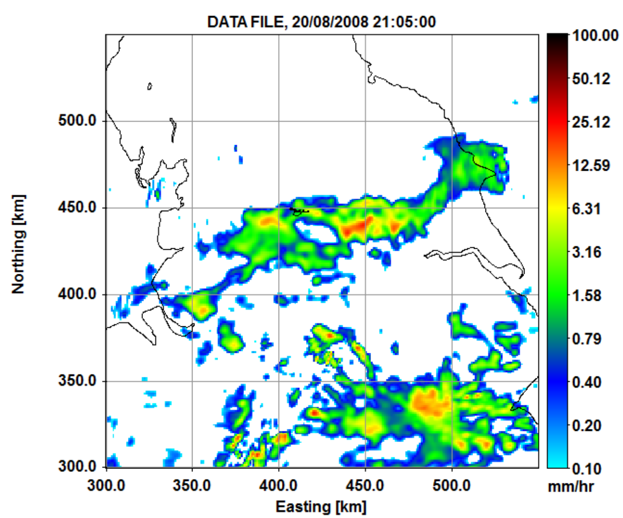
E_6



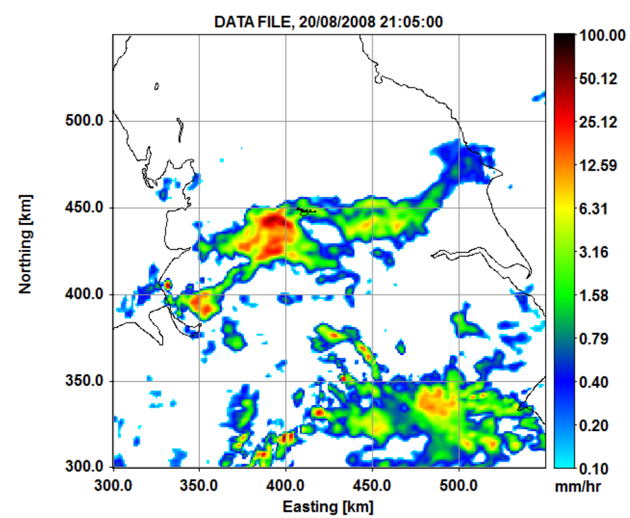
Radar



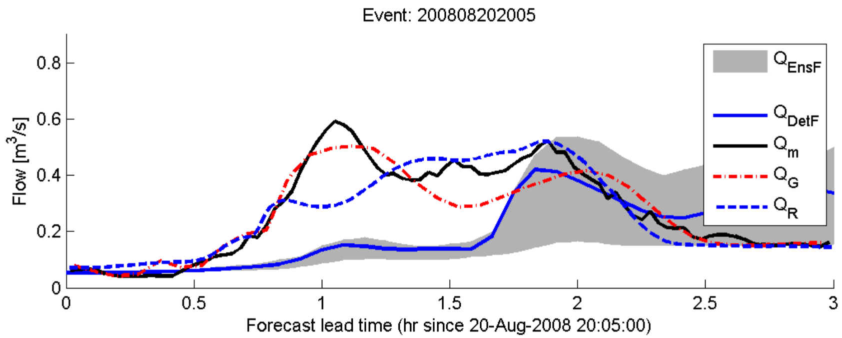
E_{12}

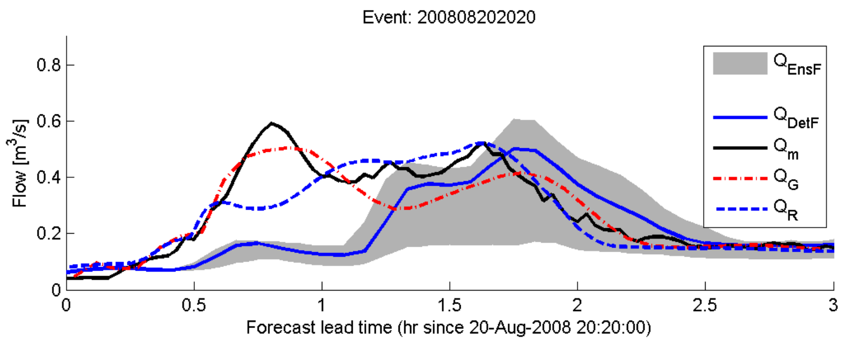


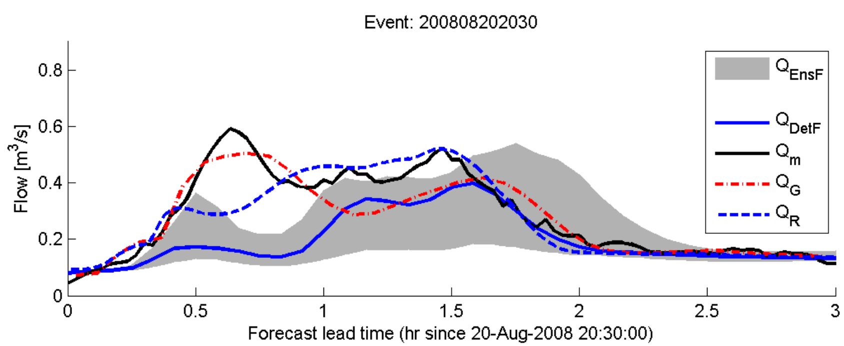
E_{18}



Ensemble flow forecasts







Summary and conclusions

- Radar Rainfall (RR) errors can be modelled by using the error covariance matrix, but this assumes that the error does not change, which is not always true.
- The results showed that in 55% of the simulated events, the uncertainties in the RR measurements are able to explain the uncertainties in the simulated flow volumes.
- There are cases where neither the raingauges nor the RR ensembles were able to capture the measured flow volumes. Additional uncertainties may come from the hydraulic model.
- Preliminary results of the application of RR ensembles in nowcasting showed that some of the ensemble forecasts are able to capture the peaks of the hydrographs, but more work is needed to further validate the probabilistic nowcasts.
- There is more work to do to model additional uncertainties in nowcasting models by incorporating more meteorological knowledge (e.g. to model growth & decay processes)

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