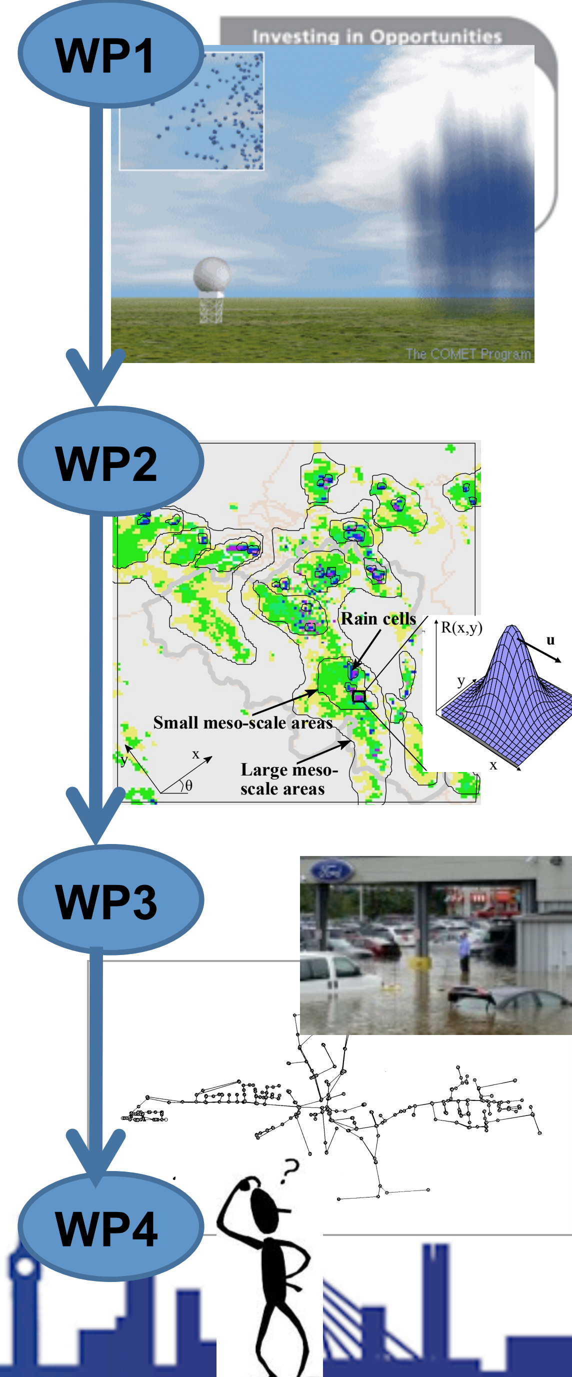
WP2: Fine-scale rainfall data acquisition and prediction:

Objective: develop and implement a system for estimation and forecasting of fine-scale (100m, minutes) rainfall

- <u>Rainfall estimation</u>: combining data from radars (X & C-band) and rain gauges
- <u>Rainfall forecasting</u>: combining with numerical weather prediction

✓implement and test for pilot sites (Leuven, Paris, Rotterdam, London)

✓applicable for urban areas of North-West Europe: guidelines, demonstrations, training, …



RainGain

Investing in Opportunities
This project has received European Regional Development Funding through INTERREG IV B.
nwe
INTERREG IVB

WP2: Fine-scale rainfall data acquisition and prediction:

Actions:

	A5 Workshop on radar technology, calibration and rainfall estimation	A6 Rainfall estimation in pilot sites	A7 Workshop on rainfall forecasting	A8 Implementation and testing of rainfall forecasting in pilot sites	A9 Writing guidelines, manuals and training material
WP2	Output: Report on methods for fine-scale rainfall estimation	Output: Rainfall estimates for storms in pilot sites	Output: Report on methods for fine-scale rainfall forecasting	Output: Operational system for rainfall forecasting in pilot sites	Output: Manuals for developed technology + training

WP2: Fine-scale rainfall data acquisition and prediction:

Actions: <u>A5: Leuven workshop on radar technology, calibration and rainfall estimation, 16 April 2012</u> (M3)

WP2: Fine-scale rainfall data acquisition and prediction:

Actions: <u>A5: Leuven workshop on radar technology, calibration and rainfall estimation, 16 April 2012</u> (M3)

- ✓ *Document: "Methods and experiences in radar based fine scale rainfall estimation"*

- ✓ *First version ready*
- ✓ *Lively document*


Review document:

Methods and experiences in radar based fine scale rainfall estimation

WP2: Fine-scale rainfall data acquisition and prediction:

Document: "Methods and experiences in radar based fine scale rainfall estimation"

Boxes with illustration of applications by RainGain partners

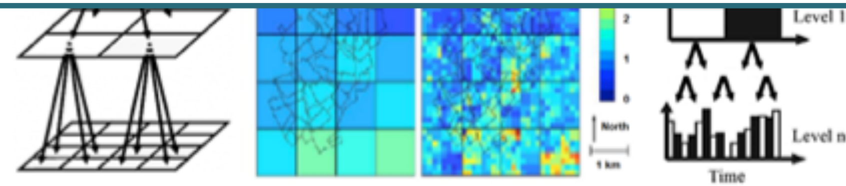


Figure 19: Rainfall downscaling a) downscaling of rainfall fields in space (adapted from Bocchiola, 2007), an example of the spatial downscaling based on real data (adapted from Gires et al., 2012a) and c) downscaling of rainfall series in time (adapted from Lu and Yamamoto, 2008)

For an extensive overview on and review of these techniques, the reader is referred to Lovejoy and Schertzer (2007) or Schertzer and Lovejoy (2011) and the references therein. Applications in our field include e.g. Marsan et al., 1996; Pathirana and Herath, 2002; Biaou et al., 2003; Ferraris et al., 2003; Macor et al., 2007; Royer et al., 2008; De Montera et al., 2009; Gires et al., 2012a and b, among others.

Example from RainGain consortium: Multifractal cascade downscaling methods in practice:

Gires et al. (2012b) investigated the effect of the uncertainty due to the unknown smaller scale variability on a semi-distributed urban rainfall-runoff model. The spatial resolution of the used C-band radar data was 1 km; the temporal resolution was 5 minutes. In order to quantify the effect of the small scale variability, an ensemble set of realistic fine scale rainfall fields was generated based on the universal multifractal cascade approach. These ensembles are then used as input for the urban rainfall runoff model and the in-sewer conduit flows were simulated. The variability among the simulated hydrographs is then estimated to quantify the uncertainty. This approach is applied on the Cranbrook catchment, which is a 900ha urban area situated in the east of London, UK.

They implemented 4 multifractal downscaling methods, 2 spatial downscaling (2D) methods and 2 spatio-temporal downscaling (3D) methods. A schematization of the two approaches is shown in Figure 20. Comparison led to the conclusion that the 2D approach might overestimate the results, whereas the 3D approach gives more realistic results. They concluded that it is strongly recommended to use distributed (radar) rainfall in urban hydrology. Moreover, they encourage the use of X-band radar, which allows measuring rainfall at a higher resolution. The extra added value of radar measurements during summer is also endorsed by their results, especially for intense small scale convective events.

WP2: Fine-scale rainfall data acquisition and prediction:

Document: "Methods and experiences in radar based fine scale rainfall estimation"

- ✓ *Mid 2013: Reference document for WP2 activities*
- ✓ *Mid 2015: Guidelines for "good practise"*

WP2: Fine-scale rainfall data acquisition and prediction:

Actions: <u>A6: rainfall estimation in pilot sites</u>

- ✓ Outcomes: fine-scale rainfall estimates for recent storms in pilot sites + comparison with traditional rainfall estimates (without radar)

- ✓ Tasks:
  - ✓ Fine-scale rainfall estimation, fine-scale (X-band, city scale; super-resolution C-band) with rain gauge and coarser (NWE-scale) C-band radar data
  - ✓ Fine-scale rainfall estimation error/uncertainty analysis
  - ✓ Interfacing with the applications in WP3 & WP4

Investing in Opportunities
This project has received European Regional Development Funding through INTERREG IV B.
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WP2: Fine-scale rainfall data acquisition and prediction:

Fine-scale rainfall estimation: different steps

- ❖ **Radar adjustment: Corrections to the raw radar signal**
- ❖ **Radar adjustment: Corrections to rain gauge measurements**

  OR

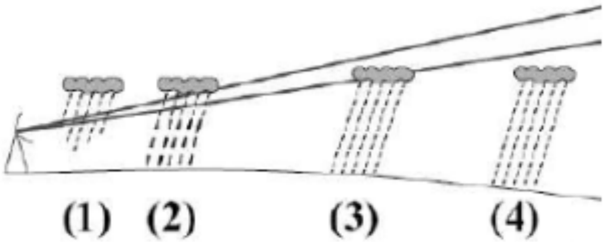
- ❖ **Radar – rain gauge integration**

- ❖ **Downscaling**

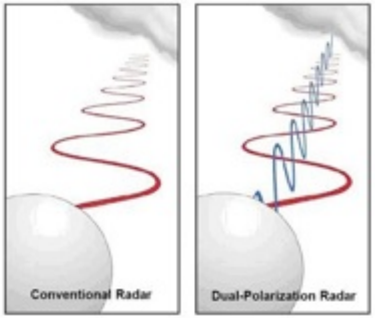
WP2: Fine-scale rainfall data acquisition and prediction:

Radar adjustment: Corrections to the raw radar signal

- Noise cut off
- Volume correction
  - Volume and VPR correction methods
  - Anomalous propagation correction methods
  - Partial beam blockage correction methods
  - Other…



- Attenuation correction
  - Based on a reflectivity – specific attenuation relation
  - Based on PHIDP and KDP – specific attenuation relation
  - Other…

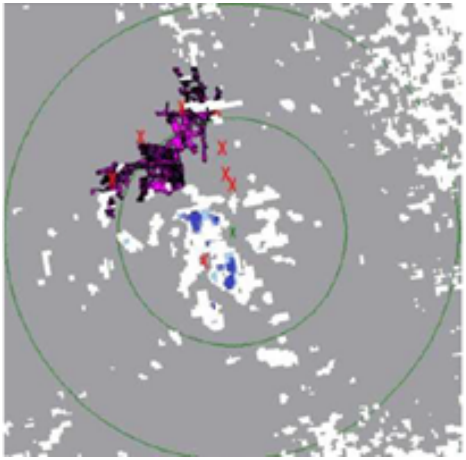


WP2: Fine-scale rainfall data acquisition and prediction:

Radar adjustment: Corrections to the raw radar signal

❖ Clutter correction

- Clutter map
- Doppler measurements
- Statistical clutter removal
- Dual polarization radar measurements
- Combinations



WP2: Fine-scale rainfall data acquisition and prediction:

Radar adjustment: Corrections to rain gauge measurements

- Statistic or dynamic correction (or combined)

- Mean field bias correction
- Range-dependent adjustment
- Brandes correction
- Quantile mapping

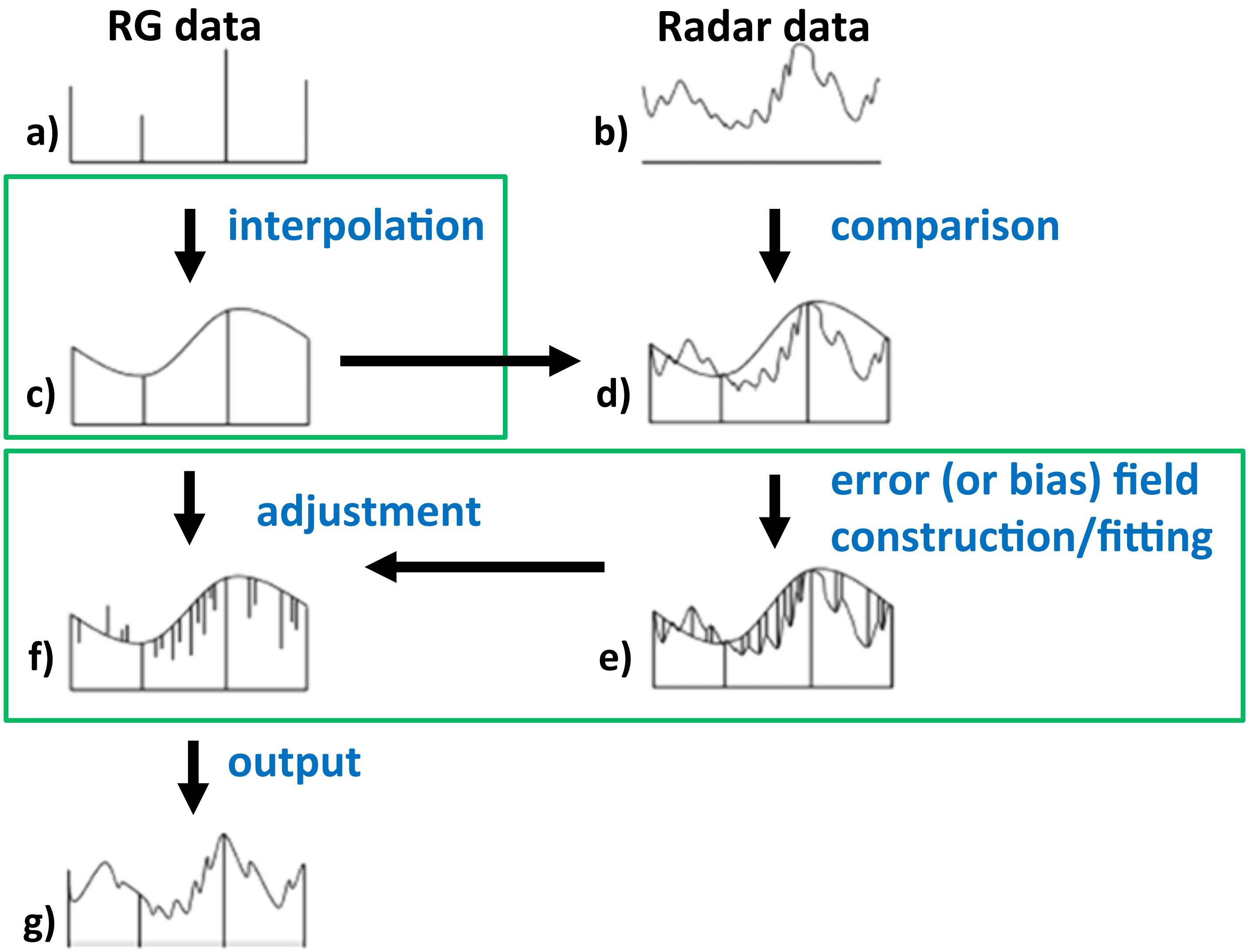
- Kriging with radar-based error correction (KRE)
- Kriging with external drift (KED)
- Regression kriging

WP2: Fine-scale rainfall data acquisition and prediction:

Radar – rain gauge integration (merging, based on error variance minimization):

- Co-kriging
- Kalman filter (taking radar and rain gauge measurement errors or uncertainties into account), Bayesian approach
- + Local singularity analysis

Radar - rain gauge merging

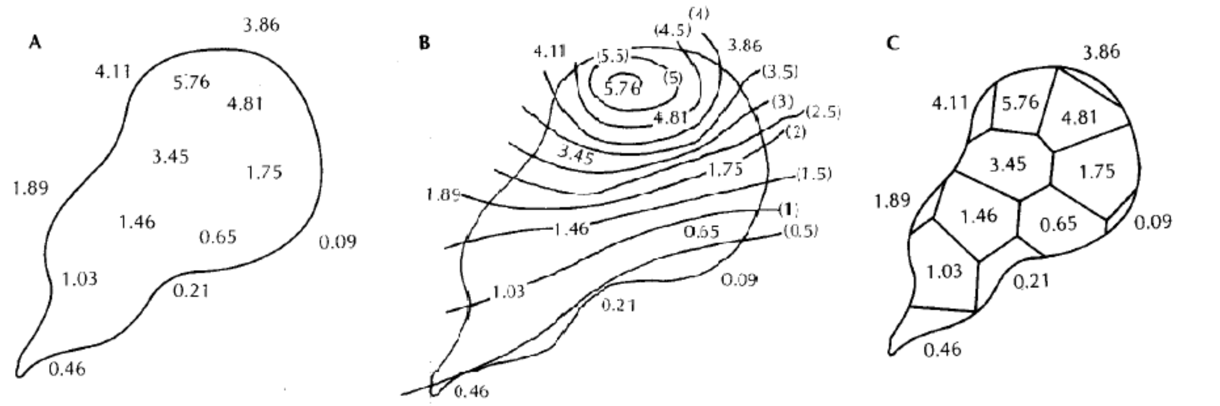


(Todini, 2001; Ehret et al., 2008)

WP2: Fine-scale rainfall data acquisition and prediction:

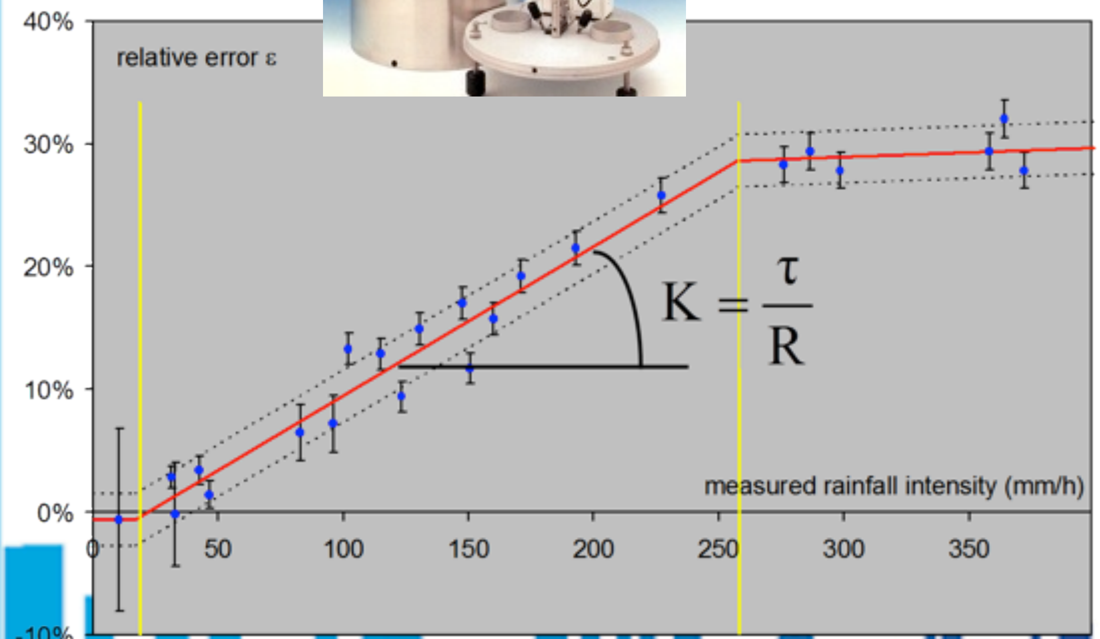
Rain gauge interpolation:

- Thiessen polygon method
- Isohyetal method
- Inverse distance weighting
- Kriging



WP2: Fine-scale rainfall data acquisition and prediction:

Rain gauge error estimation

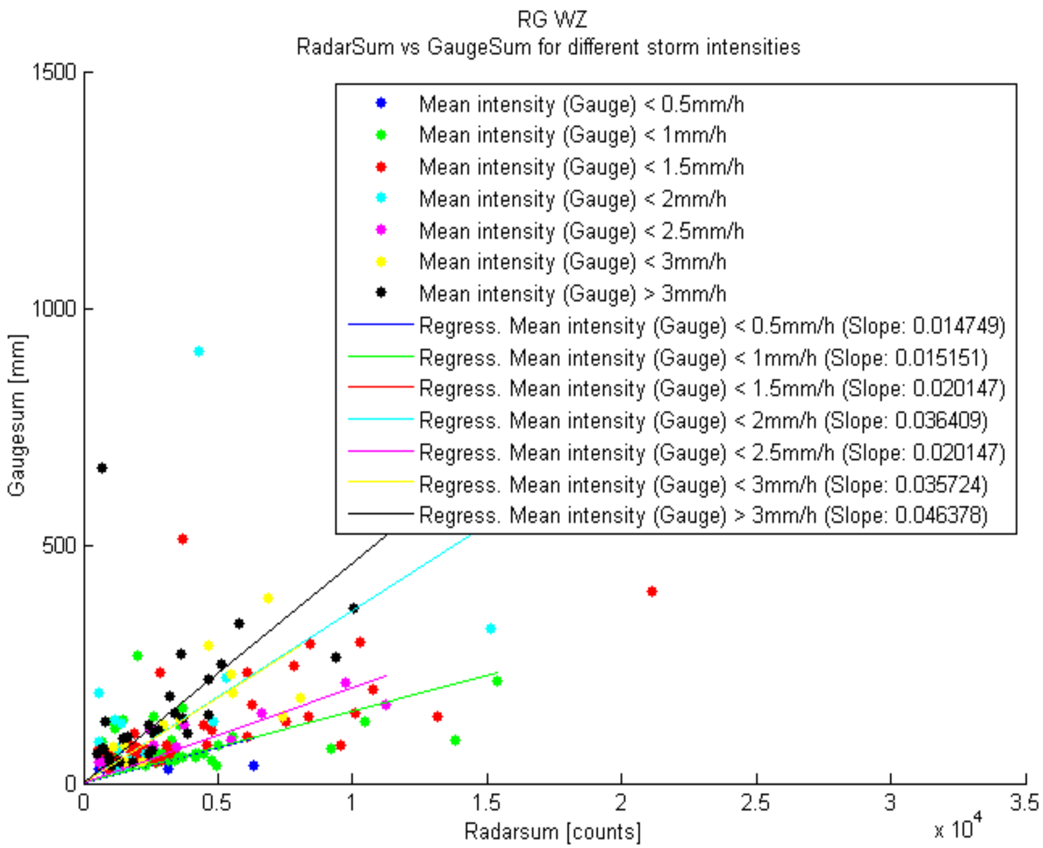


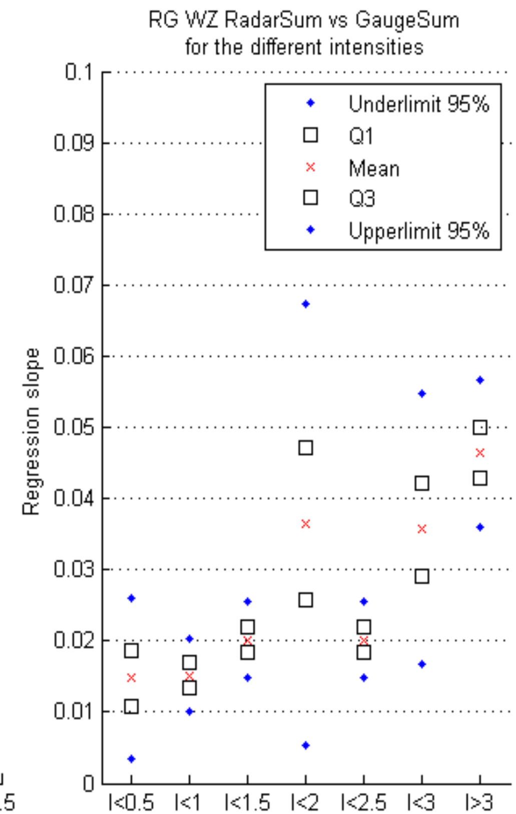
Accuracy tipping-bucket rain gauges:

- resolution R (0.1 mm, 0.2 mm, 0.5 mm)
- uncertainty calibration curve (± 1%)
- influence of wind and local disturbances (± 3 to 5%)

WP2: Fine-scale rainfall data acquisition and prediction:

Radar error estimation





WP2: Fine-scale rainfall data acquisition and prediction:

Downscaling:

- Empirical transfer functions (generalized linear models, quantile mapping, neural network models, …)
- Resampling, weather typing
- Stochastic disaggregation methods:
  - Based on point process theory
  - Cascade or multifractal methods

WP2: Fine-scale rainfall data acquisition and prediction:

Actions: <u>A6: rainfall estimation in pilot sites</u>

✓ Leuven (LAWR X-band radar):

- Clutter correction
- Radar adjustment to rain gauges:
  - Mean field bias correction
  - Range-dependent adjustment
  - Brandes correction
  - Adjustment factor depending on season, storm type, intensity, wind speed, wind direction, temperature, spatial size, location of storm
  - Quantile mapping

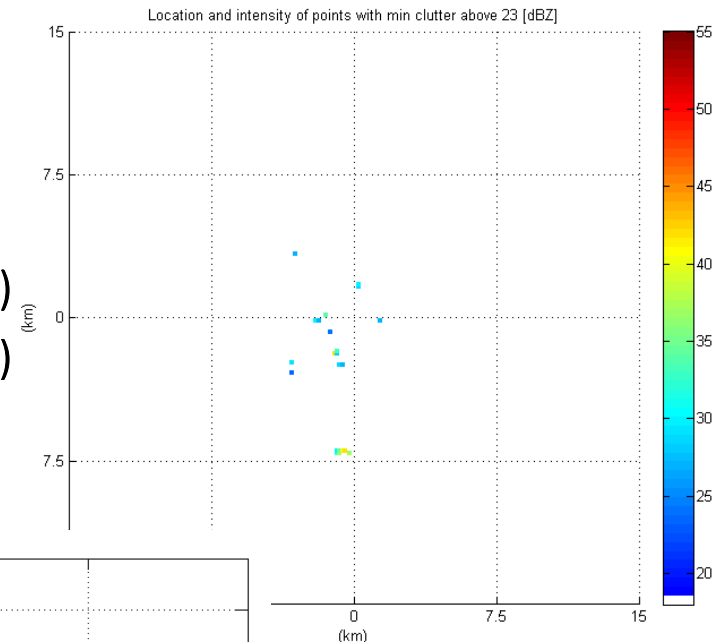
WP2: Fine-scale rainfall data acquisition and prediction:

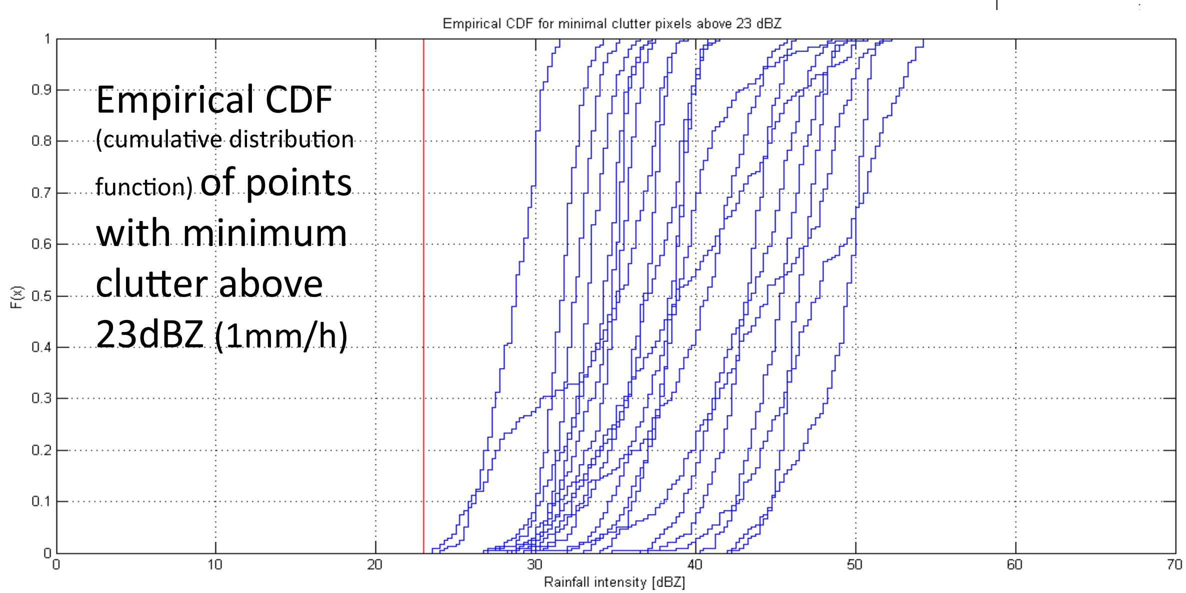
Clutter correction Leuven case:

Statistics on clutter prone locations

Persistent clutter during dry weather:

- Mean value above 1dBZ: 3274 pixels (= 5.68%)
- Mean value above 23dBZ: 281 pixels (= 0.49%)
- Min. value above 1dBZ: 81 pixels (= 0.14%)
- Min. value above 23dBZ: 22 pixels (= 0.04%)





WP2: Fine-scale rainfall data acquisition and prediction:

Clutter correction Leuven case:

Because some clutter pixels remain:

- Clutter filtering based on event characteristics: Identification of 'bad' pixels through the temporal behaviour of the 'bad' rainfall pixels
- Pixel filling through spatial interpolation from nearest 'good' pixels and the rain gauges (for larger areas)

Tested for a subregion: rather good results but too slow for real time operational applications

WP2: Fine-scale rainfall data acquisition and prediction:

Clutter correction Leuven case:

Therefore, alternative approach:

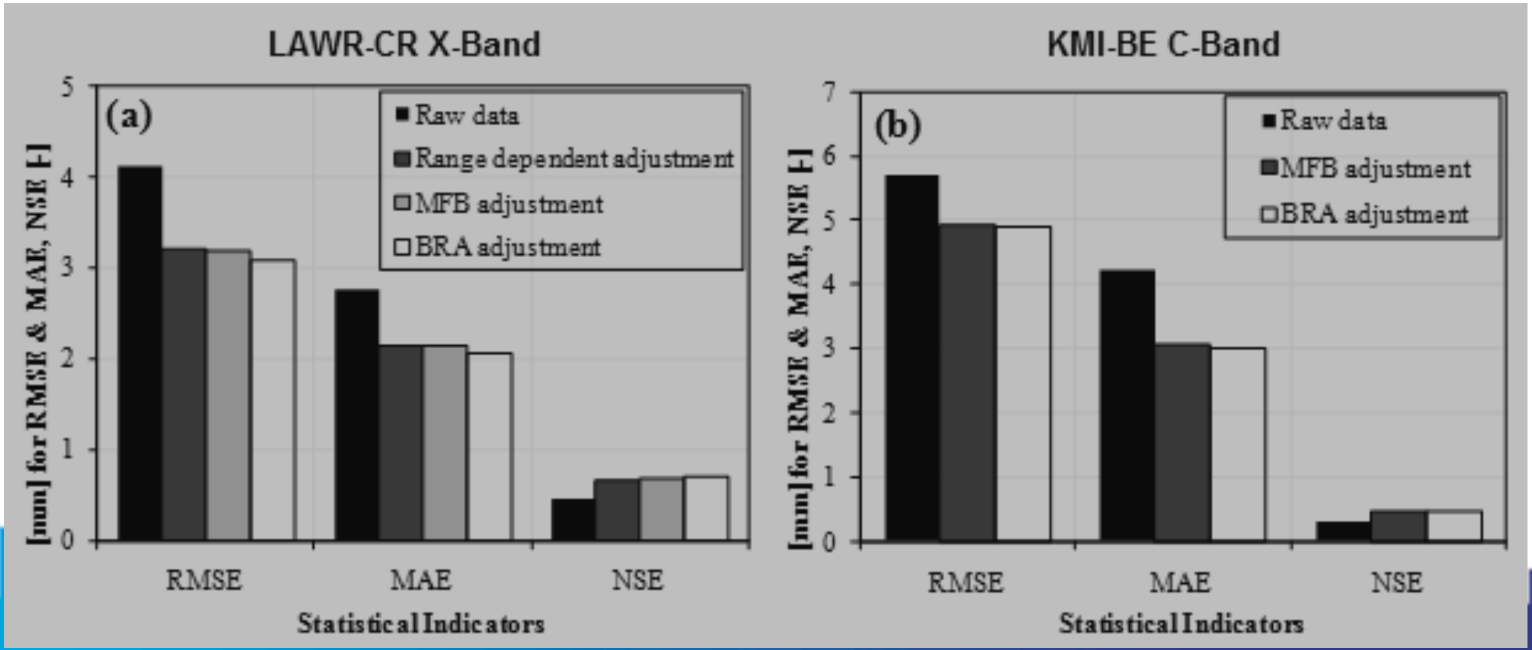
- Clutter removal based on separation of dry and rainy periods (based on the number of ‘wet’ radar cells)
- Dynamic clutter map generated during dry weather and applied during next rain events
- Pixel filling through interpolation from nearest pixels

Now used operationally

WP2: Fine-scale rainfall data acquisition and prediction:

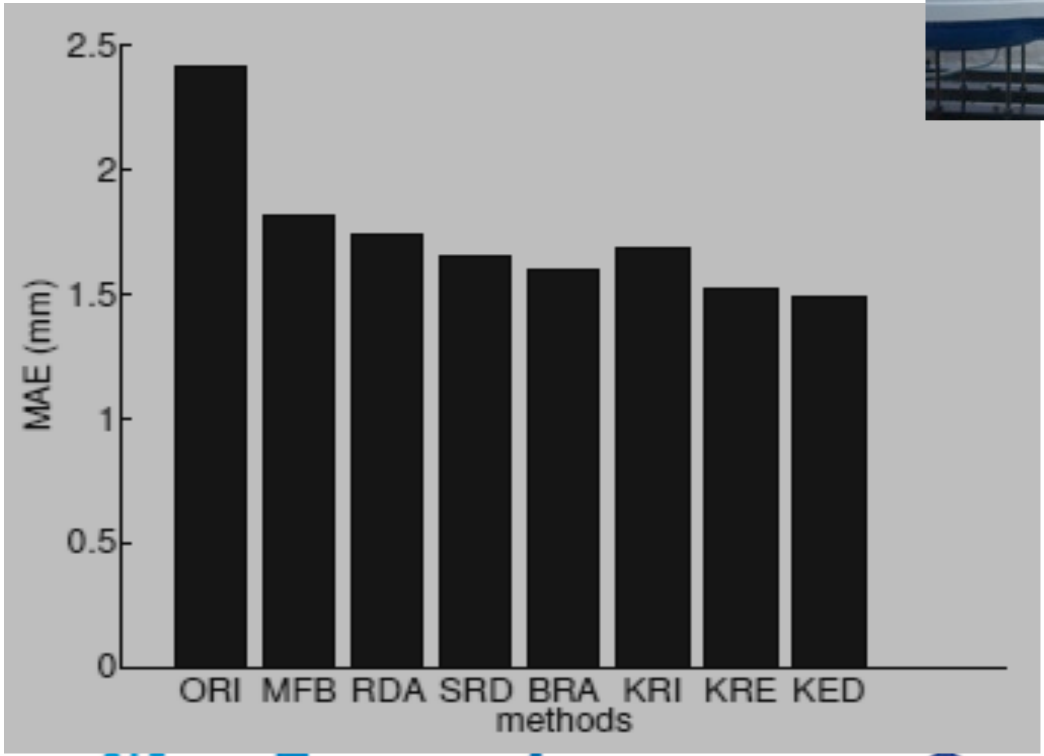
Comparison merging methods Leuven case

Statistical indicators	Summer period		Winter period	
	LAWR-CR X-band	RMI BE C-band	LAWR-CR X-band	RMI BE C-band
RMSE [mm]	3.09	4.91	3.40	3.76
MAE [mm]	2.06	3.02	2.42	4.38
NSE [-]	0.70	0.48	0.55	0.66



WP2: Fine-scale rainfall data acquisition and prediction:

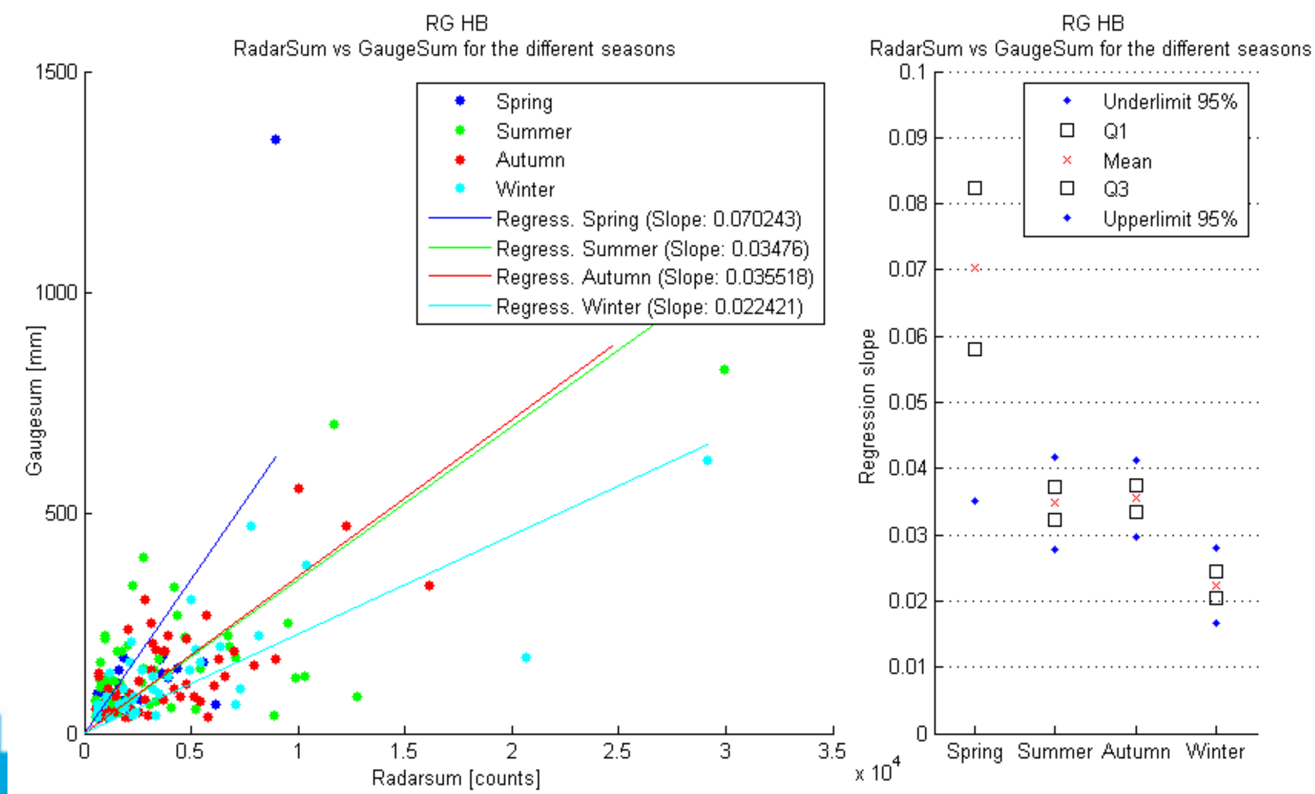
Comparison merging methods Leuven case




WP2: Fine-scale rainfall data acquisition and prediction:

Radar adjustment Leuven case:

Study on dependency of adjustment factor to season, storm type, intensity, wind speed, wind direction, temperature, spatial size, location of storm



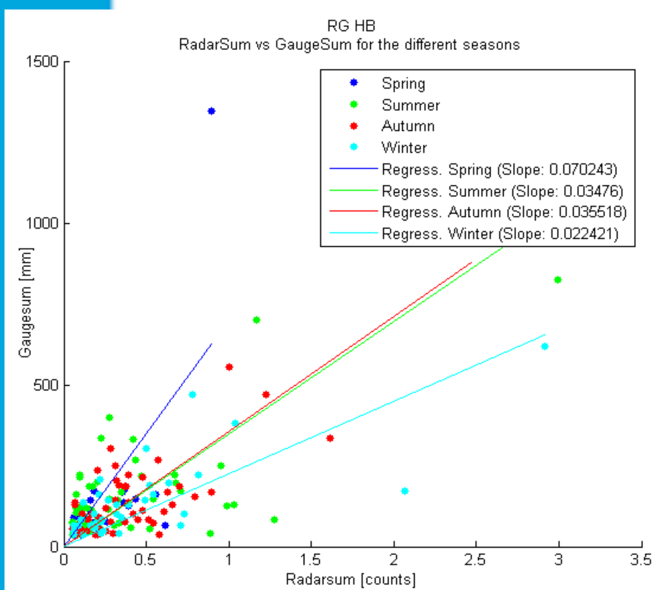
umn similar and

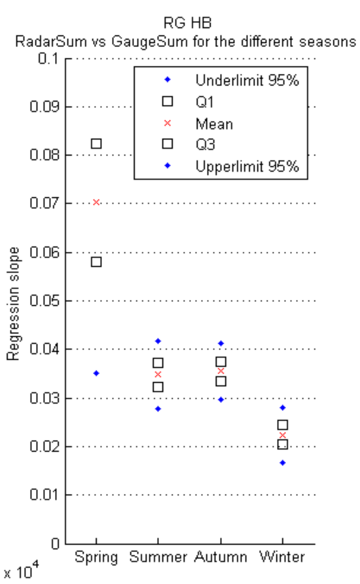
m separation

WP2: Fine-scale rainfall data acquisition and prediction:

Radar adjustment Leuven case:

Study on dependency of adjustment factor to season, storm type, intensity, wind speed, wind direction, temperature, spatial size, location of storm



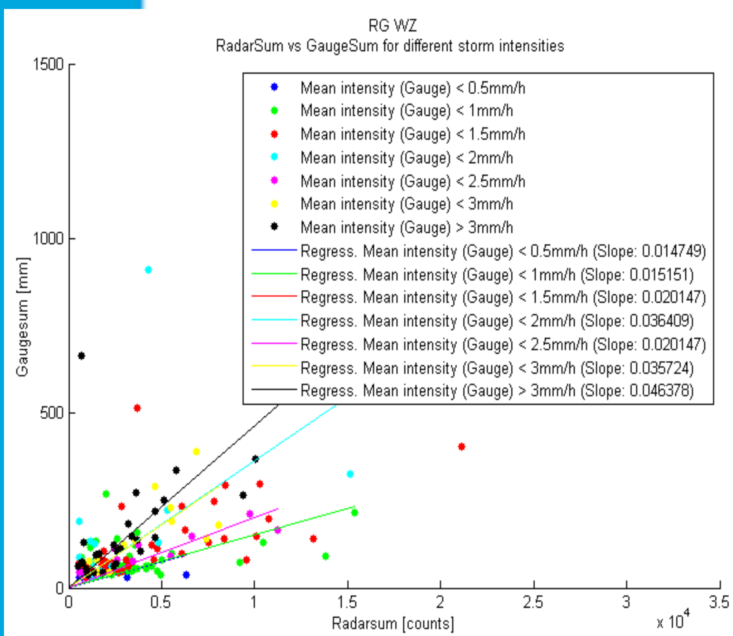


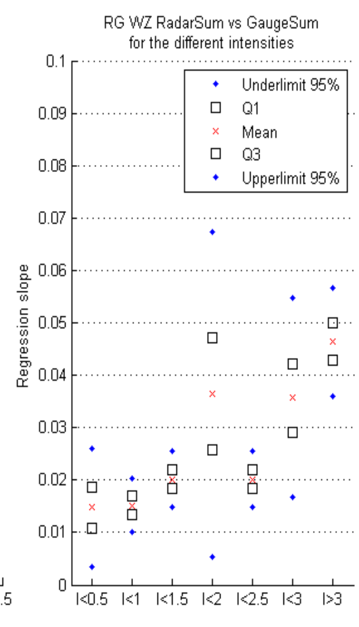
- ✓ Season:
  - Spring higher, summer and autumn similar and winter lower
  - Supports application of Convective / Stratiform separation algorithm
- ✓ Direction:
  - Nearly no East
  - West & North: similar
  - South: higher
- ✓ Speed within direction:
  - West: increasing relation found

WP2: Fine-scale rainfall data acquisition and prediction:

Radar adjustment Leuven case:

Study on dependency of adjustment factor to season, storm type, intensity, wind speed, wind direction, temperature, spatial size, location of storm





- ✓ Area:
  - No increasing relation
  - For relative radar filling levels within 40-50%: higher relation
  - Supports Convective / Stratiform separation algorithm
- ✓ Temperature:
  - T <10° : lower
  - 10°< T<20° : higher
  - T > 20° : mean
  - Supports Conv./Strat.
- ✓ Intensities:
  - Weak increasing relation

WP2: Fine-scale rainfall data acquisition and prediction:

Spatial quantile mapping Leuven case:

Investigate the distribution of radar peak intensities based on:

- Location of the peaks
- Intensity levels of the peaks
- Persistence over a range of rainfall aggregation times

Goal: quantify radar data quality and assess the effectiveness of adjustment methods

This project has received European Regional Development Funding through INTERREG IV B.

WP2: Fine-scale rainfall data acquisition and prediction:

Spatial quantile mapping Leuven case:

Expected outcome: An approx. uniform rainfall quantile field (for different aggregation times and percentile levels)

Possible error sources:

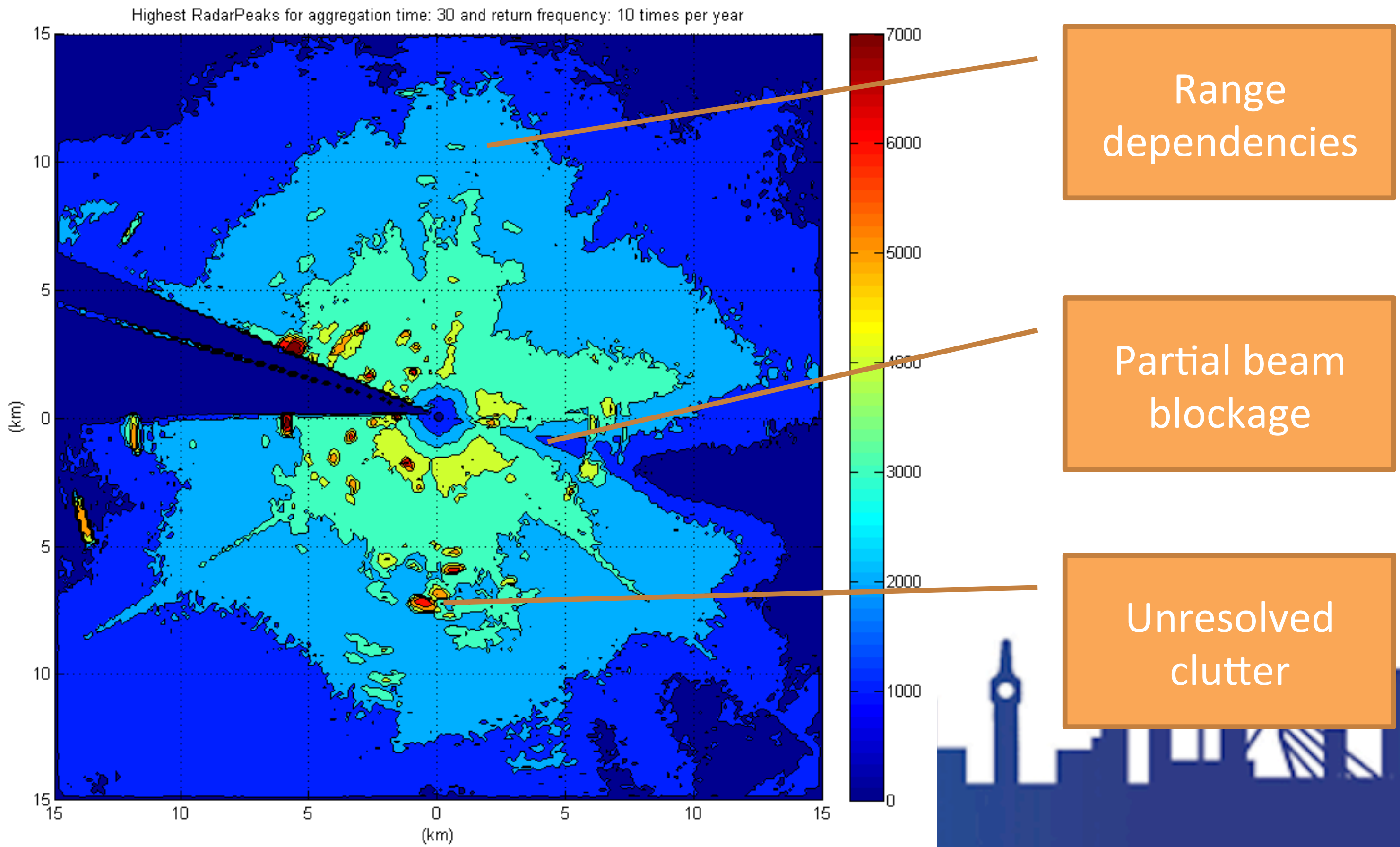
- ✓ Unresolved clutter issues
- ✓ Attenuation effects
- ✓ (Partial) beam blockage effects

Post-correction: quantile bias correction (quantile mapping)

WP2: Fine-scale rainfall data acquisition and prediction:

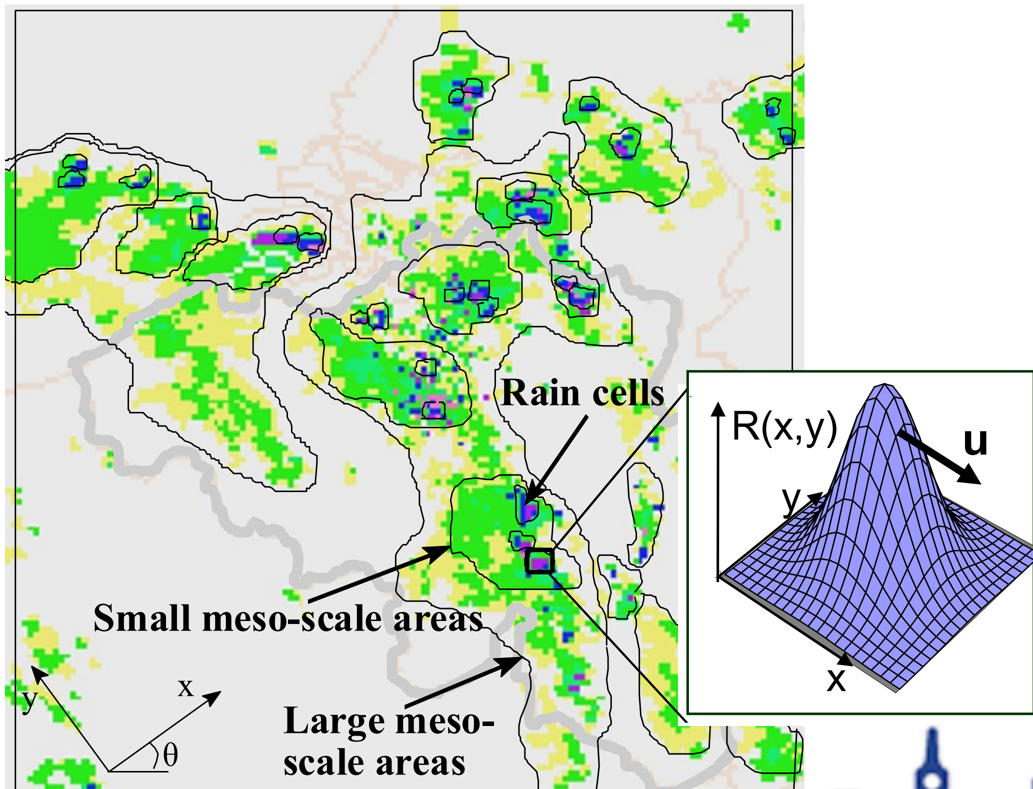
Spatial quantile mapping Leuven case:

Preliminary results for recent (short) time period & 30 min aggregation time:



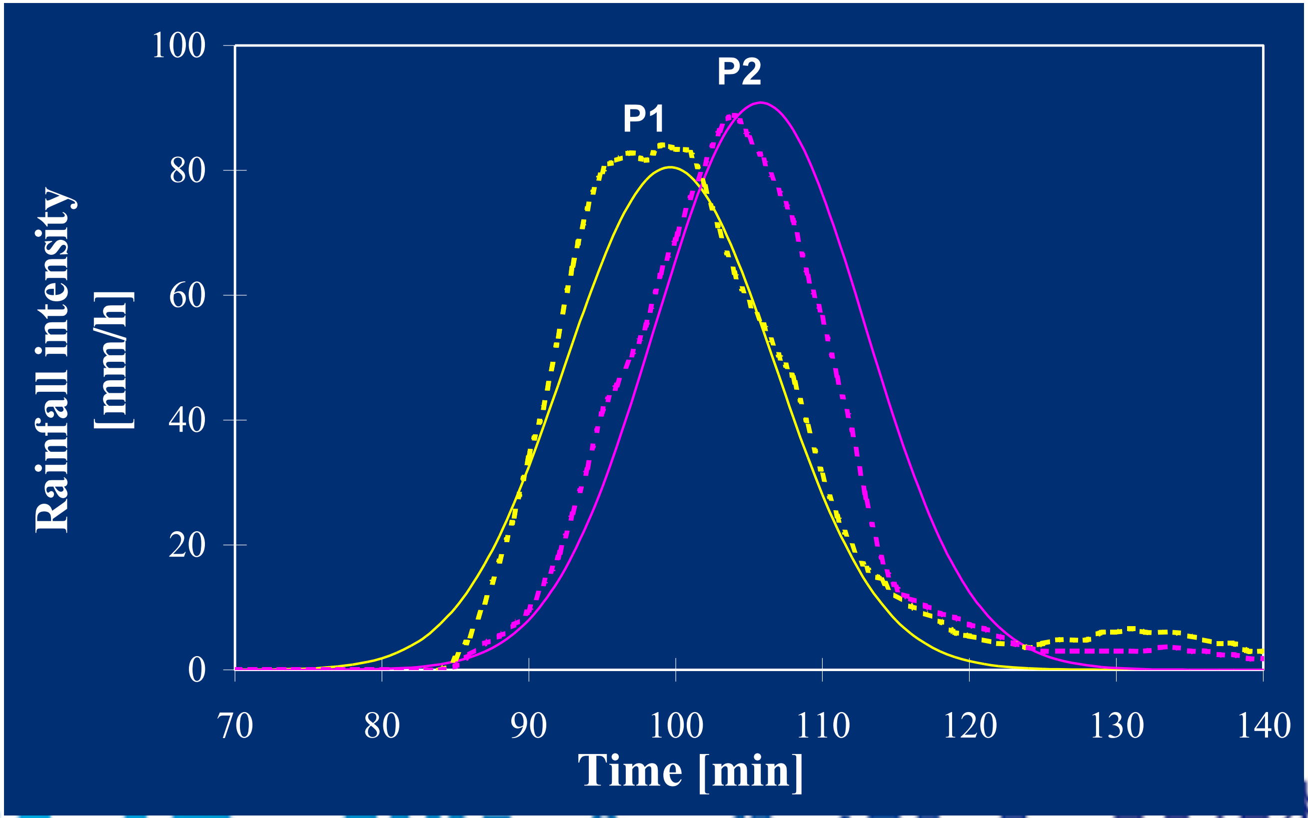
WP2: Fine-scale rainfall data acquisition and prediction:

Calibration conceptual rain storm model Leuven case



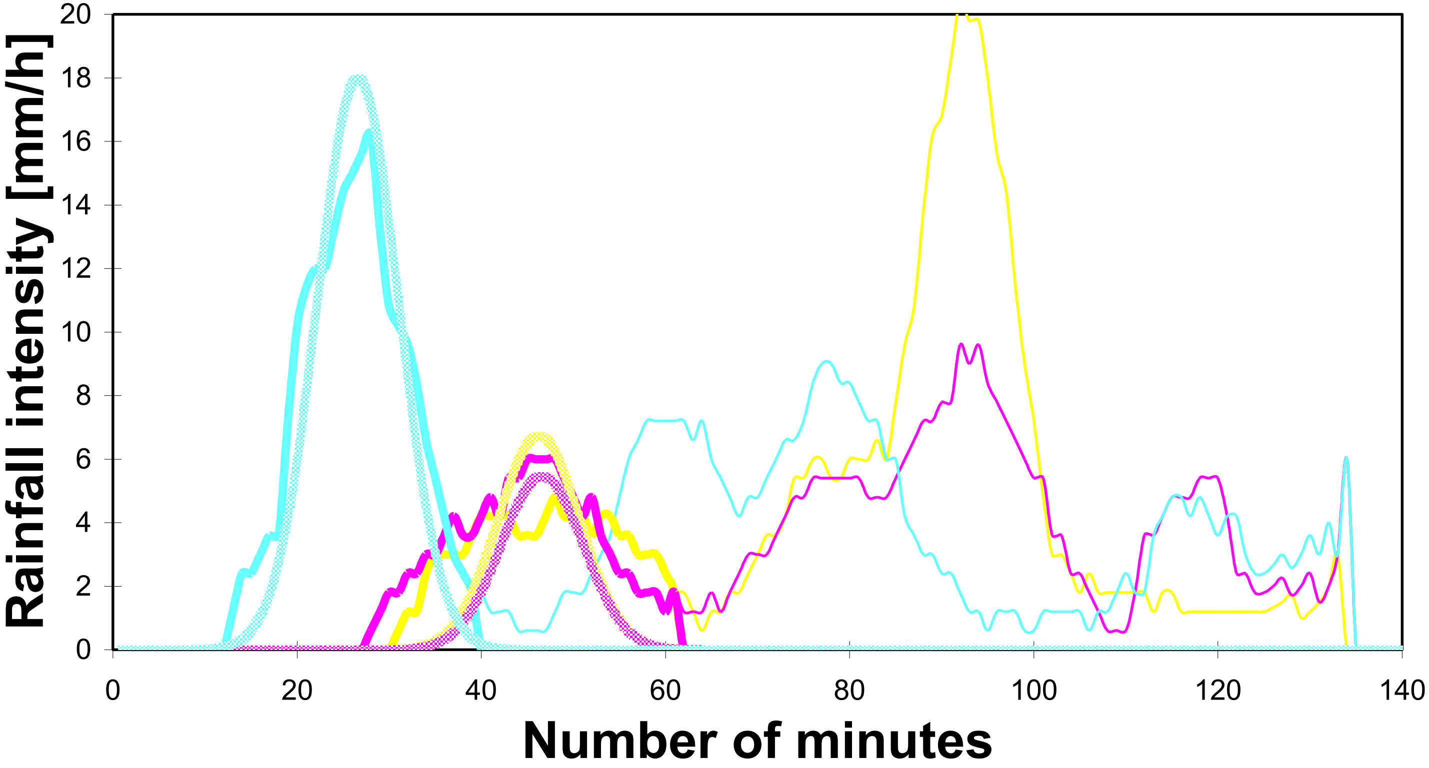
WP2: Fine-scale rainfall data acquisition and prediction:

Calibration conceptual rain storm model Leuven case



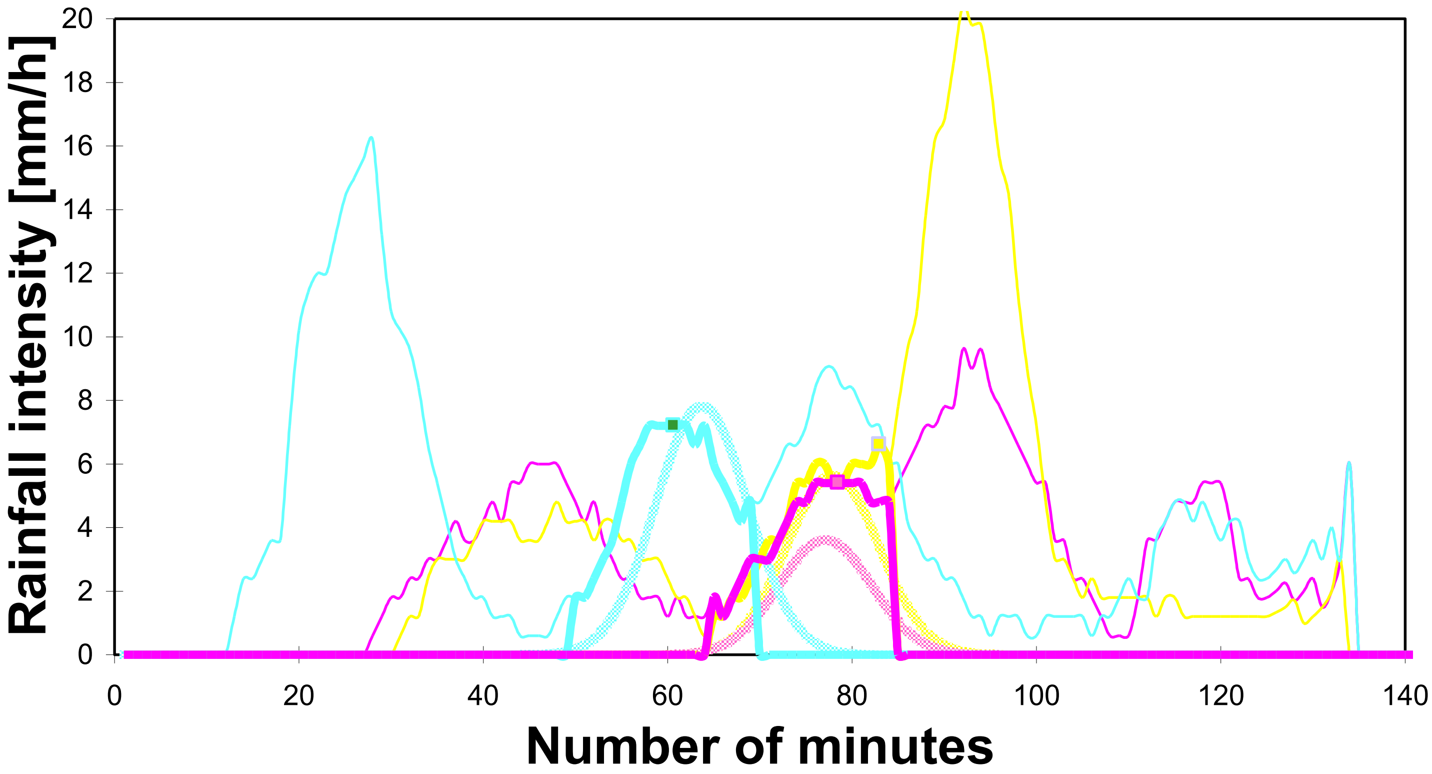
WP2: Fine-scale rainfall data acquisition and prediction:

Calibration conceptual rain storm model Leuven case



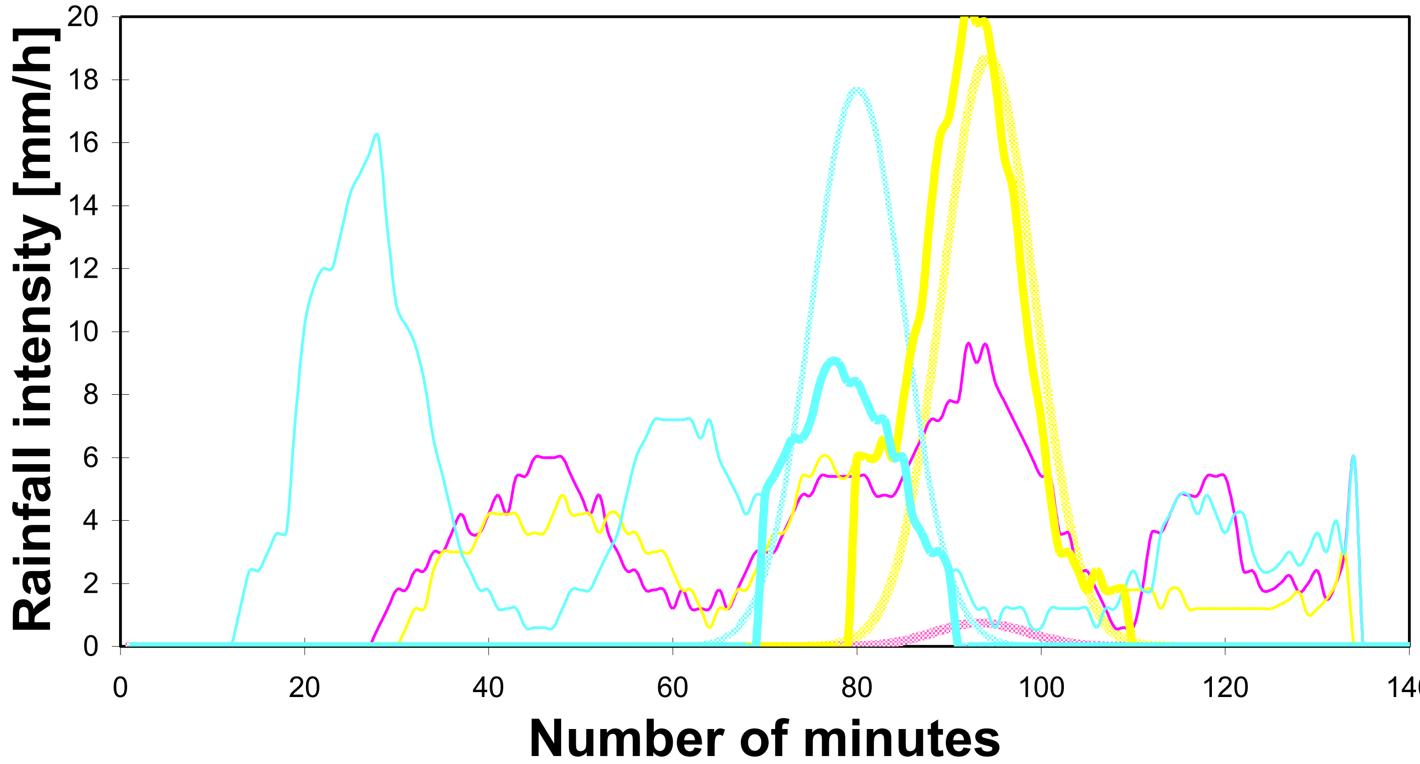
WP2: Fine-scale rainfall data acquisition and prediction:

Calibration conceptual rain storm model Leuven case



WP2: Fine-scale rainfall data acquisition and prediction:

Calibration conceptual rain storm model Leuven case



WP2: Fine-scale rainfall data acquisition and prediction:

Actions: <u>A6: rainfall estimation in pilot sites</u>

✓ Leuven (X-band radar DHI):

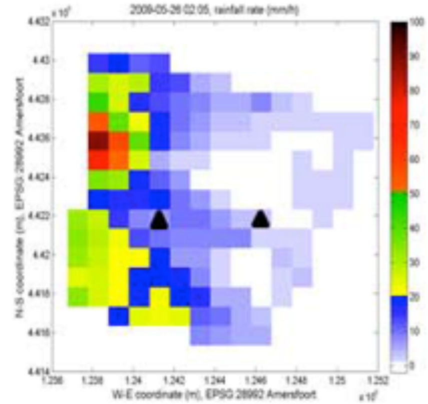
- Future:
  - Other merging methods: Kalman filter, quantile mapping, weather typing, scaling relations
  - Conceptual rain storm model:
    - filling-up missing sector direction airport
    - calibration stochastic spatial rainfall generator
    - nowcasting

WP2: Fine-scale rainfall data acquisition and prediction:

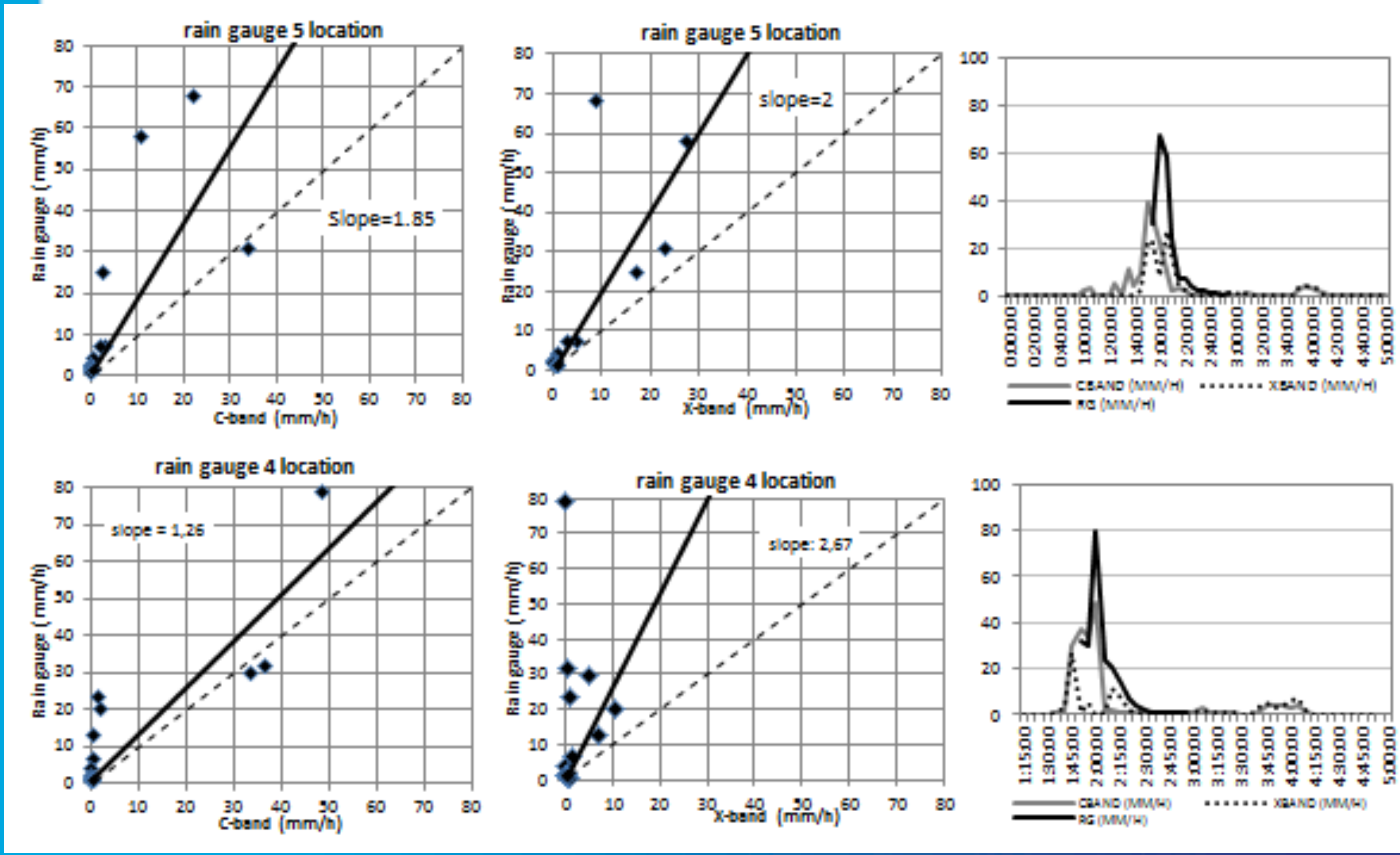
Actions: <u>A6: rainfall estimation in pilot sites</u>

- ✓ Rotterdam: experiences with Cabauw Experimental Site for Atmospheric Research (CESAR)
    - Comparison C-band, X-band & rain gauges data

WP2: Fine-scale rainfall data acq iction:



Radar – rain gauge comparison:



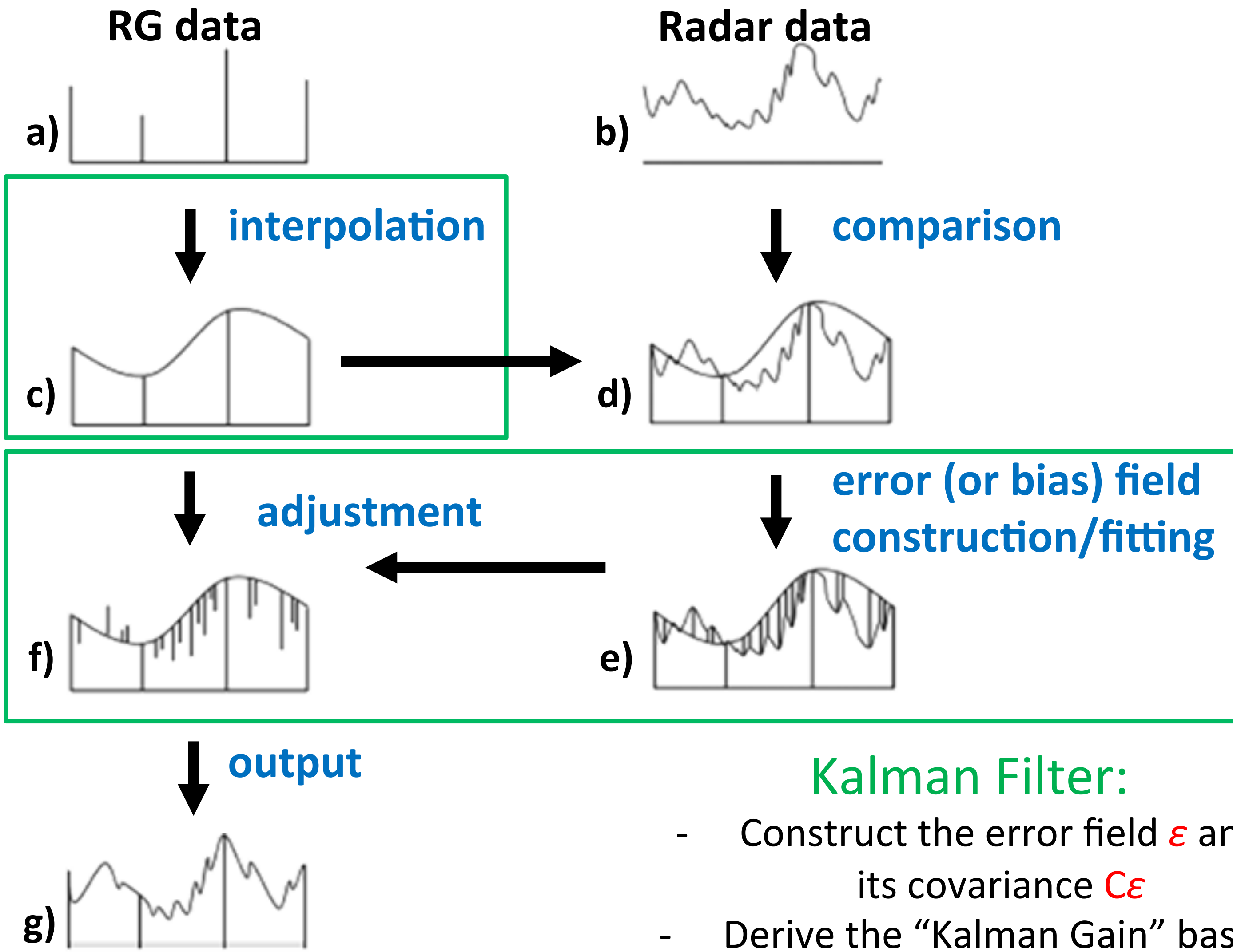
WP2: Fine-scale rainfall data acquisition and prediction:

Actions: <u>A6: rainfall estimation in pilot sites</u>

- ✓ London ("super resolution" C-band Met Office + soon: X-band Rainscanner Selex):
  - Clutter correction
  - Radar adjustment to rain gauges:
    - Mean Field Bias
    - KED
    - Static, dynamic & combined (Wood et al., 2000)
  - Radar – rain gauge integration:
    - Kriging & Kalman filter
    - + Local singularity analysis

Radar – rain gauge merging

Block-Kriging Interpolation:
- RG field y^G
- estimation error covariance $C\varepsilon_G$

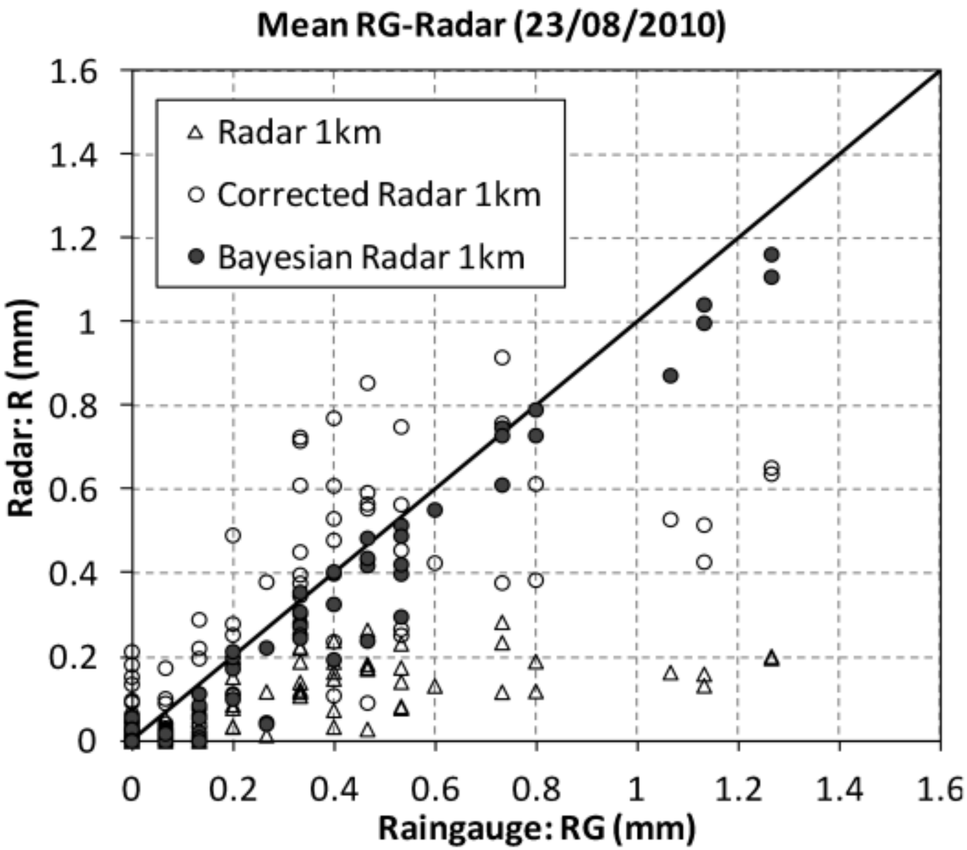


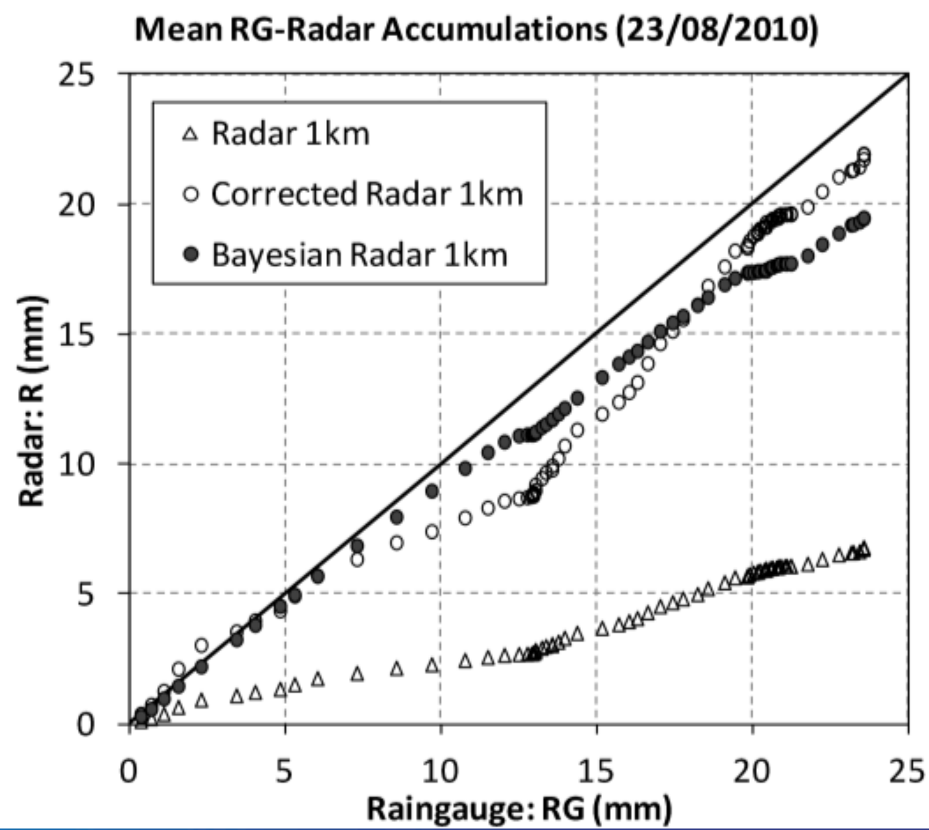
Kalman Filter:

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

WP2: Fine-scale rainfall data acquisition and prediction:

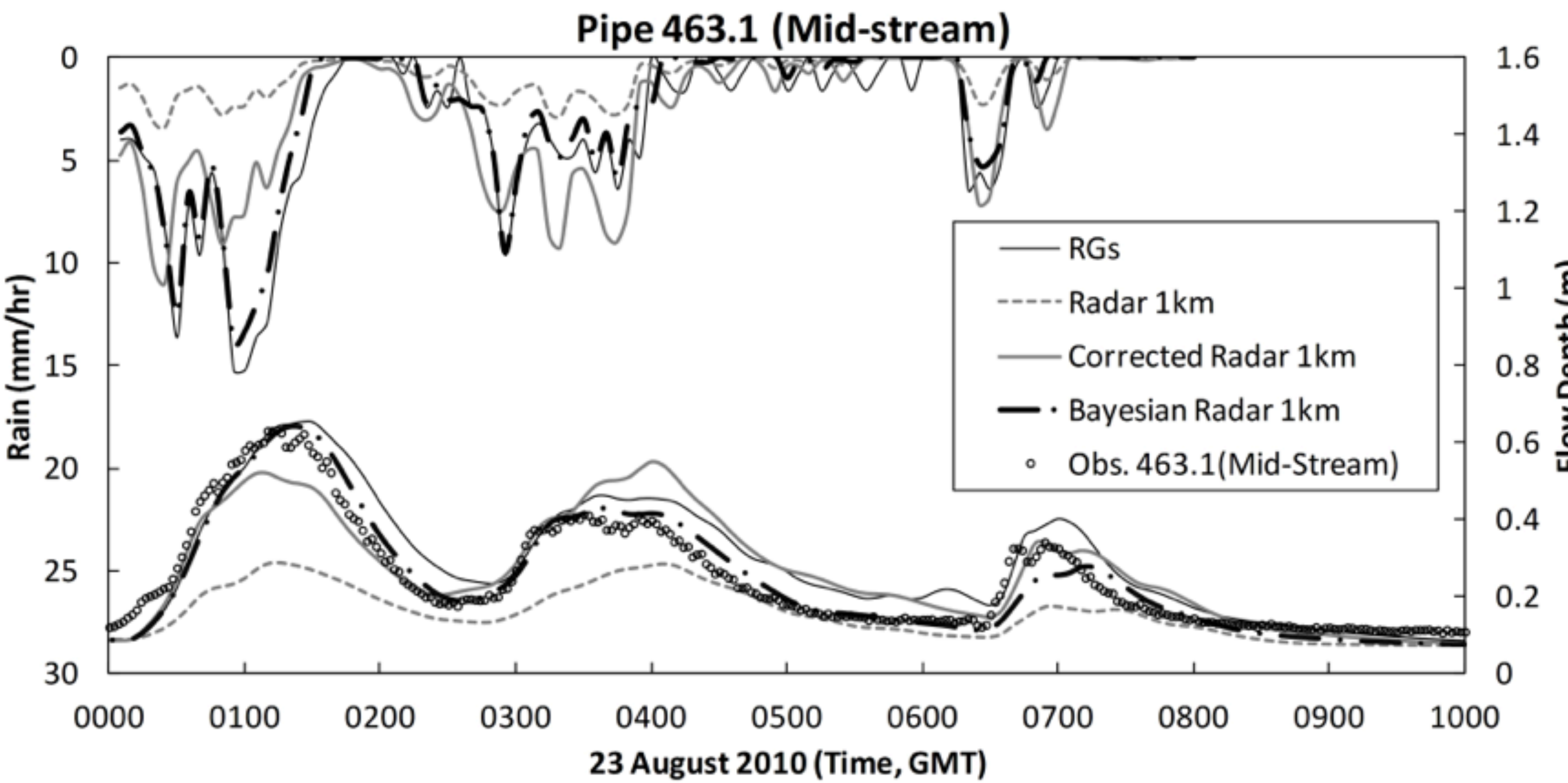
Comparison of radar adjustment methods (MFB, Kalman filter/Bayesian approach) London case:

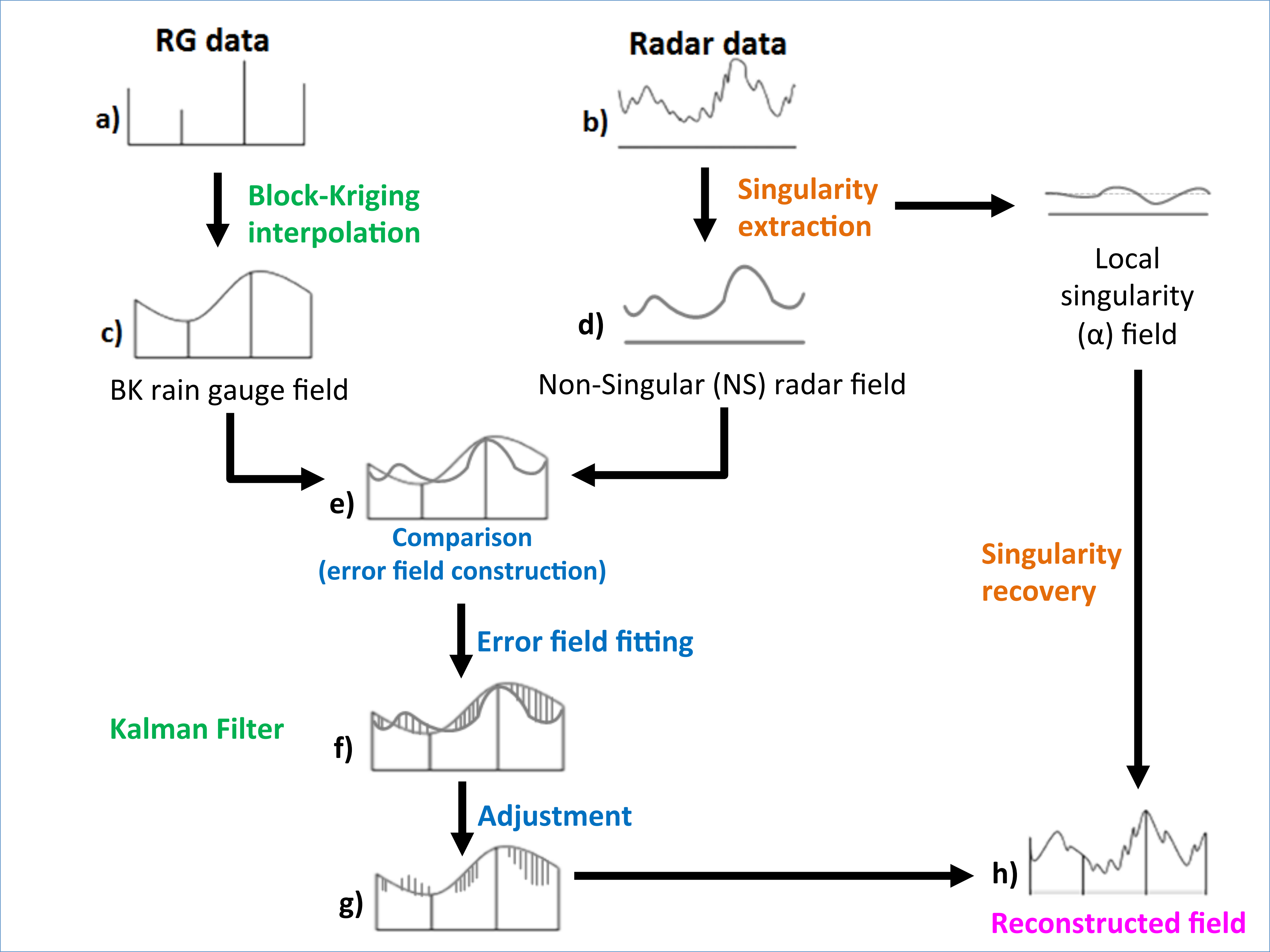




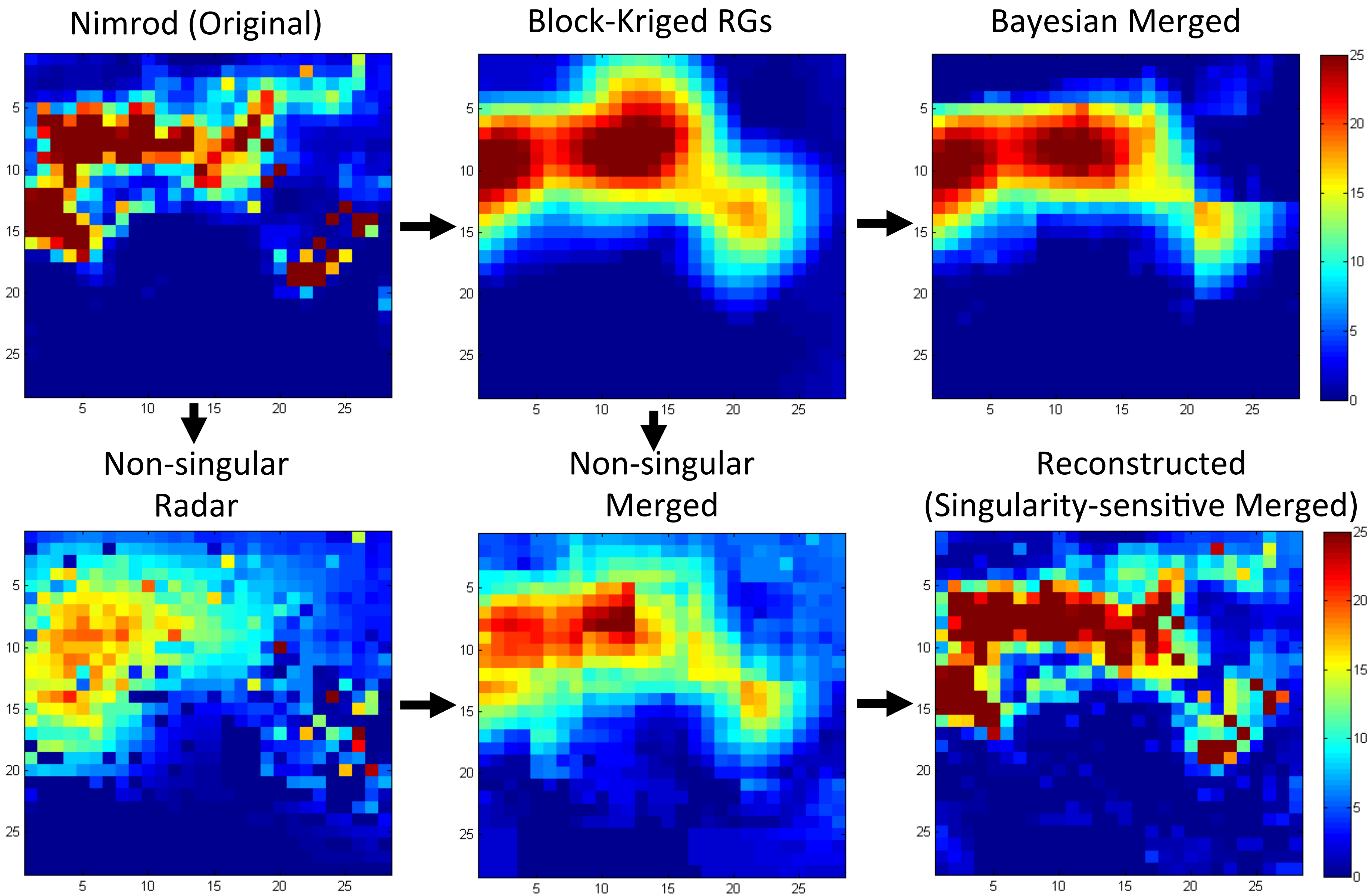
WP2: Fine-scale rainfall data acquisition and prediction:

Comparison of radar adjustment methods (MFB, Kalman filter/Bayesian approach) London case:

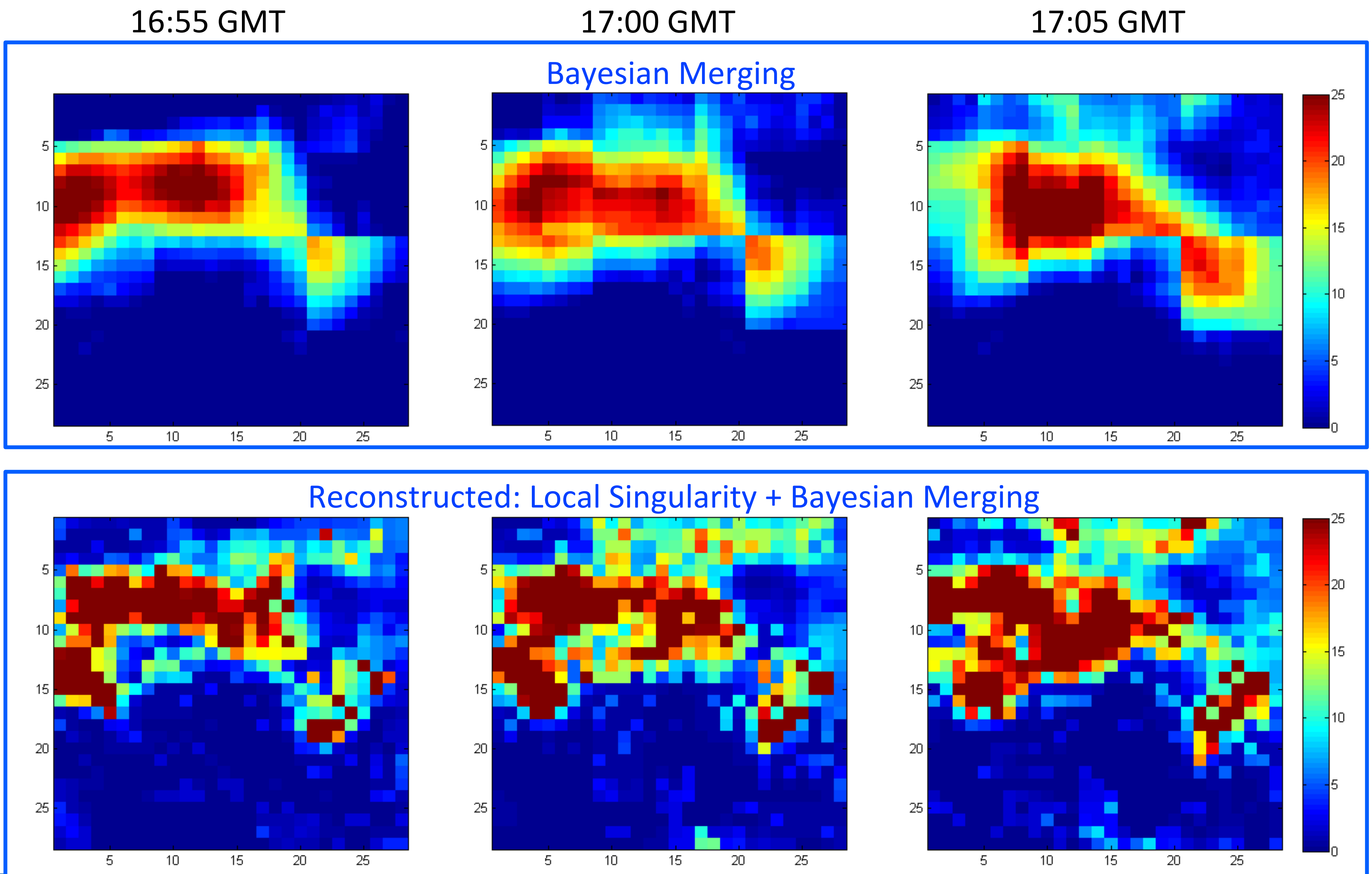



RG data
Radar data
a)
b)
Block-Kriging
interpolation
Singularity
extraction
Local
singularity
(α) field
c)
d)
BK rain gauge field
Non-Singular (NS) radar field
e)
Comparison
(error field construction)
Singularity
recovery
Error field fitting
Kalman Filter
f)
Adjustment
g)
h)
Reconstructed field

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



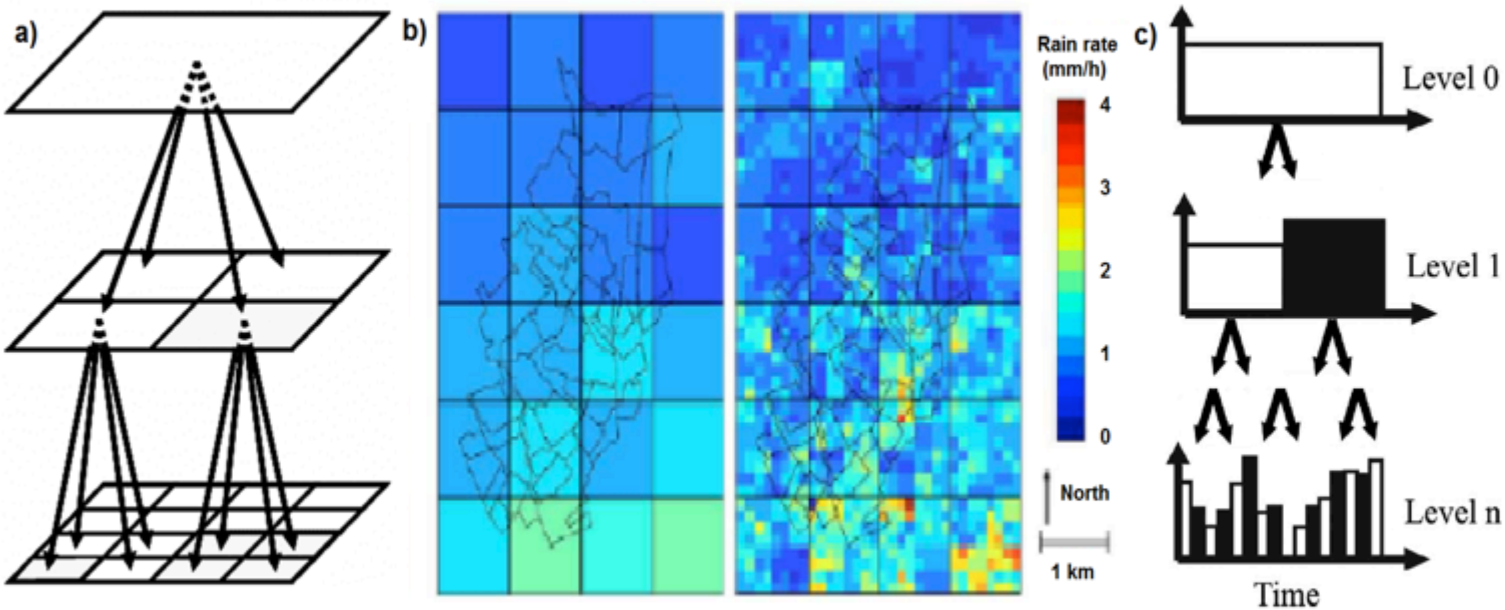
Merged radar rainfall estimates with local singularity analysis are visually more realistic and show better temporal continuity



WP2: Fine-scale rainfall data acquisition and prediction:

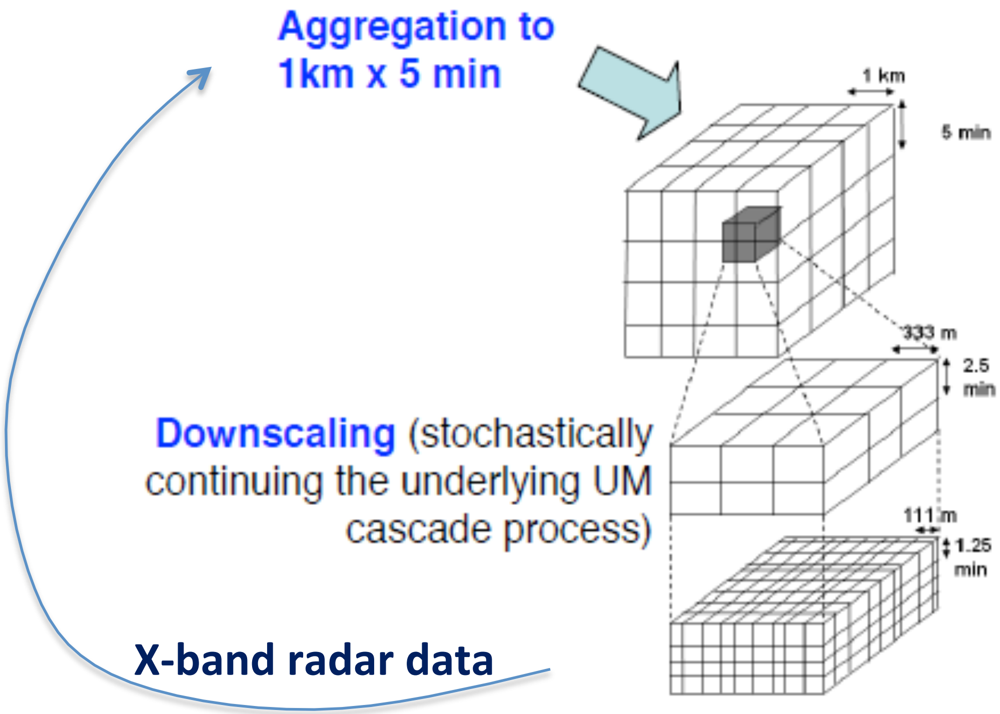
Actions: <u>A6: rainfall estimation in pilot sites</u>

- ✓ Paris:
  - ○ Multifractal based downscaling method, tested for C-band radar of Trappes (Météo-France) & dense network of point measurements (16 disdrometers Switzerland)



WP2: Fine-scale rainfall data acquisition and prediction:

Stochastic downscaling approach (Universal Multifractal cascade process)
Paris case:



WP2: Fine-scale rainfall data acquisition and prediction:

Stochastic downscaling approach (Universal Multifractal cascade process) Paris case:

- ✓ Estimation of uncertainty associated with small scale unmeasured rainfall variability (i.e. below the C-band radar resolution)
- ✓ Making use of scaling behaviour of rainfall in space and time
- ✓ Also hydrological model outputs have scaling behaviour! (water depth, discharge, velocity)
- ➢ Obtain extremes at very high resolution (e.g. 1 m) without having to run the model at these resolutions

WP2: Fine-scale rainfall data acquisition and prediction:

Actions: A6: rainfall estimation in pilot sites

Timing:

- ✓ Leuven & London: by spring 2014
- ✓ Rotterdam & Paris: by autumn 2014 (first results)
  summer 2015 (final results)

WP2: Fine-scale rainfall data acquisition and prediction:

Actions: <u>A7: Workshop on rainfall nowcasting (M6)</u>

- ✓ Outcome: recommended methods for fine-scale and short-term rainfall forecasting
- ✓ 31 March 2014, Antwerp
- ✓ Active role for radar meteorologists (MetOffice, RMI, Meteo France, KNMI)

WP2: Fine-scale rainfall data acquisition and prediction:

Actions: <u>A8: implementation for pilot sites</u>

- ✓ Outcomes: operational system for fine-scale rainfall forecasting in pilot sites + results for min. 10 extreme storms

✓ Timing:

Leuven & London: by summer 2015

WP2: Fine-scale rainfall data acquisition and prediction:

Actions A7 & A8: Rainfall forecasting (short-term forecasting = nowcasting)

Subtopics addressed:

- Combination of (fine and coarse scale) radar data with Numerical Weather Prediction (provided by national meteo services)
- Use of lightning detection data
- Advective-statistical forecast model
- Spatial and temporal downscaling
- Error/uncertainty estimation in function of forecast lead time / probabilistic forecasts
- Interfacing with the applications in WP3 & WP4

WP2: Fine-scale rainfall data acquisition and prediction:

Action A8: Rainfall forecasting (short-term forecasting = nowcasting)

London (ICL & Met Office i.c.w. Bristol University):

- STEPS nowcasting model (some tests already ongoing)

Leuven (KU Leuven i.c.w. RMI, linked to BelSPO PLURISK project):

- INCA nowcasting model RMI (C-band based)
- STEPS nowcasting model (some tests already ongoing)

Investing in Opportunities
This project has received European Regional Development Funding through INTERREG IV B.
INTERREG IVB

WP2: Fine-scale rainfall data acquisition and prediction:

Action A9: Guidelines

- ✓ Outcome: reference and user's manuals on developed technologies for rainfall estimation and nowcasting
- ✓ Training and dissemination during National Observer Meetings

WP1 & WP2:

RainGain fact sheets on "<u>rain gauge measurements in urban areas</u>"

Proposed outline:

- ✓ Different types of rain gauges
- ✓ Installation - location and surroundings
- ✓ Calibration
- ✓ Data retrieval
- ✓ Maintenance

No theoretical guidelines, but examples of "good practices" from RainGain pilot sites