Post-processing of radar rainfall estimates to enhance their applicability for urban hydrology

by

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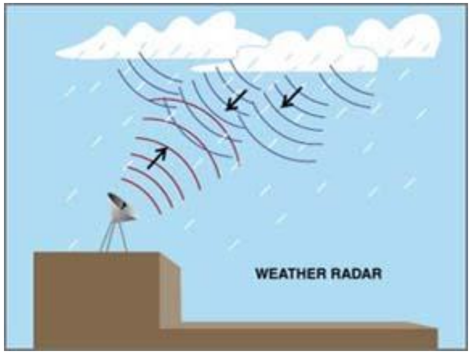
Generation of Radar Quantitative Precipitation Estimates (QPEs)

1. Reflectivity measurements (Z)



Source: Windows to the Universe

2. Corrections to reflectivity measurements

- Noise filtering
- Clutter filtering
- Beam blockage correction
- Spurious echo identification
- Attenuation correction
- Vertical profile reflectivity correction

3. Rain Rate Estimation

Single-Pol: $R = a \cdot Z^b$

Dual-Pol: $R = R(Z, Z_{\mathrm{DR}})$

$R = R(K_{\mathrm{DP}}, Z_{\mathrm{DR}})$

Polarimetric Radar QPEs

- May still contain errors
- Resolution may be insufficient for hydrological applications

Further post-processing may improve accuracy and improve their applicability for hydrological applications

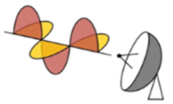
Post-processing techniques investigated throughout the RainGain project:

- **<u>Merging of radar & rain gauge rainfall estimates</u>** to combine their advantages and overcome their disadvantages.

  Investigations conducted at two scales:

  - Nation-wide strategies (complementary project)
  - Localised (urban) strategies

Localised, accurate



Good coverage and spatial description

- **<u>Temporal interpolation of radar images</u>** to obtain higher temporal resolution radar estimates

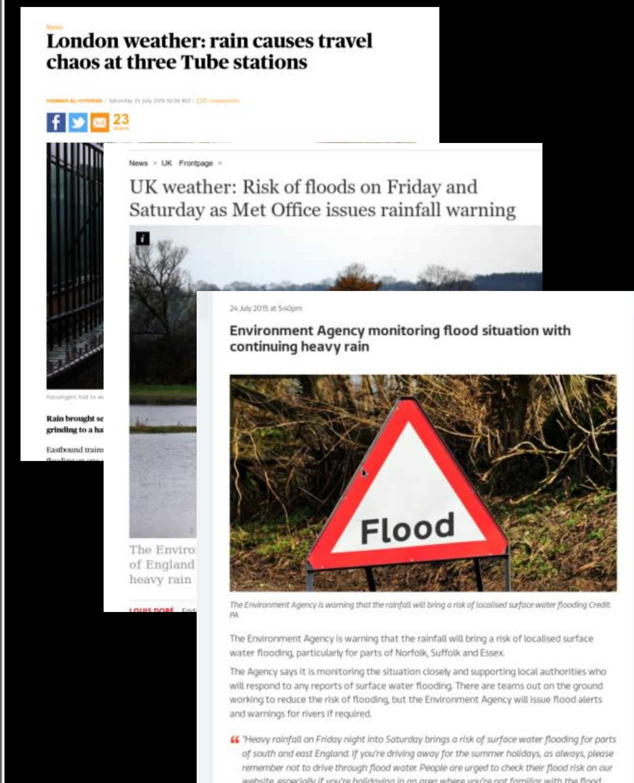
Merging Gauge and Radar Data

Sharon Jewell, Shona Bryce and Katie Norman

RainGain NOG Meeting, 11th September 2015

Environment Agency

Merging Gauge and Radar Data


London weather: rain causes travel chaos at three Tube stations

News > UK > Frontpage >

UK weather: Risk of floods on Friday and Saturday as Met Office issues rainfall warning

24 July 2015 at 5:40pm

Environment Agency monitoring flood situation with continuing heavy rain

The Environment Agency is warning that the rainfall will bring a risk of localised surface water flooding Credit: PA

The Environment Agency is warning that the rainfall will bring a risk of localised surface water flooding, particularly for parts of Norfolk, Suffolk and Essex.

The Agency says it is monitoring the situation closely and supporting local authorities who will respond to any reports of surface water flooding. There are teams out on the ground working to reduce the risk of flooding, but the Environment Agency will issue flood alerts and warnings for rivers if required.

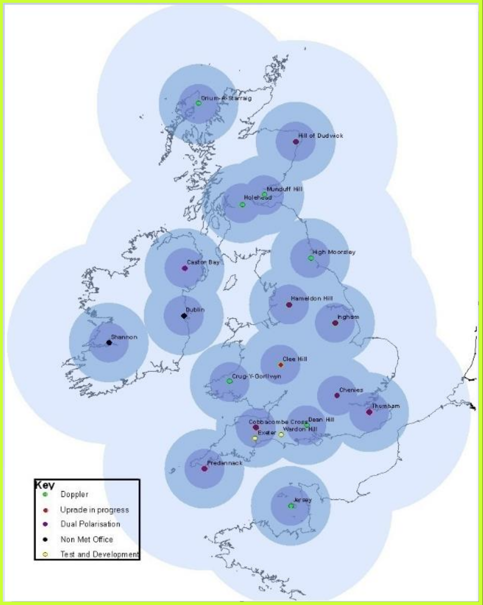
"Heavy rainfall on Friday night into Saturday brings a risk of surface water flooding for parts of south and east England. If you're driving away for the summer holidays, as always, please remember not to drive through flood water. People are urged to check their flood risk on our website, especially if you're holidaying in an area where you're not familiar with the flood

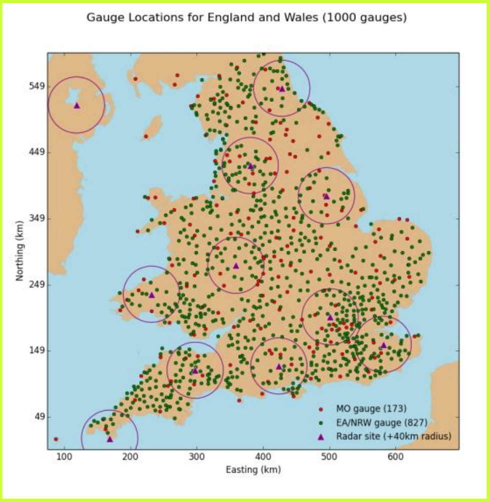
- A joint project is underway between the Met Office and the Environment Agency to *deliver a raingauge-radar merged product, every 15 minutes, for hydrological modelling applications.*
- Preliminary studies showed that merging produced a QPE with errors lower than either of the two input datasets.
- Currently in the process of turning the prototype into an operational product for England and Wales.

Merging Gauge and Radar Data

Met Office

- British Isles Radar composite:
  - Measures rain*rates* every 5 minutes (mm/h)
  - 18 sites available (10 in England and Wales)
  - Best quality data within ~40 km of radar site
- MO and EA gauge networks:
  - 1000 TBR gauges in total (August 2015)
  - 0.2 mm quantisation
  - Polling (i.e. Data downloaded to a central hub) varies from every 15 minutes to daily
    - 55% of data available within 3 hours (July 2015)
    - 99% of data available within 24 hours.





Gauge – Radar Merging: Gauge QC

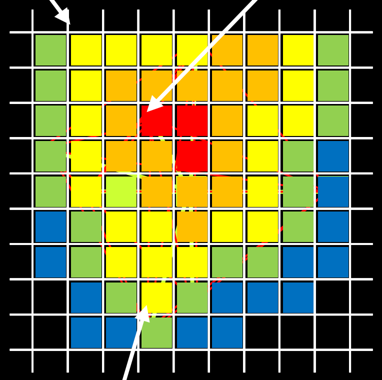
Met Office

- Real-time gauge QC process applied to gauge data prior to merging
- Potential errors are flagged and rated
- Tests include:
  - Multiple tips (Time of Tip info)
  - Blocked gauges (Cumulative sum)
  - Spatial check (Compare with nearest neighbours)
  - Air / Soil temperature (Identify snow / frozen precipitation)
- Our studies show that it is preferable to use a threshold approach in order to retain gauges with a low error probability than to reject all flagged gauges.

Tipping Bucket Raingauge mechanism

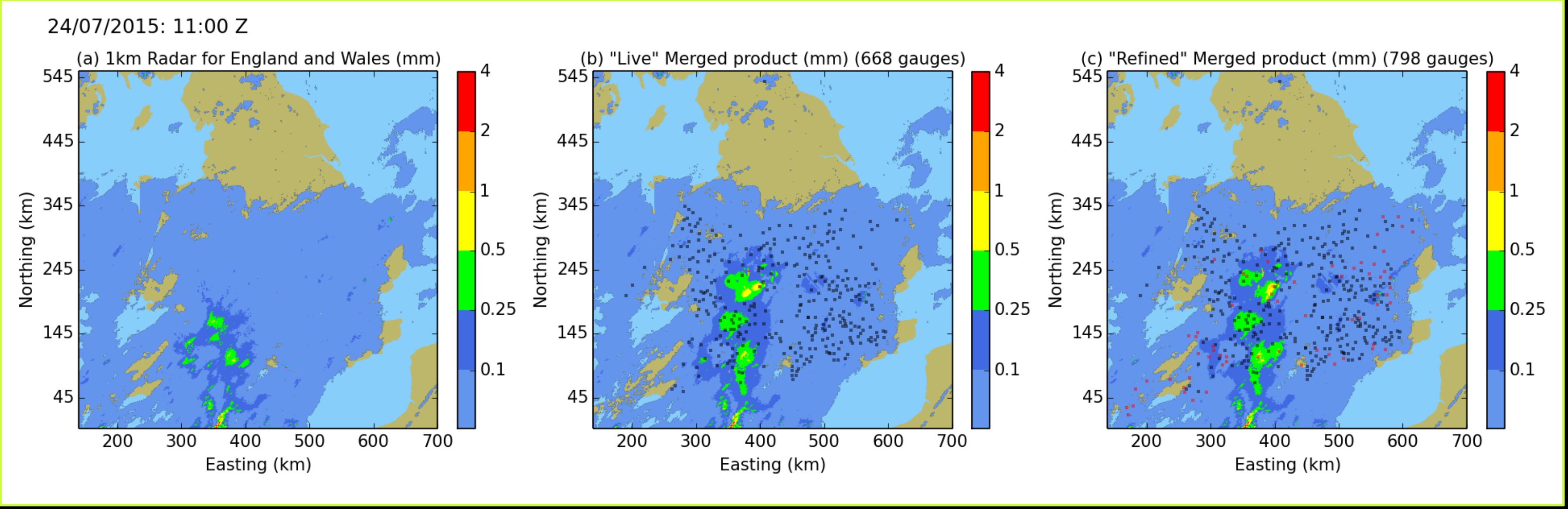
Gauge – Radar Merging: Kriging

- Radar and QC'd gauge data are blended using Kriging with External Drift
- For each 1 km pixel in the composite, the merged value is calculated by applying weightings to the nearest neighbour gauges, which are derived from:
  - Distance from the nearest neighbour gauges
  - Covariance of the gauges (i.e. How they are spatially distributed)
  - Spatial variation of the radar data
- Output is a 1km resolution grid 525 km x 580 km
- Code takes < 20 minute to run (currently un-optimised).



Gauge – Radar Merging: Output

- Scheme operational since November 2014
- Runs every 15 minutes, 3 hours and 24 hours behind the validity time



Examples of radar, "Live" merged and "Refined" merged rainfall for a single 15 minute rainfall accumulation at 11:00 on 24th July 2015

Merged product: General Skill Scores

- Analysis performed on 10 weeks of data collected between 8th Nov 2014 – 17th Jan 2015.
- Measurable improvement in the merged MAE and bias for high thresholds.
- Detection efficiency also improves.

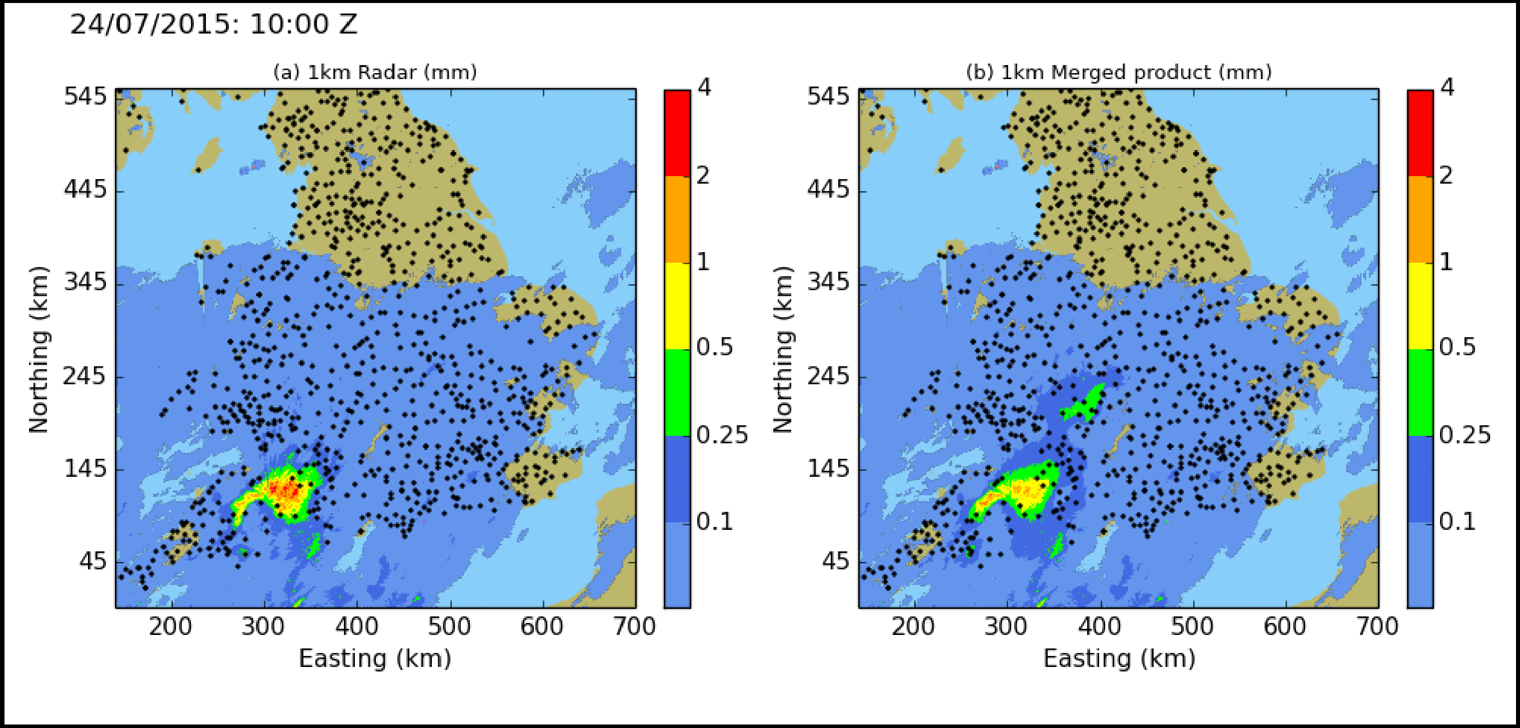
Mean Average Error (mm per 15 minute accumulation)			
Threshold	Radar MAE	Merged MAE	Δ MAE
≥ 0.4 mm	±0.39	± 0.34	- 0.05 (12 % reduction)
≥ 1.0 mm	± 0.81	± 0.69	- 0.12 (15 % reduction)
≥ 2.0 mm	± 1.80	± 1.60	- 0.20 (11 % reduction)
≥ 3.0 mm	± 2.88	± 2.67	- 0.21 (7 % reduction)

Bias (mm per 15 minute accumulation)			
Threshold	Radar bias	Merged bias	Δ bias
≥ 0.4 mm	-0.24	-0.21	+ 0.03 (13 % reduction)
≥ 1.0 mm	-0.68	-0.56	+ 0.11 (17 % reduction)
≥ 2.0 mm	-1.75	-1.50	+ 0.25 (14 % reduction)
≥ 3.0 mm	-2.88	-2.67	+ 0.21 (7 % reduction)

	Critical Success Index (CSI)			Probability of detection (POD)		
Threshold	Radar	Merged	**Δ CSI**	Radar	Merged	**Δ POD**
≥ 0.4 mm	0.41	0.48	**+0.07**	0.41	0.48	**0.07**
≥ 1.0 mm	0.18	0.26	**+0.08**	0.23	0.32	**0.09**
≥ 2.0 mm	0.05	0.09	**+0.04**	0.07	0.12	**0.05**
≥ 3.0 mm	0.01	0.04	**+0.03**	0.02	0.05	**0.03**

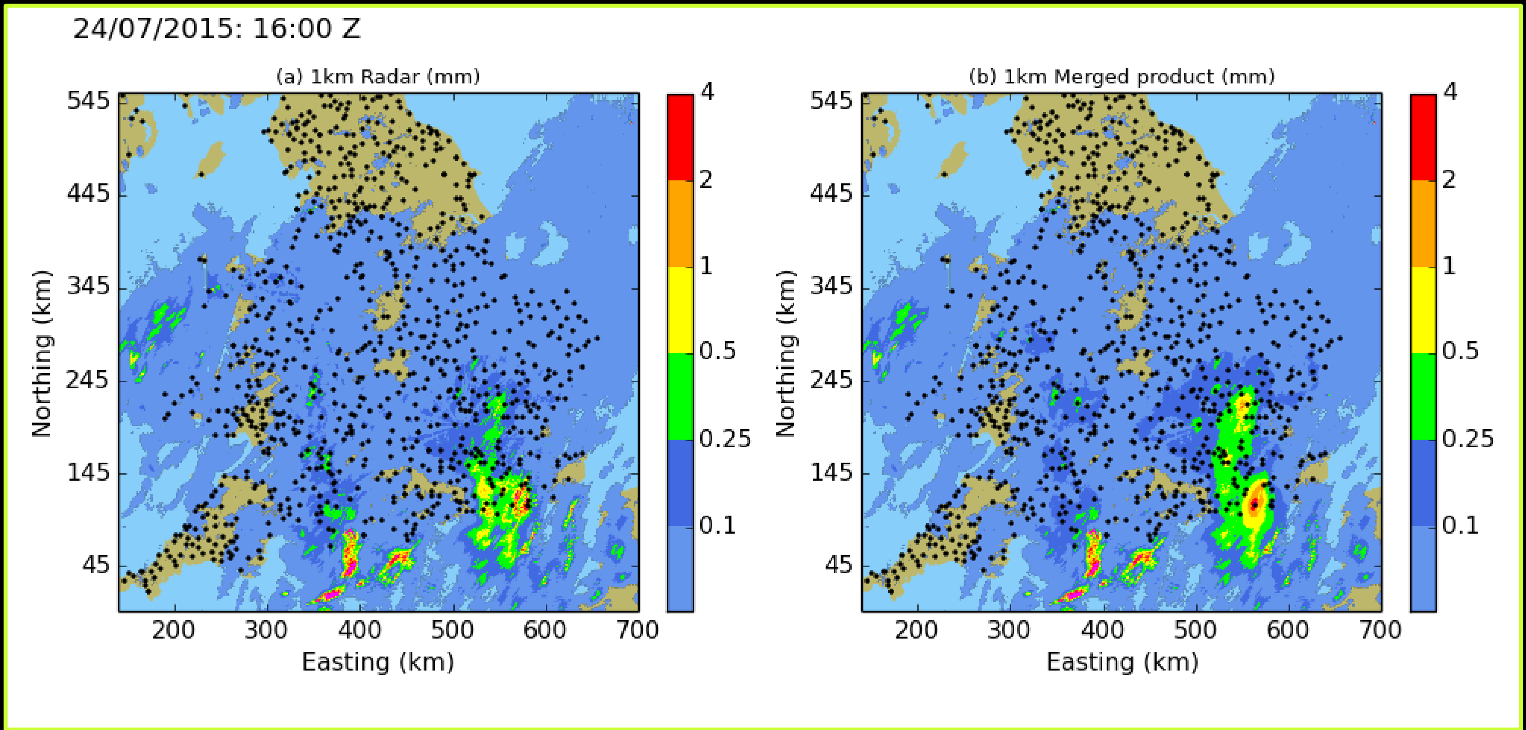
Merged product case study:
- Embedded intense rainfall

15 minute accumulations on 24/07/2015



Merged product case study: - Embedded intense rainfall

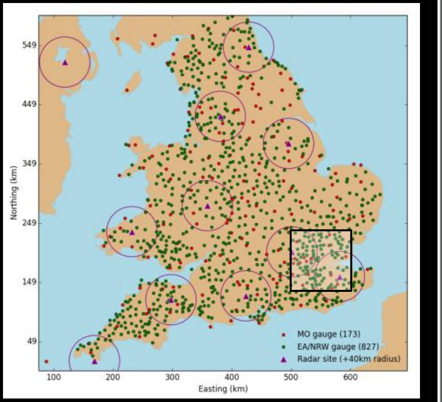
15 minute accumulation ending 24/07/2015 16:00 Z



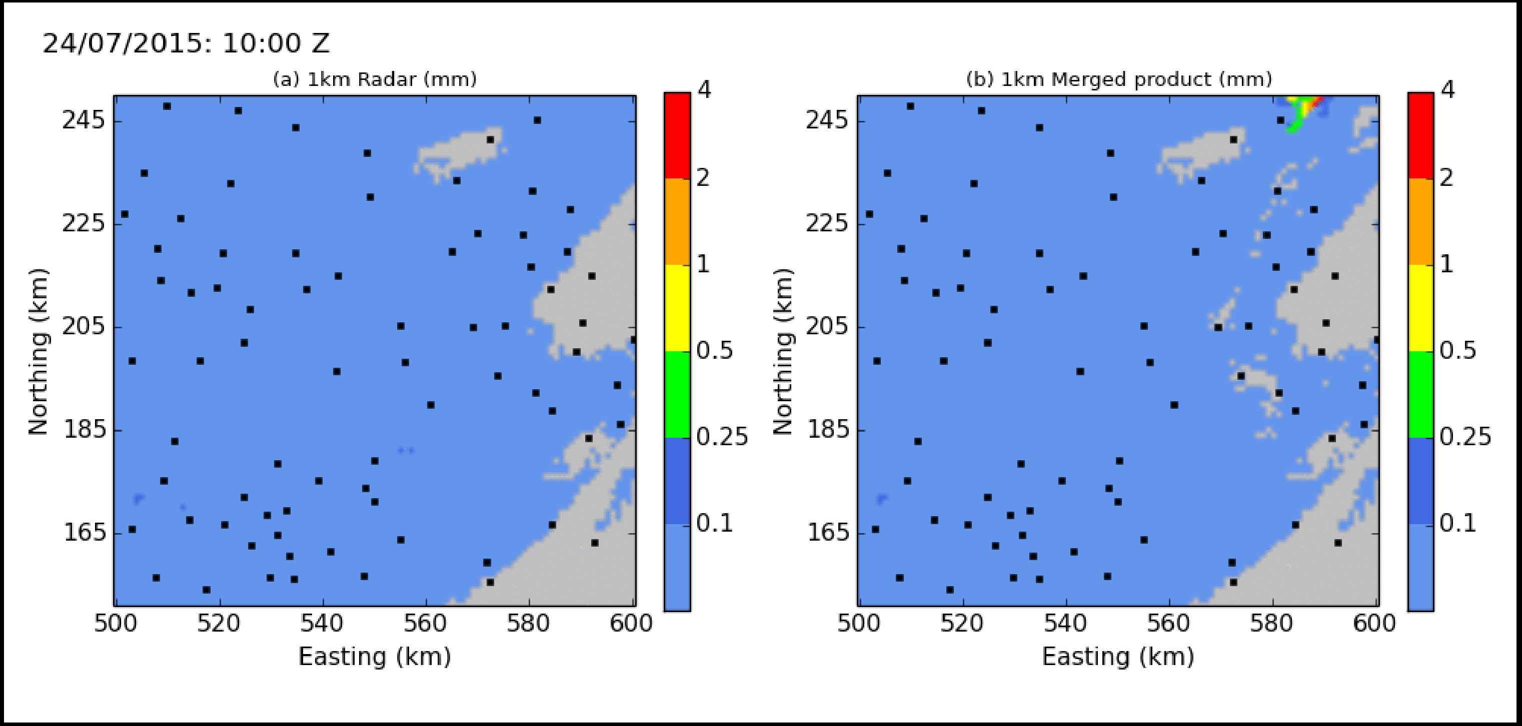
Widespread embedded intense rainfall event across England and Wales (1.0 mm threshold)						
Scheme	**RMSE**	**MAE**	**bias**	**CSI**	**POD**	**Fbias**
Radar	0.96 mm	0.72 mm	-0.52 mm	0.25	0.31	0.59
Merged	0.81 mm	0.53 mm	-0.40 mm	0.36	0.43	0.64

Met Office

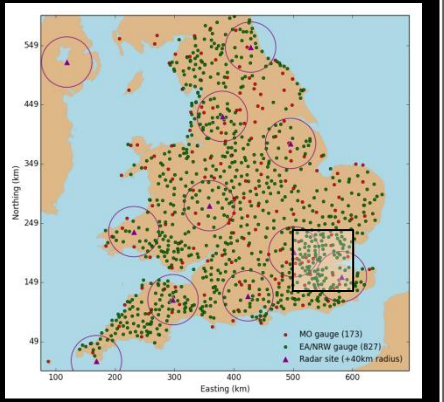
Merged product case study: - London – 24/07/2015



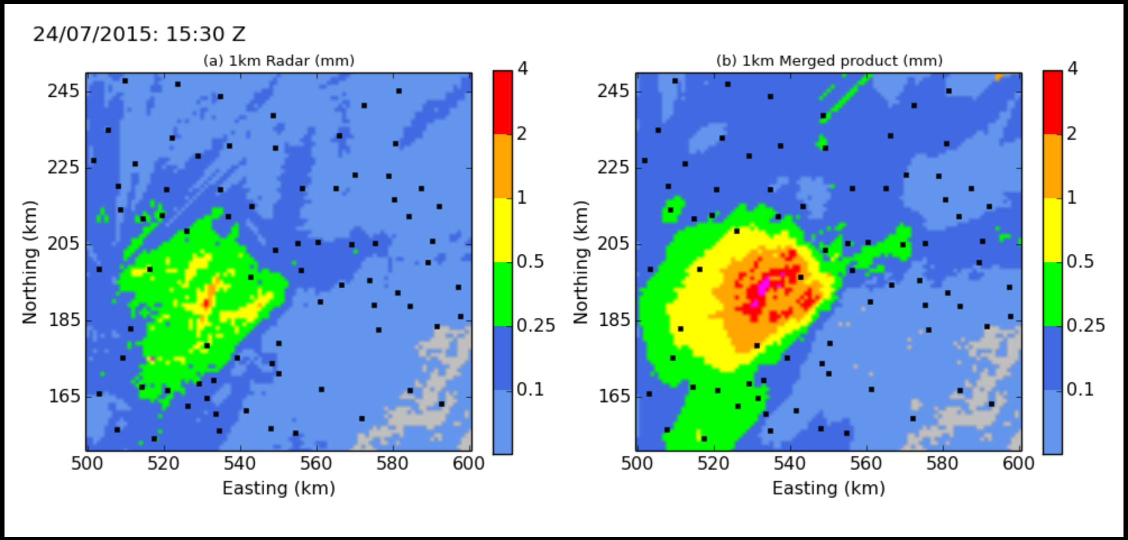
- Rainfall caused widespread travel disruption across London and the South East



Merged product case study: - London – 24/07/2015



- Statistics calculated for intense rainfall event over 24 hours from 09:00 on 24th July 2015.
- 0.2 mm threshold from 15 minute accumulations.



Intense rainfall event over London (1.0 mm threshold)						
Scheme	**RMSE**	**MAE**	**bias**	**CSI**	**POD**	**Fbias**
Radar	0.72 mm	0.60 mm	-0.54 mm	0.26	0.27	0.34
Merged	0.61 mm	0.47 mm	-0.26 mm	0.35	0.50	0.91

Conclusions

- Blending gauge information with radar data using KED produces a merged product with a lower measurement error than the constituent data-sets.
- A real-time gauge QC process maximises the available gauge density available with minimal impact on the quality of the merged product.
- A measurable improvement (> 0.2 mm) is seen in the quality of the 15 minute accumulation readings for high intensity (>2.0 mm) rainfall.

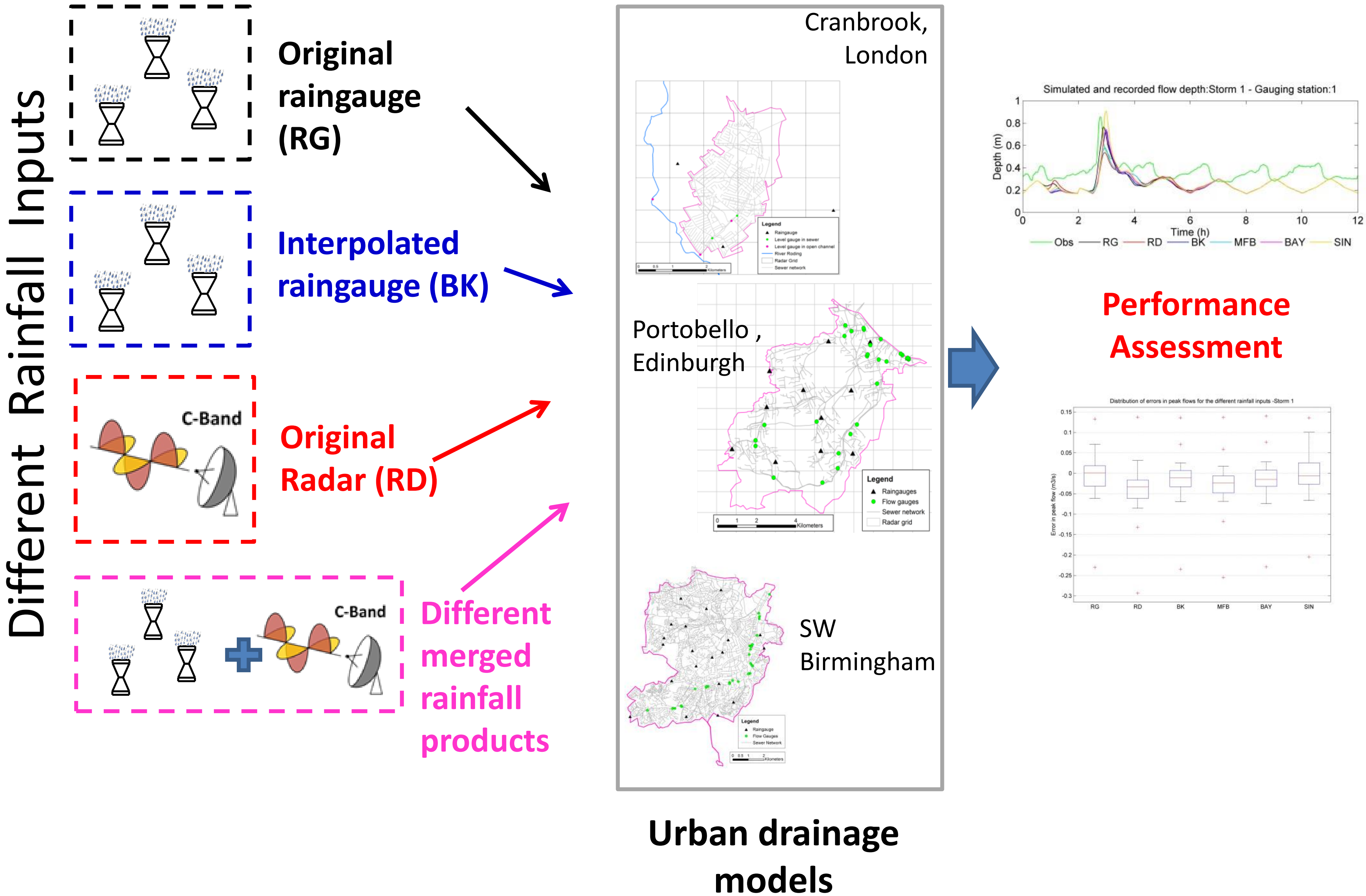
Merging of radar & rain gauge merging at urban scales

The combination of radar and rain gauge data is not a new concept

But:

- Adjustments commonly applied at large scales and resulting estimates are still of insufficient accuracy for urban hydrological applications
- Suitability of methods for urban scales has not been explored

GENERAL METHODOLOGY



RADAR-RG MERGING TECHNIQUES APPLIED IN THIS STUDY

1. Mean Field Bias (MFB) adjustment:

- Mean raingauge rainfall records over a specific area are assumed to be truth and able to represent the areal rainfall volume: $Bias_{last\ 1h} = \frac{\sum RG}{\sum RD}$

2. Kriging with External Drift (KED):

- Simple method to include radar rainfall estimates in the raingauge interpolation process.
- This is done by constraining the weighting factor (λ_i^{KED}) with the spatial association between radar values.

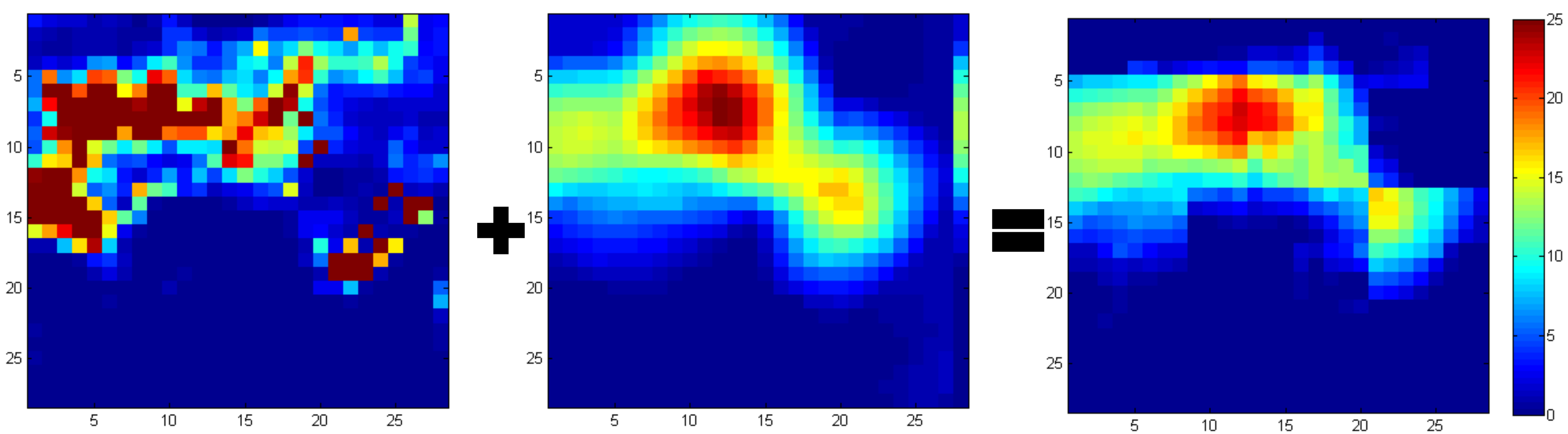
3. Bayesian (BAY) adjustment: *(Todini, 2001)*

- Neither radar nor raingauge estimates are fully trusted

- Main idea: analyse the uncertainty of rainfall estimates from different sources (in this case radar and raingauge sensors) and combine them such that the overall uncertainty is minimised

- Has shown to improve upon MFB, but, same as most merging methods, it is based upon 2nd order (statistics) approximations which smooth off peaks observed in radar fields

Nimrod (Original) Block-Kriged RGs Bayesian Merged

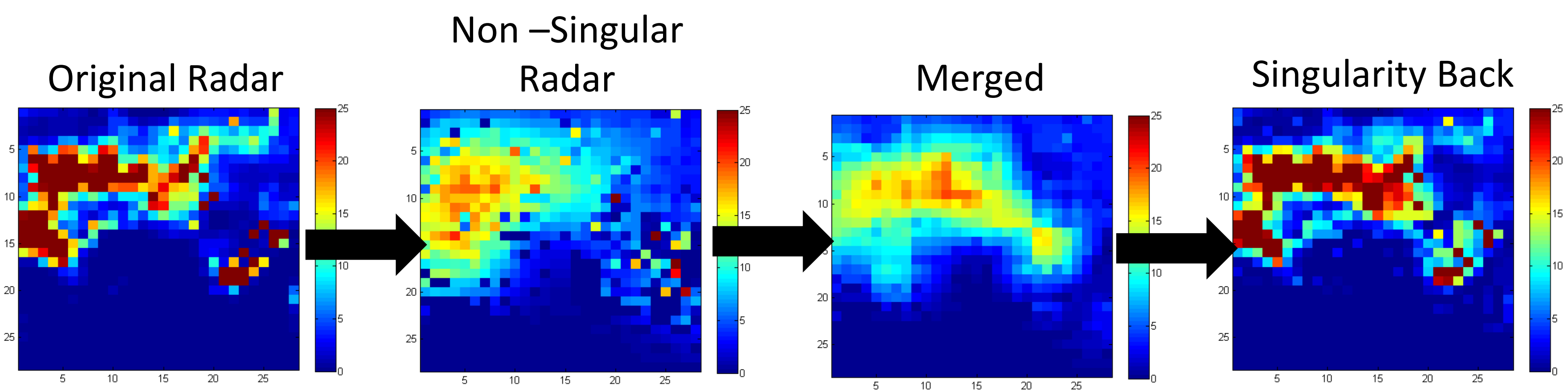


3. Singularity-Sensitive Bayesian (SIN) adjustment:

(Wang et al. (2015), HESSD)

- Developed to overcome a shortcoming of the original Bayesian (BAY), which tends to smooth storm extremes initially observed in radar images

- This method identifies **local extremes** (i.e. **singular points**) and extracts them from the radar image before the merging takes place. After the merging is finished, the singularities are applied back and proportionally to the rainfall field.



FINDINGS AND IMPLICATIONS

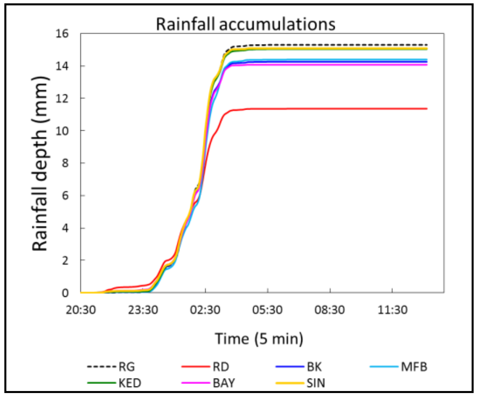
- **All adjustment methods improve the applicability of the original RD and RG rainfall estimates** to urban hydrological applications

- Degree of improvement varies for each method

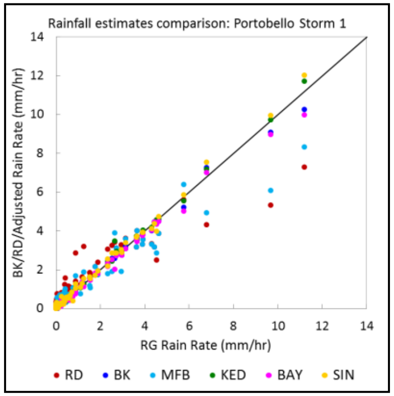
- **MFB is insufficient** for satisfactorily correcting the errors in RD -> **more dynamic and spatially varying adjustment** methods required

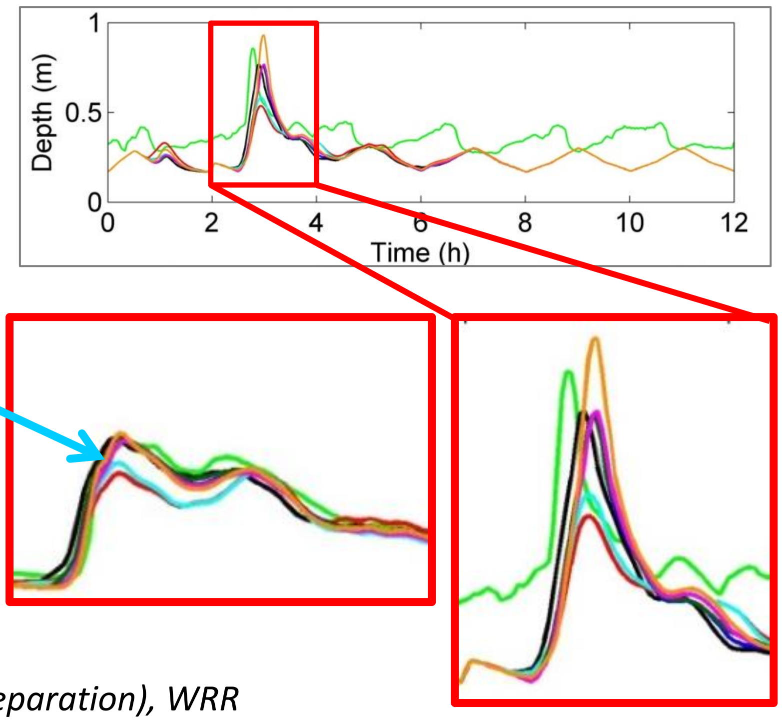
- <u>At high rain gauge densities</u>: **KED, BAY and SIN** rainfall estimates show **very good quantitative performance**

Event Accumulations

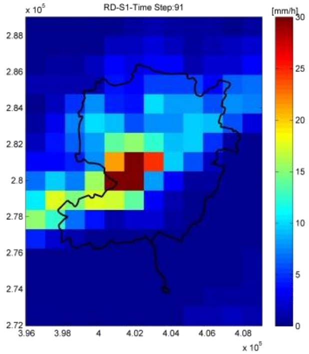


Rain Rates





Ochoa-Rodriguez et al. (2013, 2014), UDG; Ochoa-Rodriguez et al. (in preparation), WRR



Original Radar Image

IMPACT OF GAUGE DENSITY ON MERGED QPEs

Storm 1 – 05-06/10/2011 – Peak intensity (time step: 91)

High density

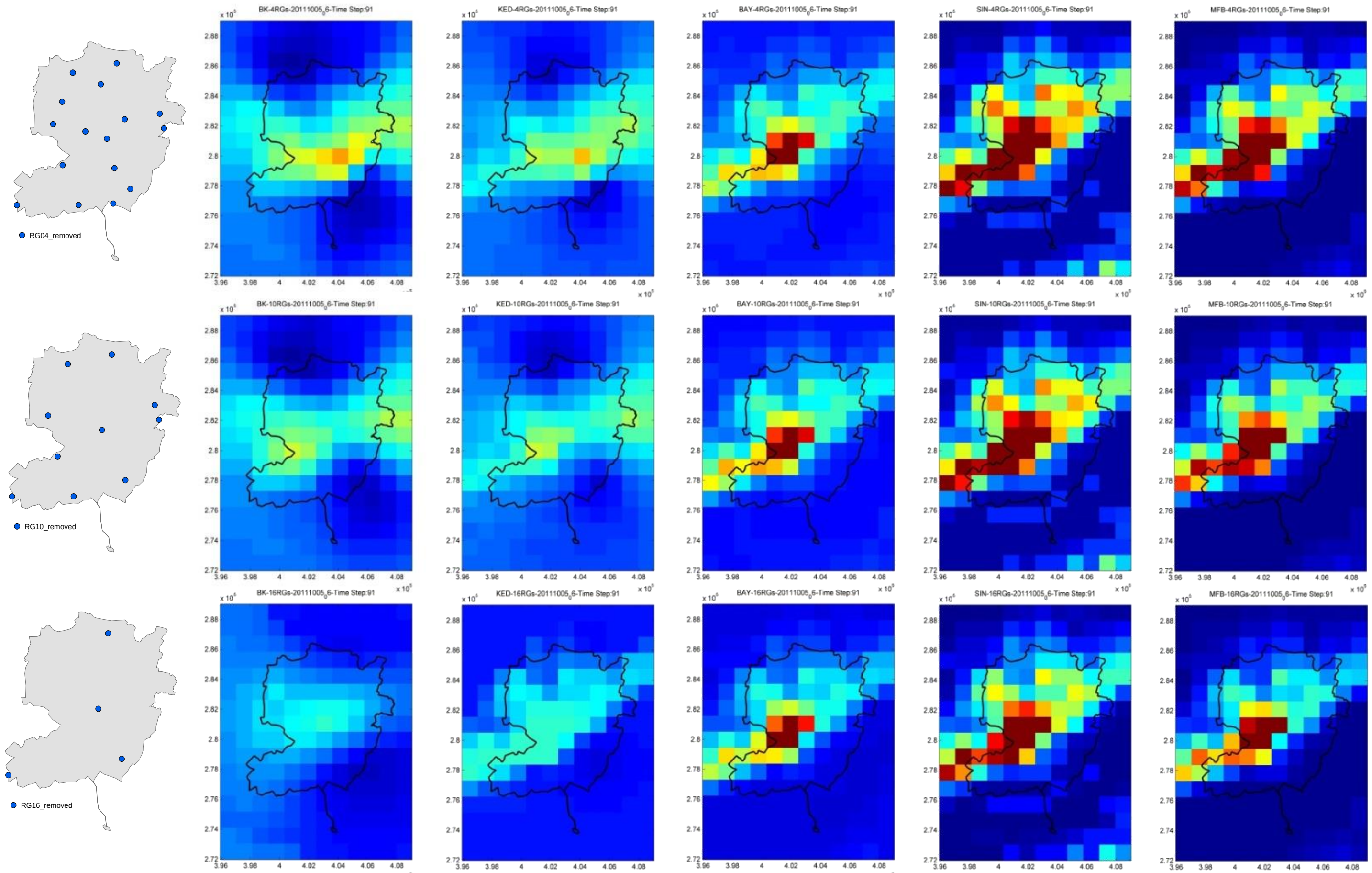
Low density

1 RG / 4 km^2

1 RG / 6.5 km^2

1 RG / 16.5 km^2

BK KED BAY SIN MFB



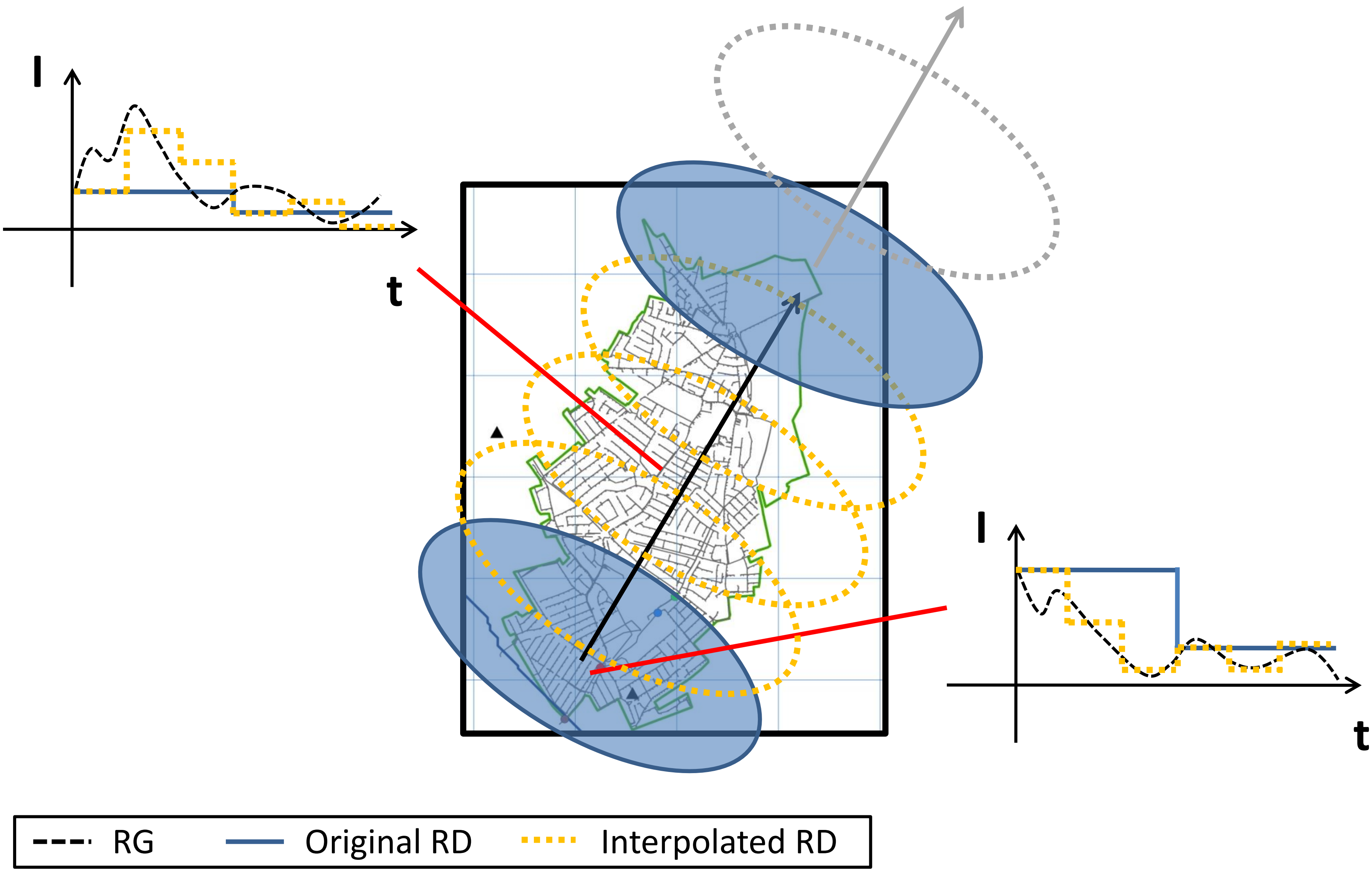
- <u>At low rain gauge densities:</u> **KED's performance decreases**, **advantage of SIN is particularly evident**

Temporal interpolation of radar images

Objective:

To obtain higher temporal resolution radar rainfall estimates (~1-2 min), based upon initial radar images taken every 5 or 10 min

STORM MOVEMENT TRACKING USING HIGH-RESOLUTION RADAR RAINFALL IMAGES



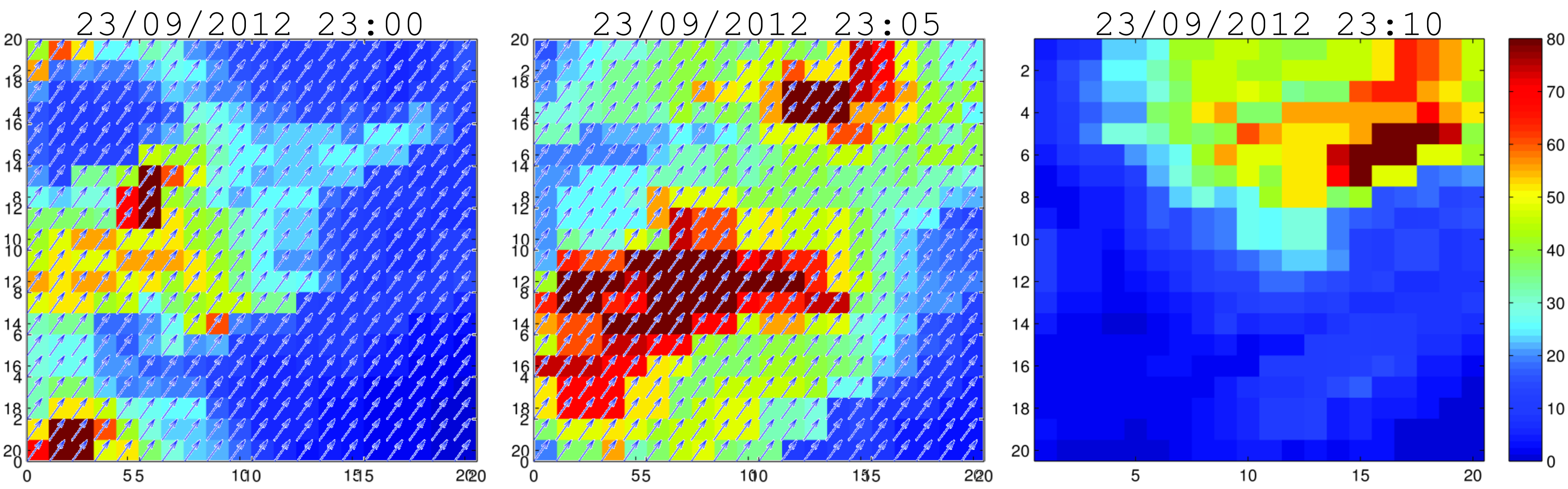
DEVELOPMENT OF A RAIN FIELD TRACKER

Optical Flow Constraint (OFC):

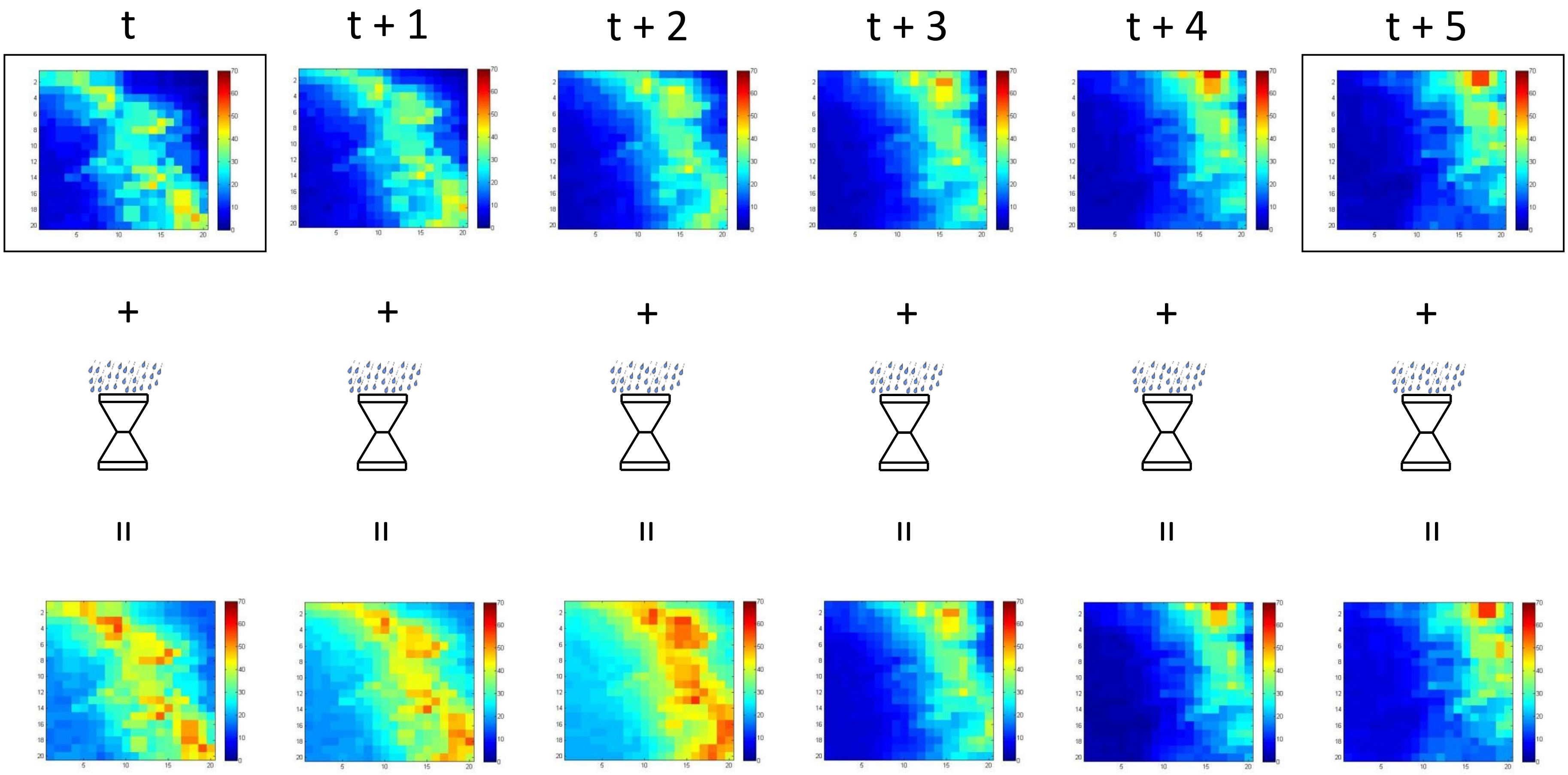
$$I(x, y, t) = I(x + u\Delta t, y + v\Delta t, t + \Delta t)$$

Two special treatments for small-scale applications:

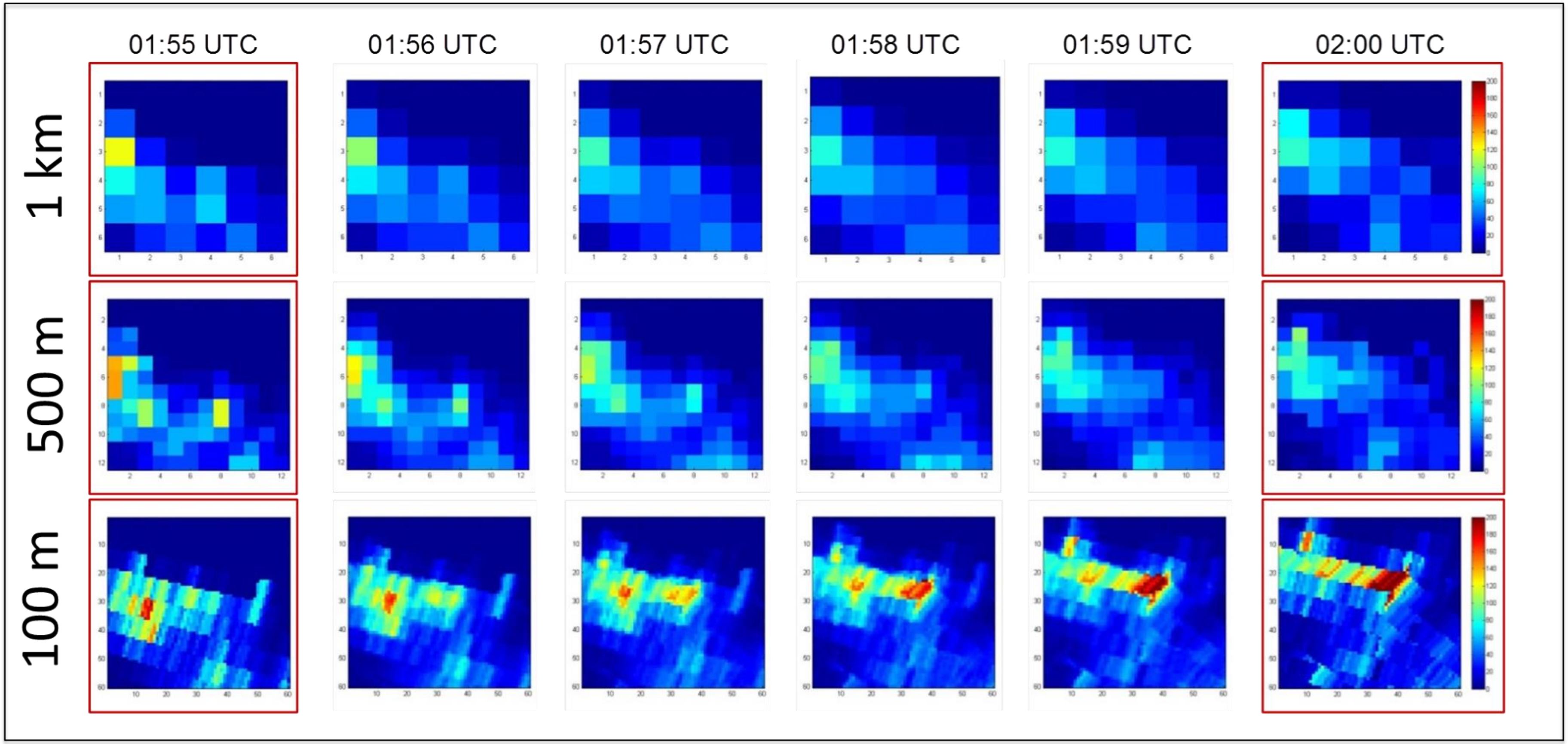
1. **Relaxation of optical flow constraint**
2. **Multi-scale numerical strategy**



ADVECTION-BASED TEMPORAL INTERPOLATION
+
GAUGE-BASED RADAR DATA ADJUSTMENT

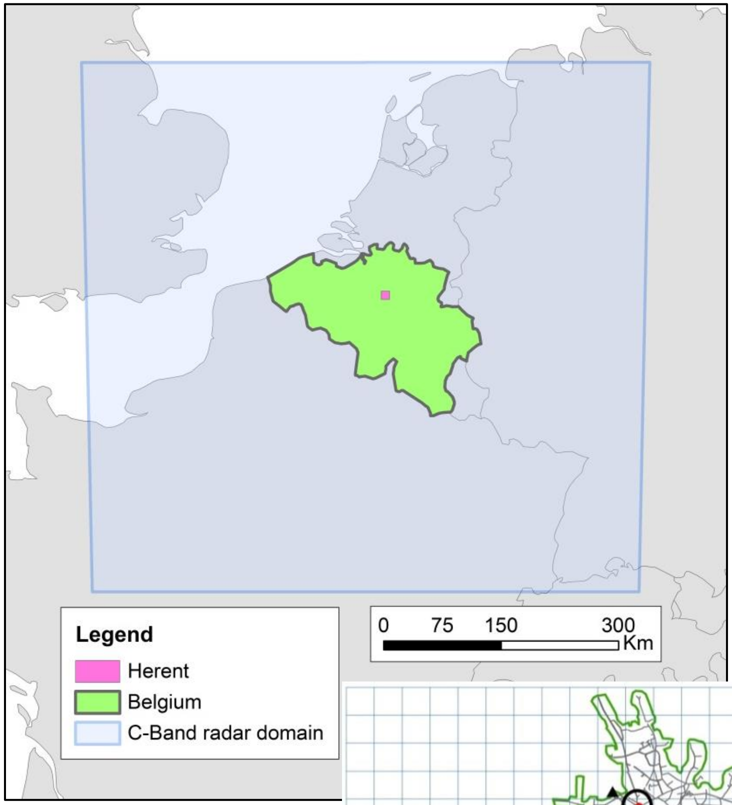


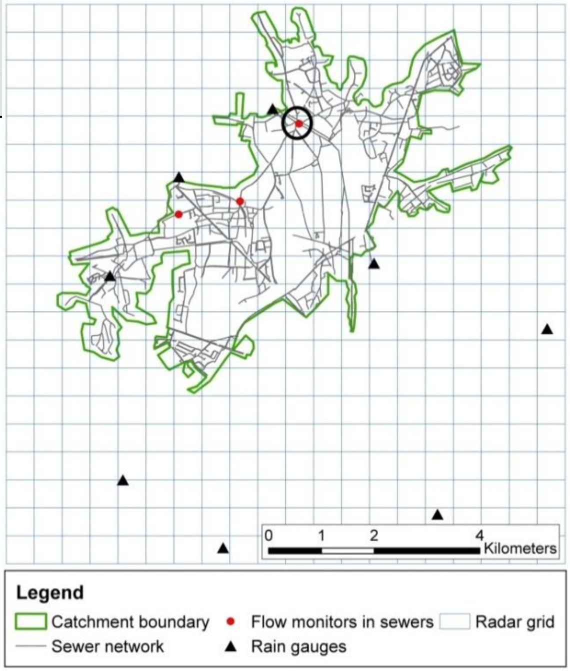
TEMPORAL INTERPOLATION OF RADAR IMAGES ACROSS MULTIPLE SPATIAL SCALES



CASE STUDY: Herent, Belgium

- **Radar data – Interpolation domain**
  - ~ 700 X 670 km^2
  - Composite reflectivity from 2 C-band radars (Royal Meteorological Institute of Belgium)
  - 5 min / 529 m
  - Marshall-Palmer Z-R relation
- **Local data - Merging domain:**
  - 10.6 X 10.6 km^2 (Herent)
  - 7-8 rain gauges, 1 min resolution
- **Hydrological/hydraulic testing:**
  - Drainage area = ~25 km^2 (14 % impervious)
  - InfoWorks CS semi-distributed sewer model
  - 3 flow gauges (2 min resolution)

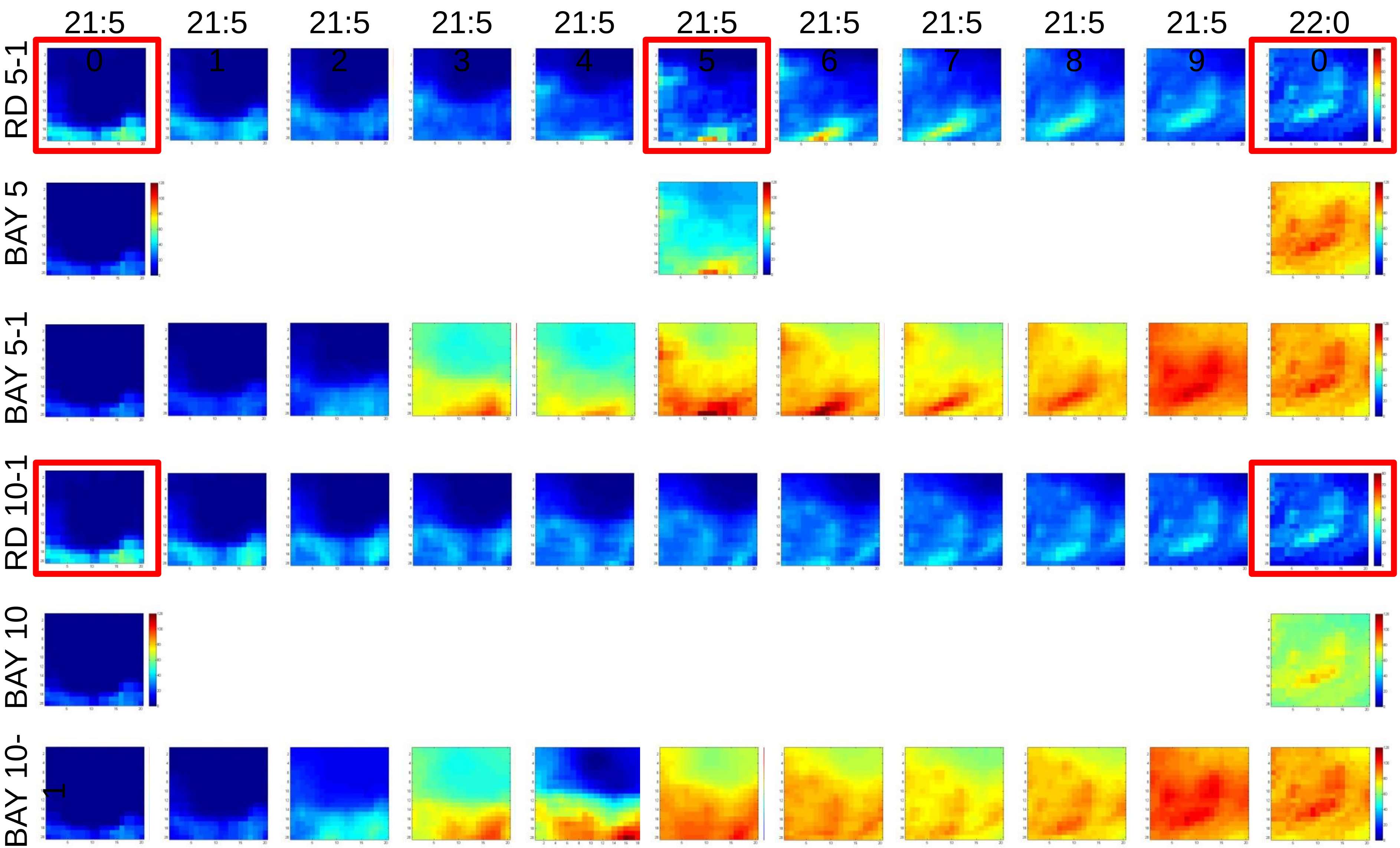




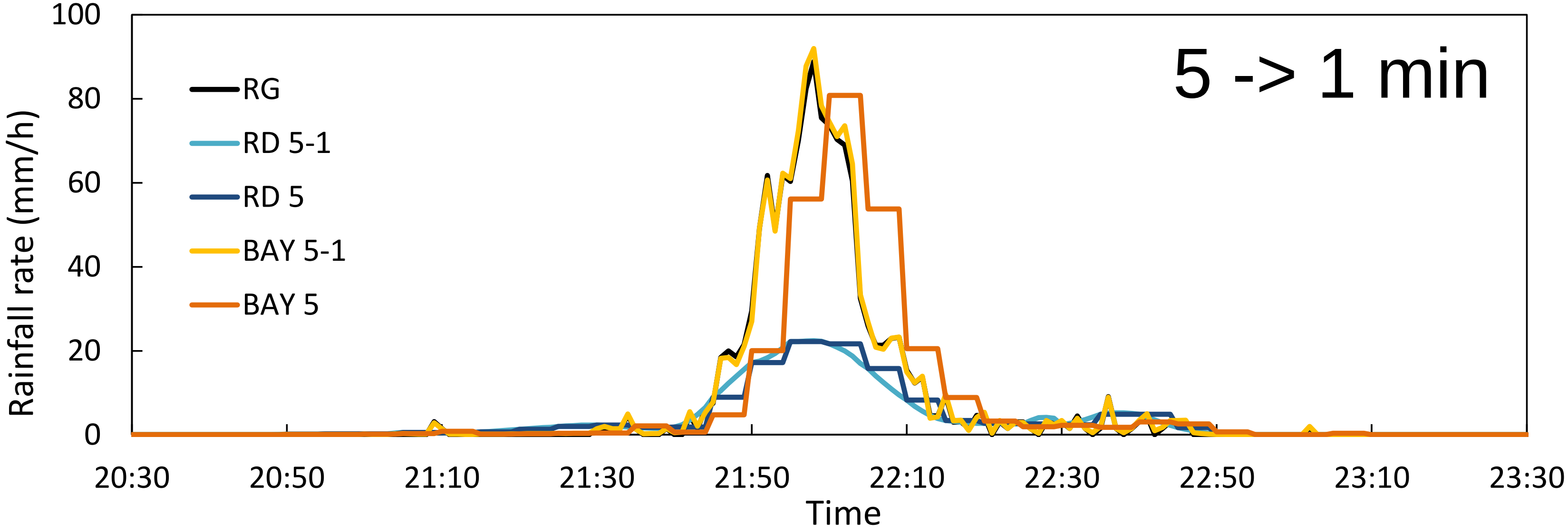
SELECTED STORM EVENTS DURING 2012-2013

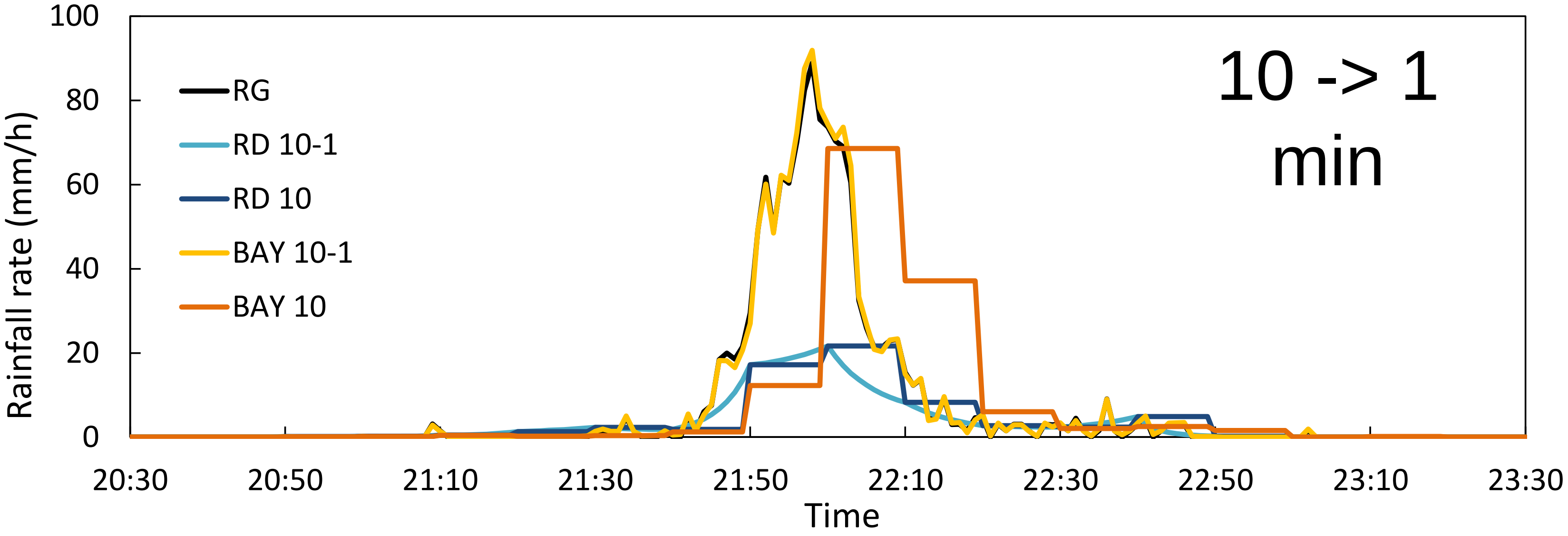
ID	Date	Duration (h)	RG #	RG Total (mm)	RG Peak (mm/h) 1/5 min	RD Total (mm)	RD Peak (mm/h) 5 min
HER-S01	23rd Sep 2012	1.8	8	9.99	25.94/20.40	20	41.89
HER-S02	08th May 2013	4	7	9.22	32.48/28.97	7.97	18.16
HER-S03	27th Jul 2013	5	8	21.39	86.11/78.94	10.06	16.2
HER-S04	27th Jul 2013	3	8	21.73	88.85/78.11	10.75	22.23

SNAPSHOTS DURING STORM PEAK: HER-S04

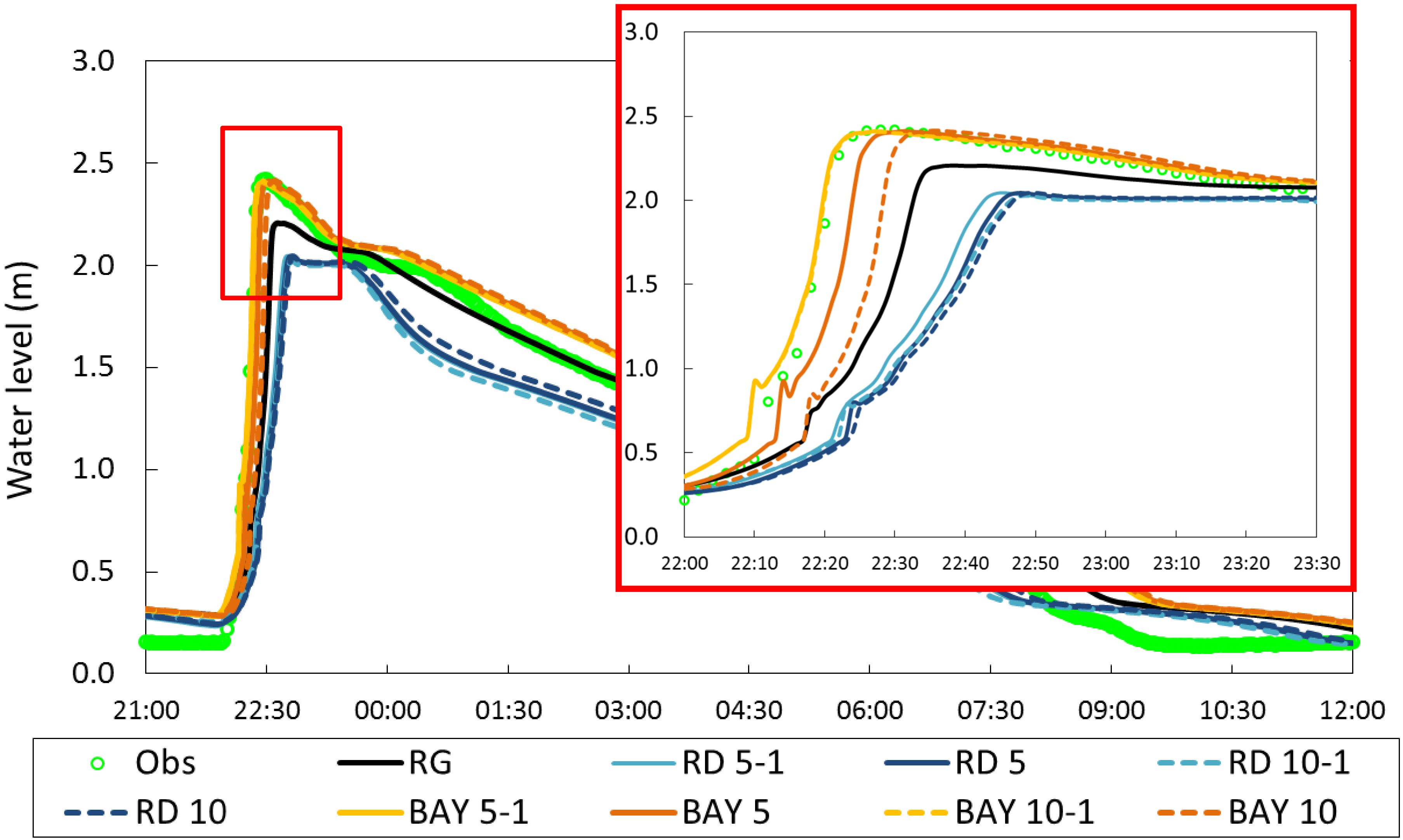


PROFILES OF AREAL-AVERAGE RAINFALL INPUTS: HER-S04





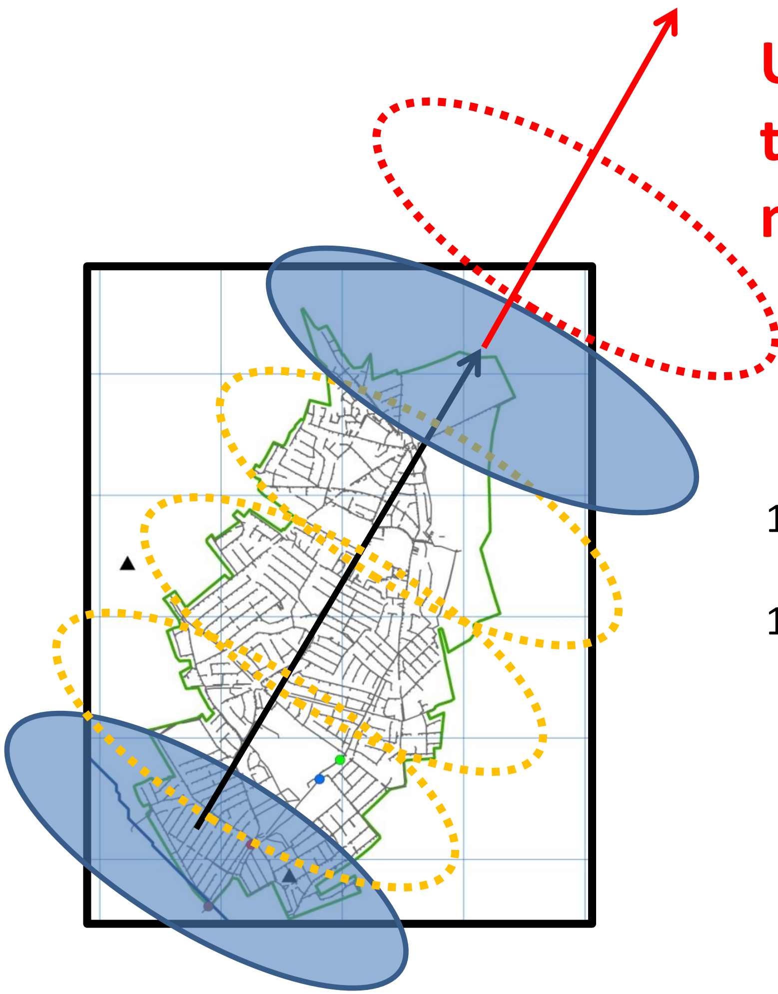
HYDROGRAPHS OF THE OBSERVED AND SIMULATED WATER LEVEL: HER-S04



HYDRAULIC PERFORMANCE FOR THE SELECTED EVENTS

ID	RG	RD 5-1	RD 5	RD 10-1	RD 10	BAY 5-1	BAY 5	BAY 10-1	BAY 10
R^2 - Coefficient of Determination									
HER-S01	0.965	0.930	0.936	0.889	0.879	0.957	0.953	0.962	0.978
HER-S02	0.962	0.903	0.892	0.903	0.892	0.943	0.919	0.941	0.905
HER-S03	0.890	0.724	0.693	0.708	0.636	0.985	0.970	0.984	0.934
HER-S04	0.929	0.888	0.869	0.870	0.856	0.994	0.979	0.994	0.937
β - Regression Coefficient									
HER-S01	1.022	1.045	1.044	1.030	1.036	0.979	0.998	1.075	1.111
HER-S02	0.734	0.520	0.524	0.474	0.571	0.731	0.712	0.692	0.781
HER-S03	0.911	0.655	0.693	0.663	0.617	0.974	0.972	0.972	0.955
HER-S04	0.846	0.786	0.775	0.766	0.775	0.904	0.897	0.903	0.877
RMSE - Root-Mean-Square Error (in m)									
HER-S01	0.144	0.170	0.162	0.199	0.236	0.197	0.162	0.118	0.111
HER-S02	0.304	0.583	0.566	0.643	0.576	0.298	0.332	0.346	0.313
HER-S03	0.230	0.432	0.409	0.418	0.474	0.152	0.171	0.152	0.210
HER-S04	0.184	0.299	0.309	0.330	0.299	0.148	0.165	0.148	0.210

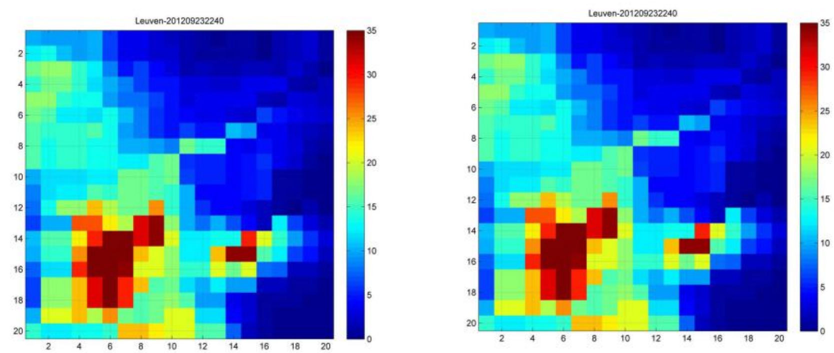
Ongoing & Future Work



Use the improved optical flow technique for short-term rainfall nowcasting

Good results achieved so far

10km X 10km



Observations Nowcast (up to 50 min LT)

However, there's a limit in the predictability of radar-based nowcasting models

Nowcasting predictability is subject to the life time of storm cells

Life time of small-scale storms (Foresti & Seed, HESS, 2014)

Storm Scale [km]	Average life time
8-38	49.8 min
4-18	19.0 min
2-8	8.3 min
2-4	5.1

Given the general scale of convective storms (~ 10 km), the predictability of advection-only nowcasting for these storms is up to 30-45 min lead time.

Work is underway which can increase lead time:

- Consider growth and decay of storm cells
- Detection of pre-convective conditions
- Ensemble nowcasting

However, lead times of radar-based nowcasting will continue to be limited; longer lead times can only be achieved with NWP

(outside of scope of RainGain, but ongoing and promising work by MetOffice, ConvexProject)

CONCLUSIONS

- A methodology was proposed to generate good quality radar rainfall estimates at high temporal resolution, which meet the requirements of urban hydrological applications.

- The proposed methodology enables best use of the sensor data normally available at urban scales

  - Accuracy and temporal resolution of rain gauges

  - Spatial description of rain fields provided by radars

- The proposed methodology can also be applied for short-term rainfall nowcasting, within limits of predictability!

Thank you for your attention

(Questions during Q&A session)