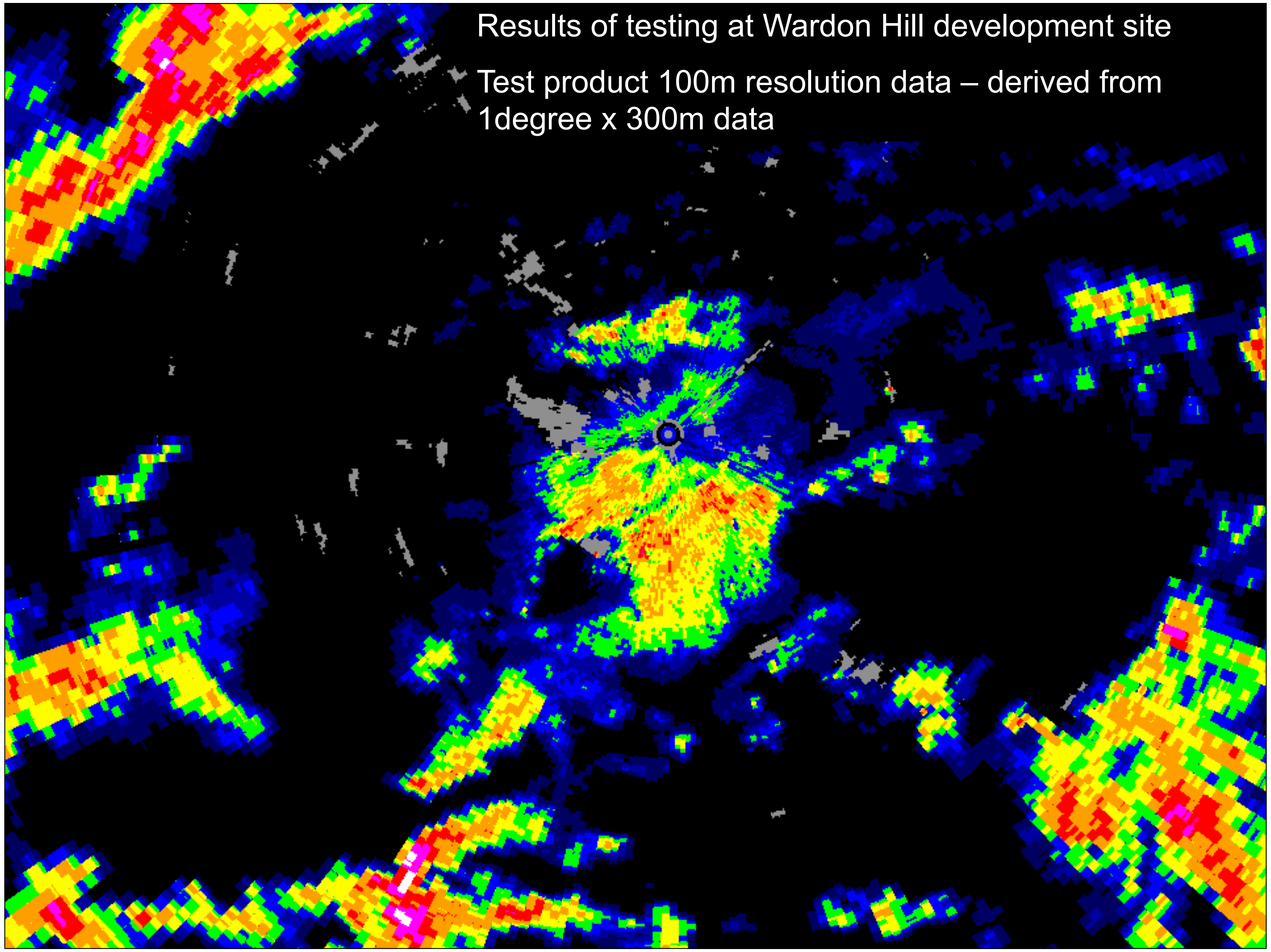
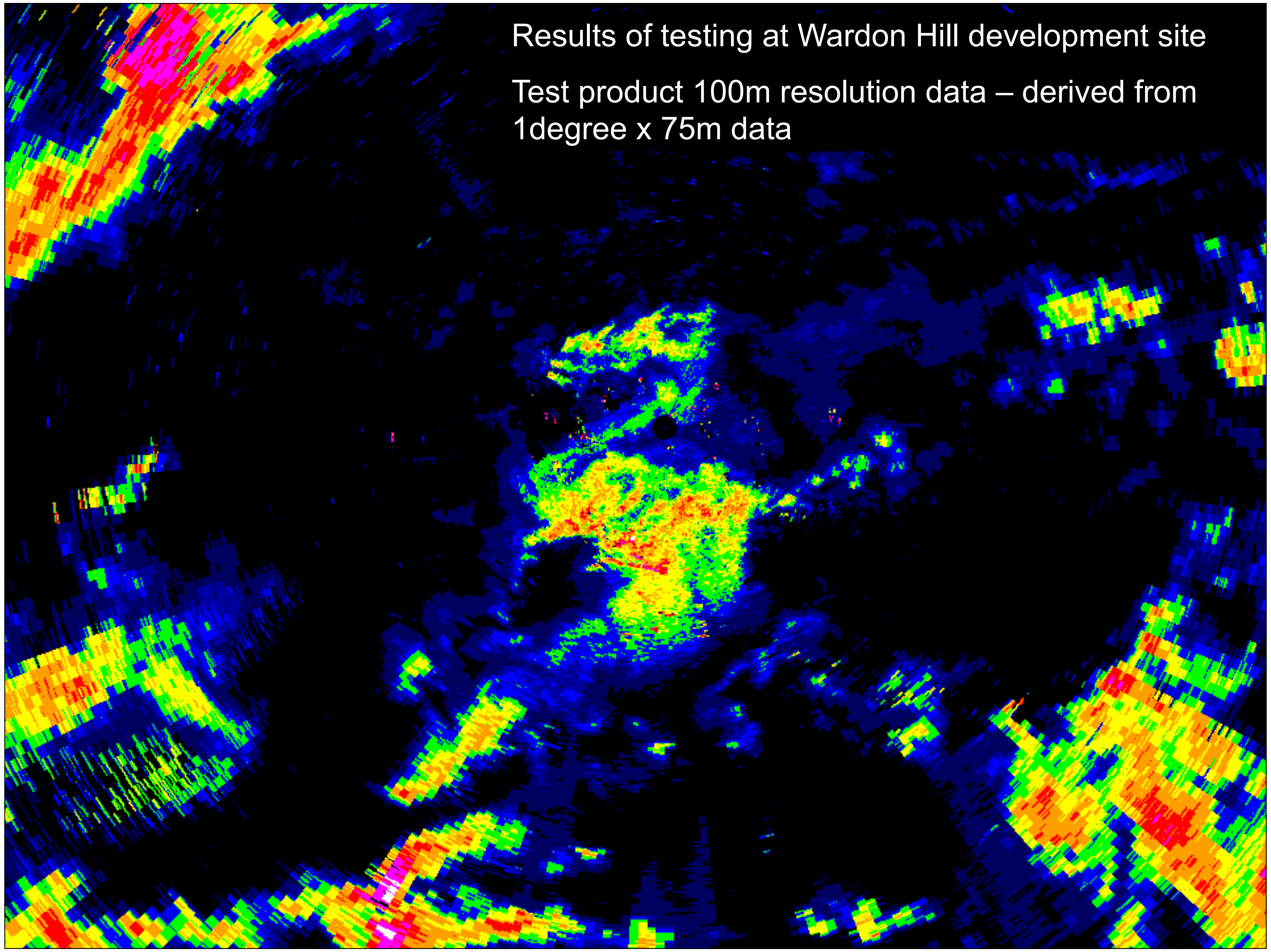

Results of testing at Wardon Hill development site
Test product 100m resolution data – derived from 1degree x 300m data


Results of testing at Wardon Hill development site
Test product 100m resolution data – derived from 1degree x 75m data

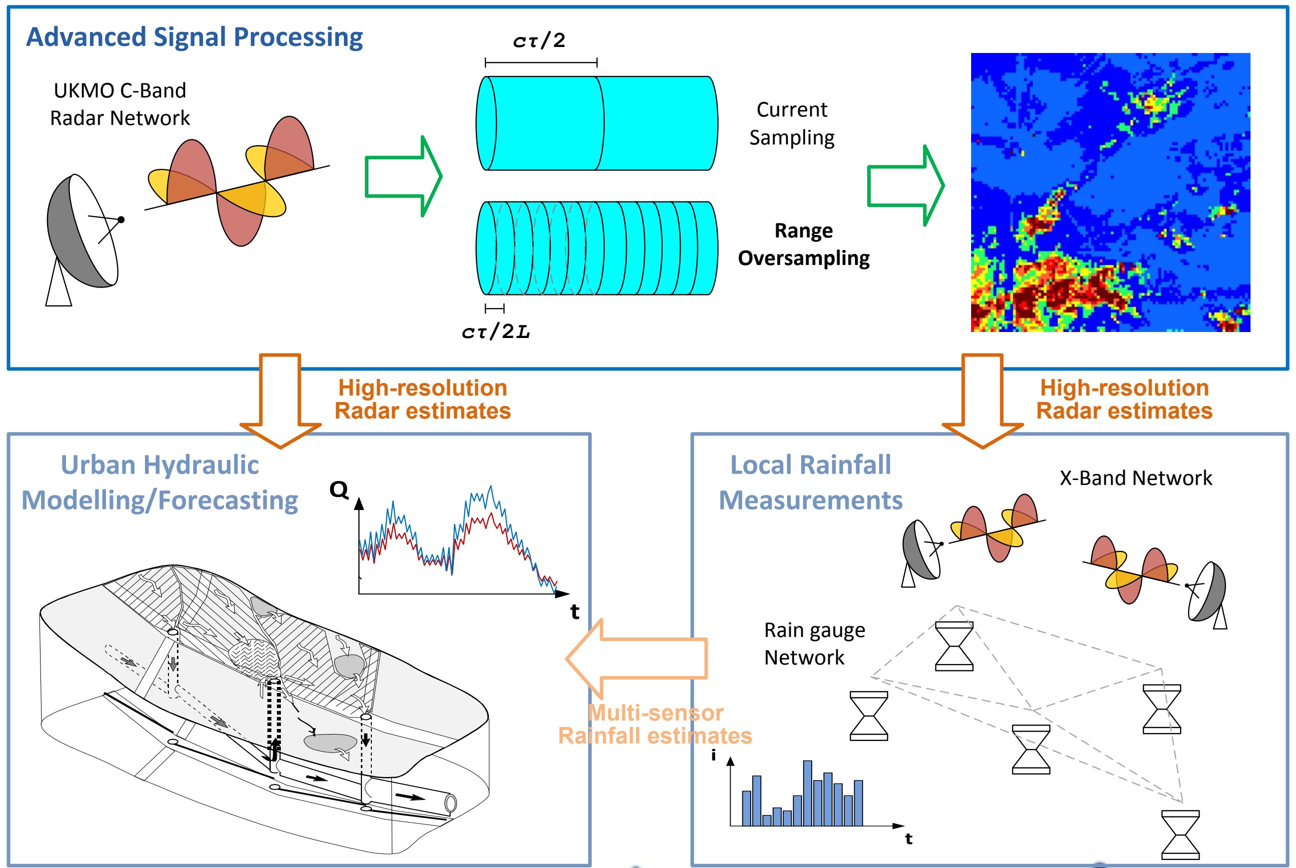
Comparison with

- Gauge testing still on going with some initial signs of improvement at 1km resolution
- Discrepancy between two months – needs to be explained
  - Weather conditions?

Data	Date	Events	POD	FAR	BIAS	RMS	RMSF
Norm	12/12	268	1.00	0.13	-1.26	2.88	2.78
Sharp	12/12	259	1.00	0.12	-0.91	2.28	2.47
Norm	13/01	60	0.60	0.36	-0.34	0.96	2.34
Sharp	13/01	67	0.60	0.25	-0.23	0.75	2.38

Range Oversampling-Introduction

Advanced signal processing to improve the accuracy and resolution of C-band radar measurements



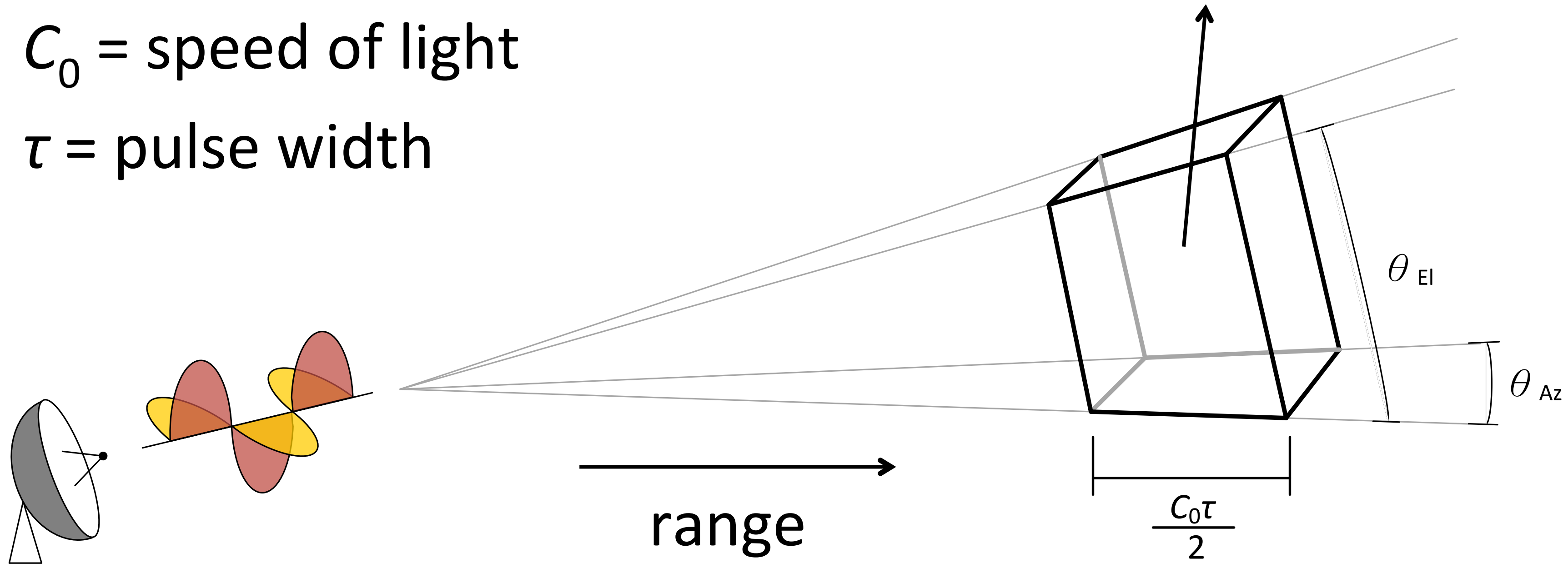
Range Resolution

$$C_0\tau \quad [m]$$

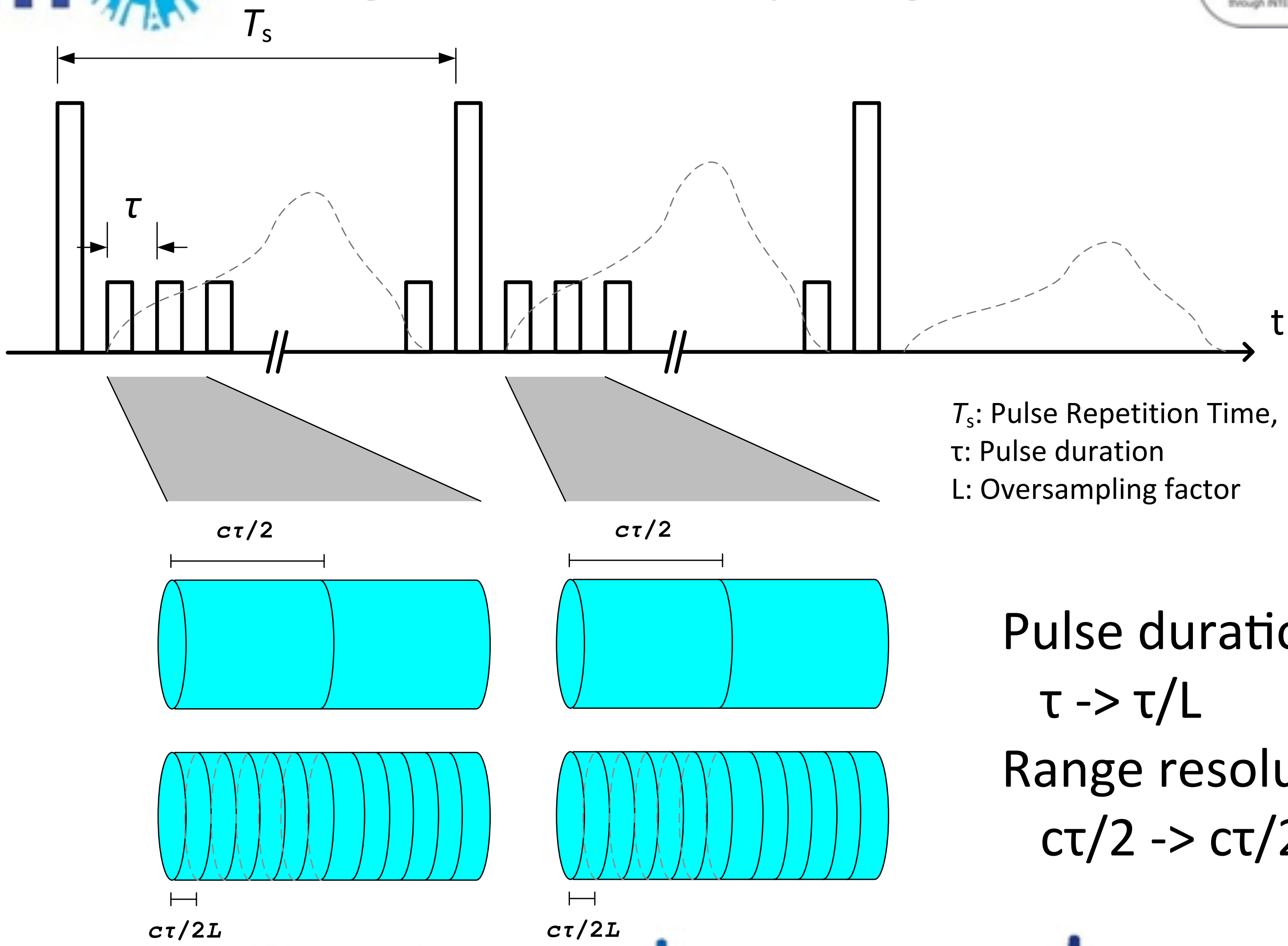
C_0 = speed of light

τ = pulse width

Resolution Cell Volume:
two separate objects that lie within the same resolution cell cannot be distinguished by radar



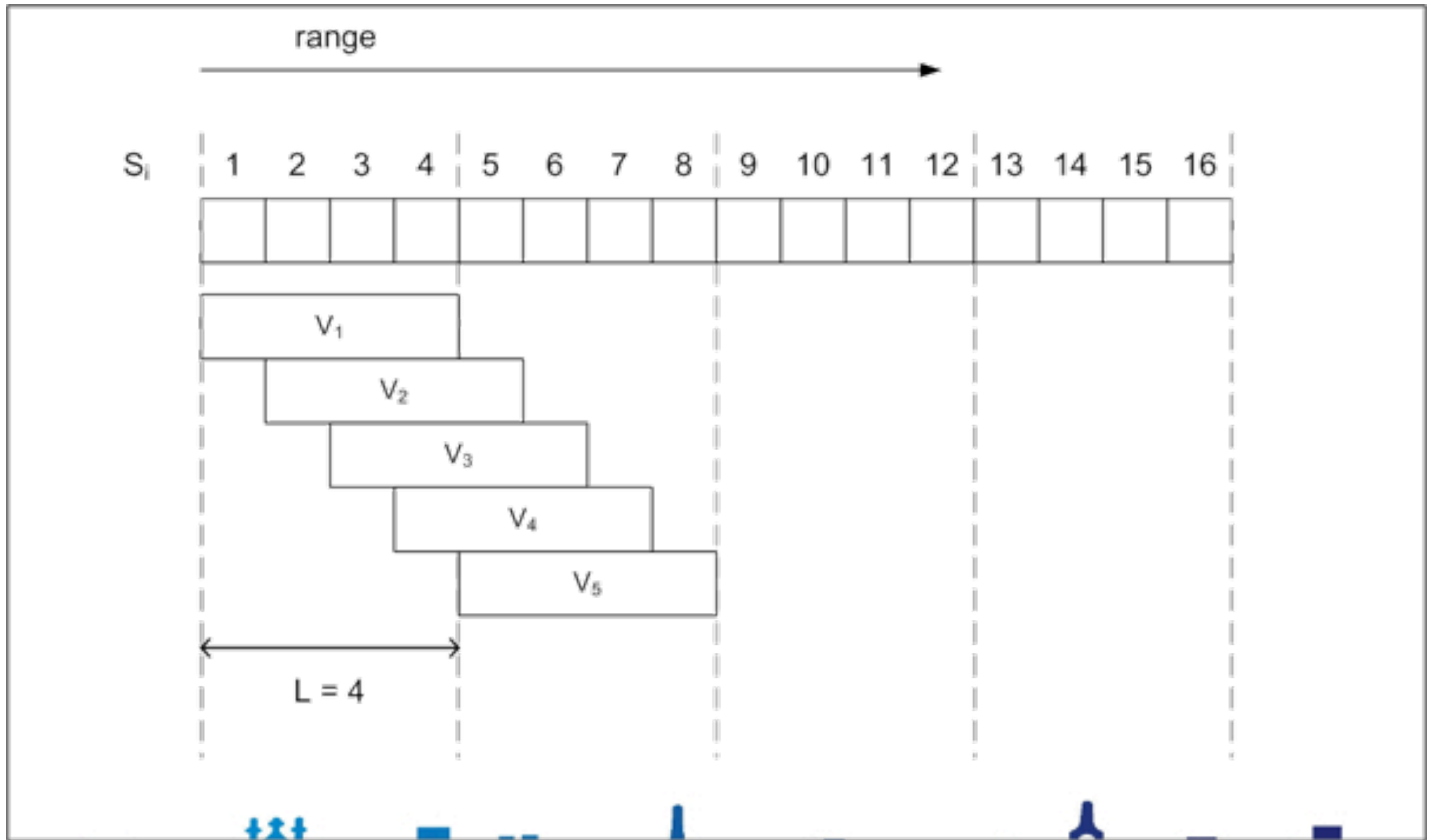
Range Oversampling (1/2)



T_s: Pulse Repetition Time, PRT
τ: Pulse duration
L: Oversampling factor

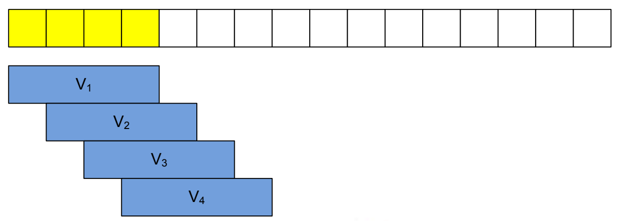
Pulse duration:
τ -> τ/L
Range resolution:
cτ/2 -> cτ/2L

Range Oversampling (2/2)



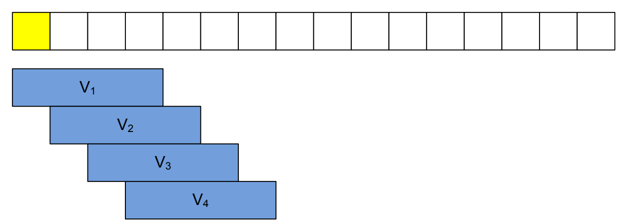
Range oversampling techniques (1/2)

- **Accuracy**: whitening transformation
  - De-correlate the oversampled signals in range for reducing the uncertainty of the estimation of spectral moments (e.g. power and velocity estimates) and polarimetric variables (e.g. reflectivity)
  - Improve the accuracy of these estimates
  - Computationally efficient for real-time operation
  - Noise is coloured (or enhanced), so performance decreases at low SNRs (e.g. snow)



Range oversampling techniques (2/2)

- **Finer-resolution**: de-convolution (or Retro) processing
  - The finer-resolution signals are assumed to be the weighted linear combination of oversampled signals, and these weights are calculated by analysing the cross-correlation functions of these oversampled signals
  - Finer-resolution signals can be really obtained
  - Time consuming (real-time operation?)
  - Bias in estimation of spectral moments



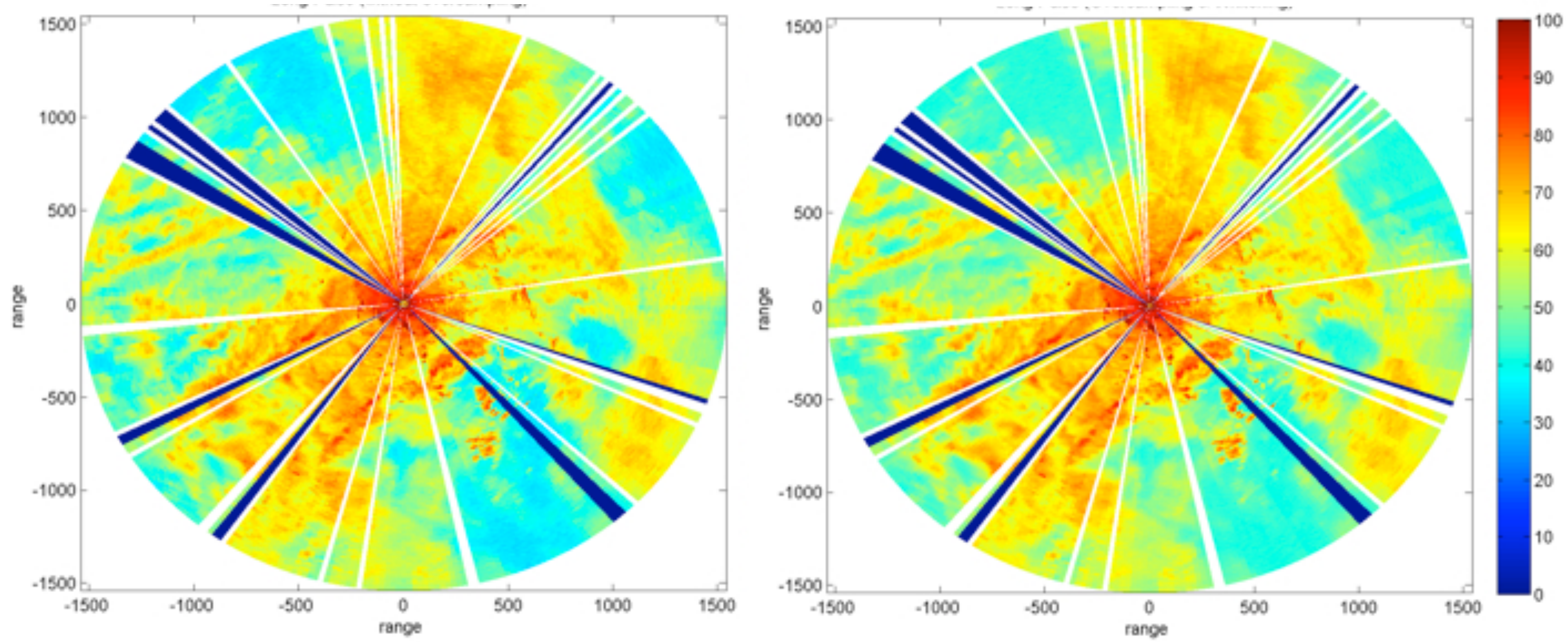
Datasets and processing

- Long pulse (1 degree X 300 m data)
  - **LP** - normal sampling (300 m)
  - **Whitened LP** – oversampling + whitening (300 m, lower uncertainty)
  - **Retro LP** - oversampling + de-convolution (75 m)
- Short pulse (1 degree X 75 m data)
  - **SP** - normal sampling (75 m)
  - **Whitened SP** – normal sampling + whitening (75 m, lower uncertainty)
  - **Whitened SP*** - oversampling + whitening (75 m, lower uncertainty)

Long Pulse (LP)

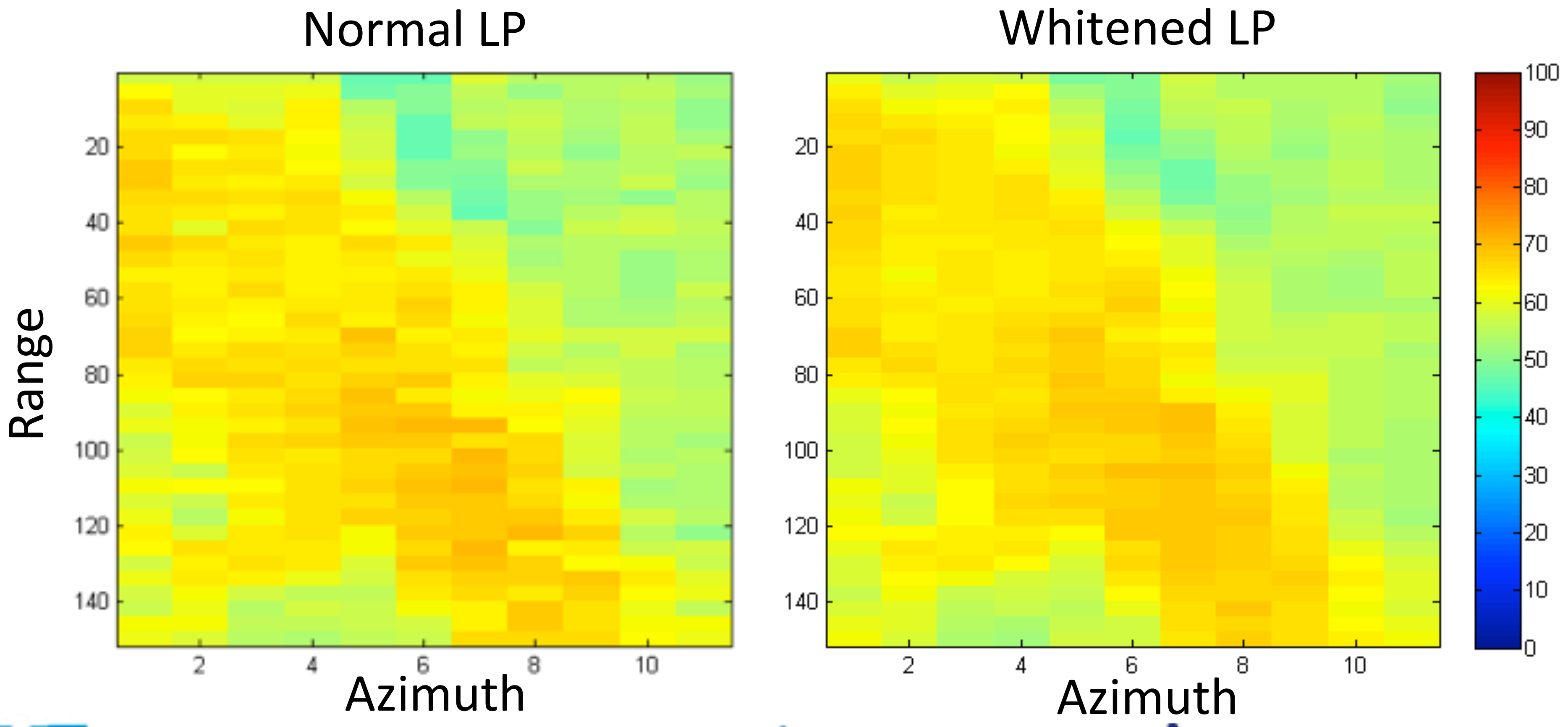
Normal Sampling

Oversampling + Whitening

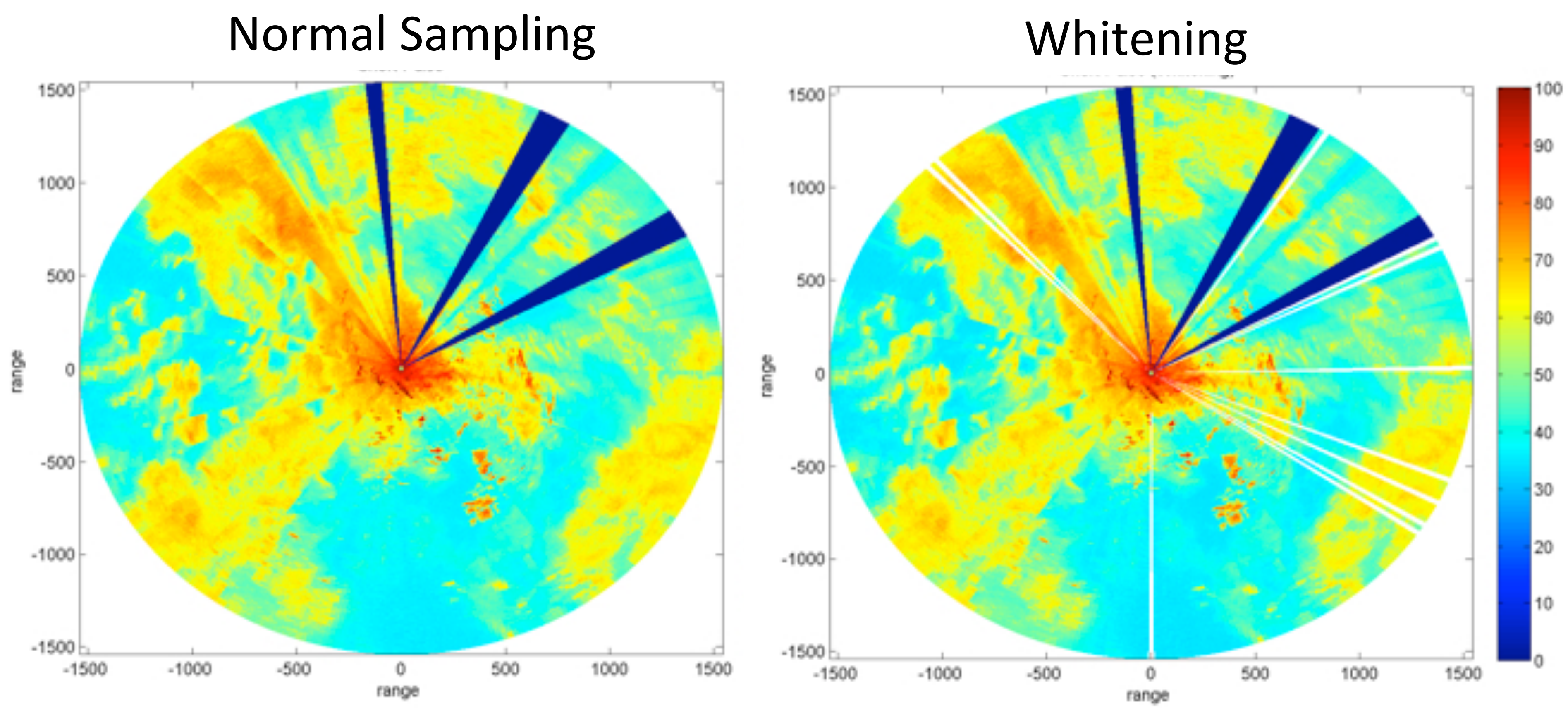


Whitened LP

Measurement variance of oversampled LP can be reduced via Whitening

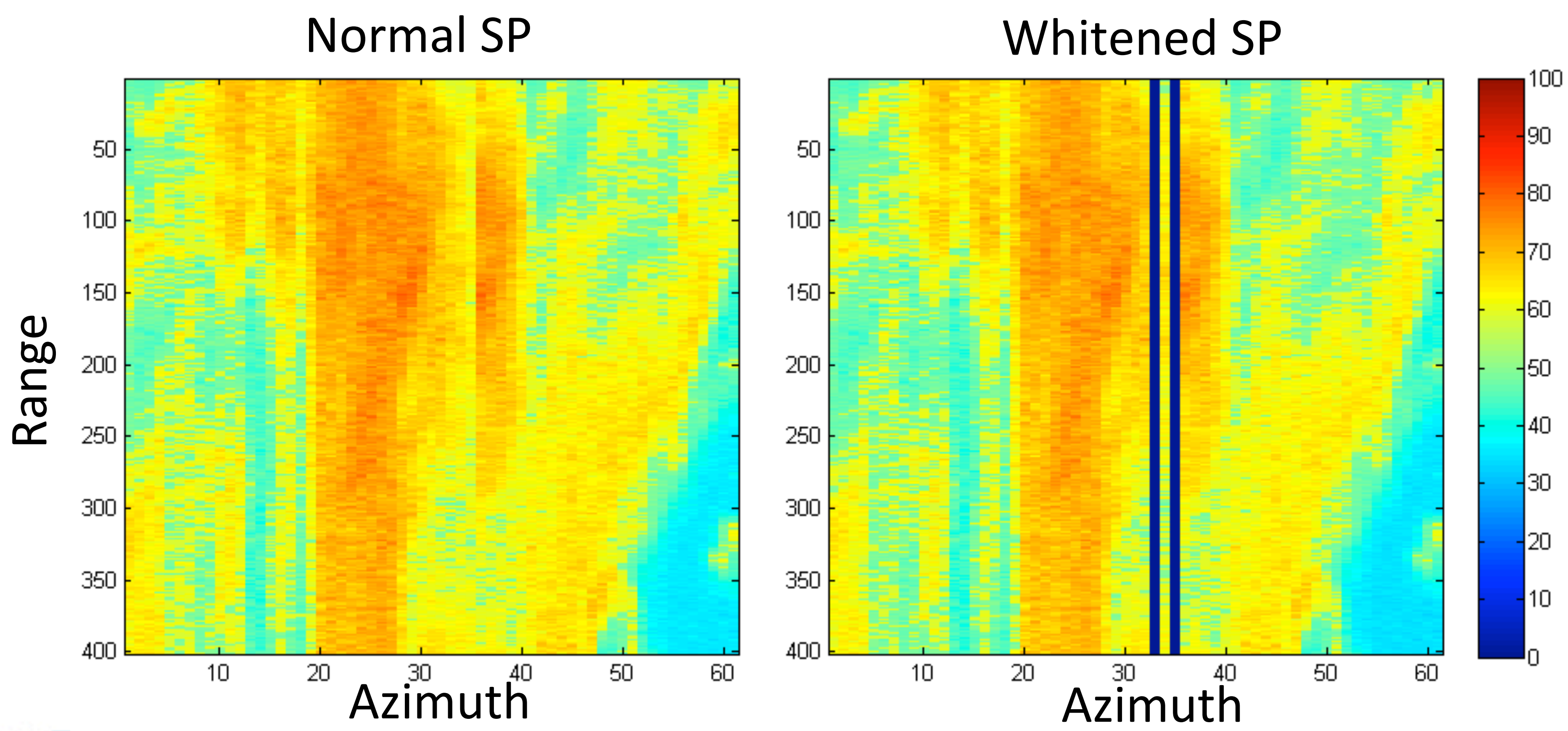


Short Pulse (SP)



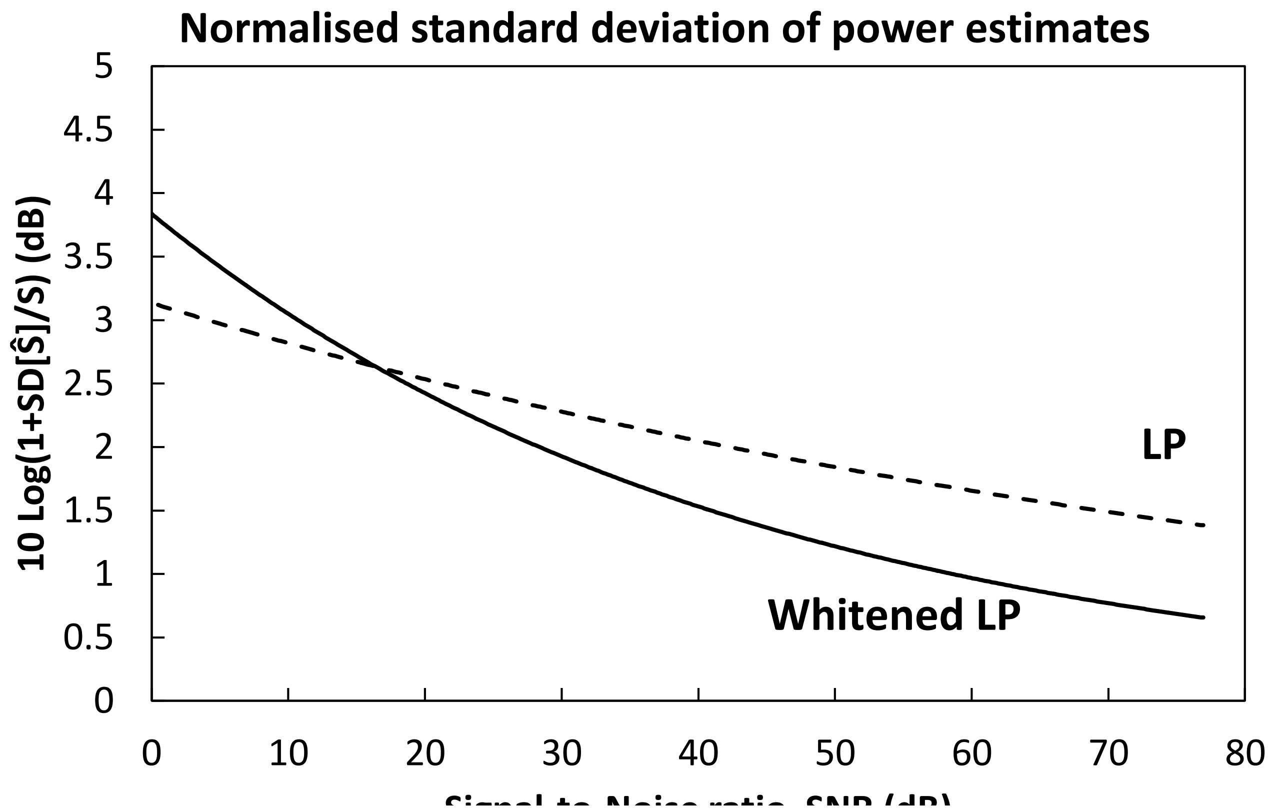
Whitened SP

Measurement variance in SP signals can be reduced via Whitening



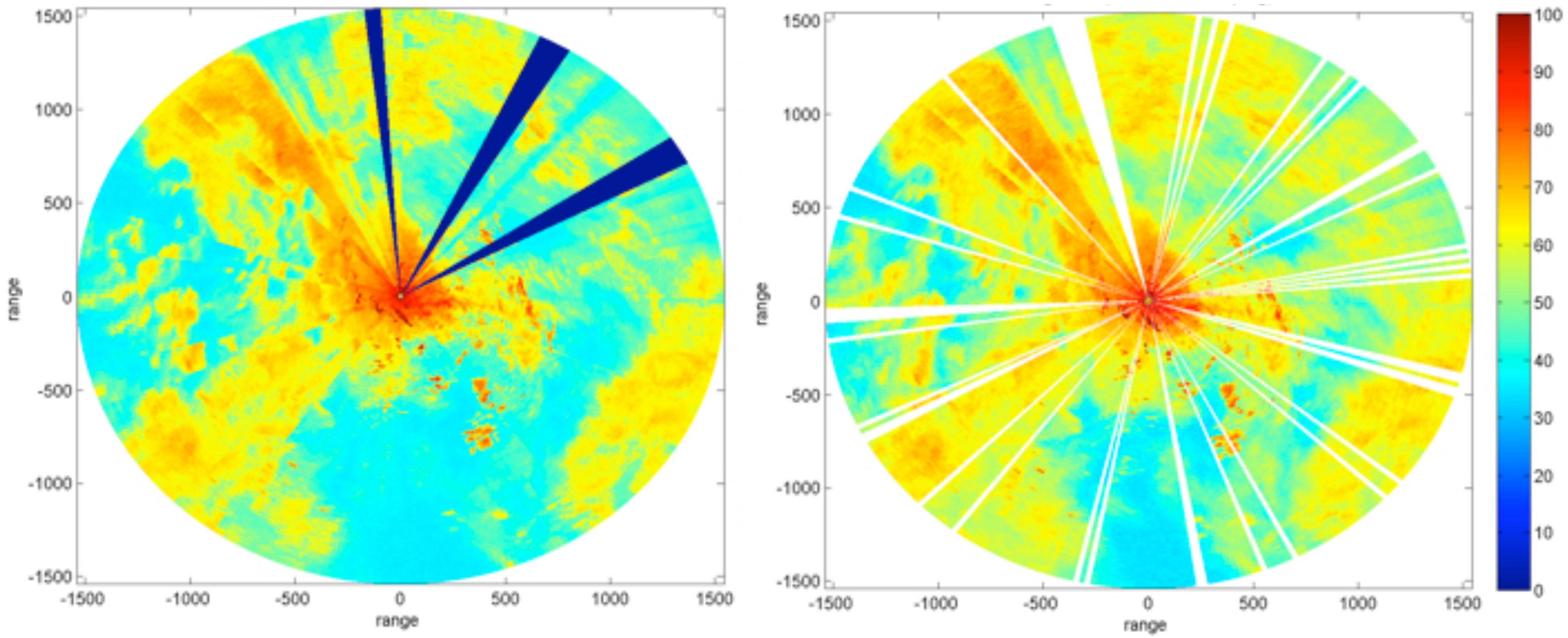
Whitened LP vs. LP

Uncertainty of power estimates can be reduced 0.5 – 1.0 dB on average as SNR is larger than a specific value.



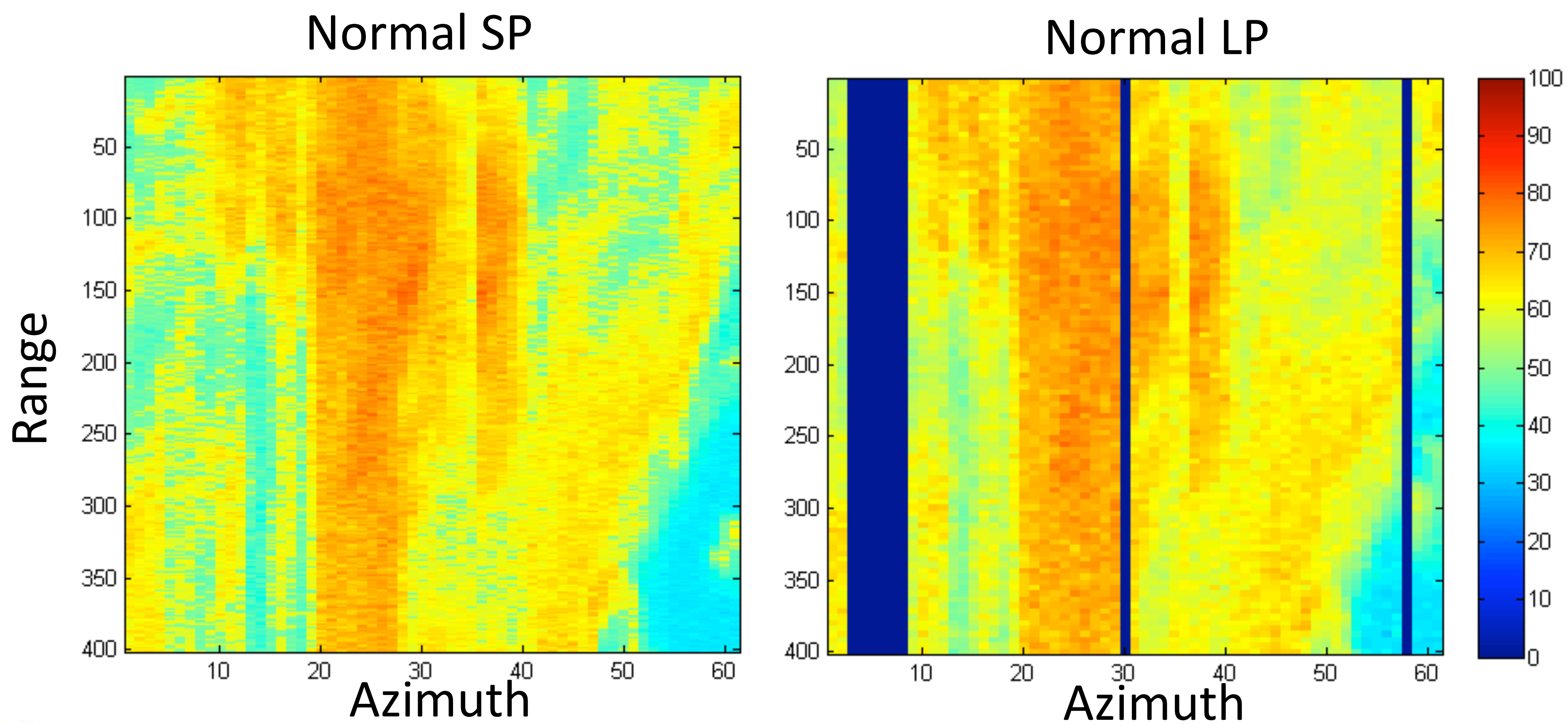
SP vs. LP

Short Pulse **Long Pulse**



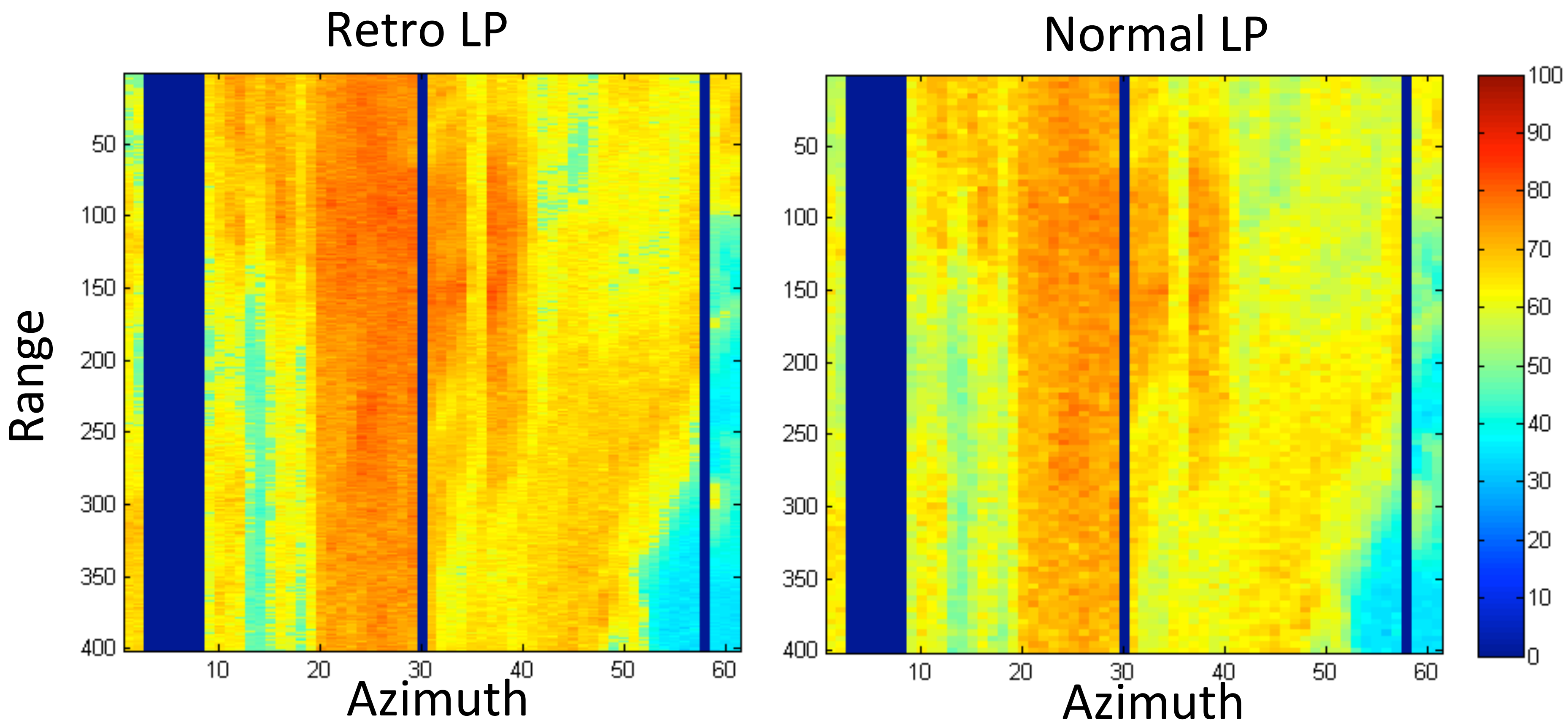
SP vs. LP

More details (yet of higher variance) can be observed in SP signals



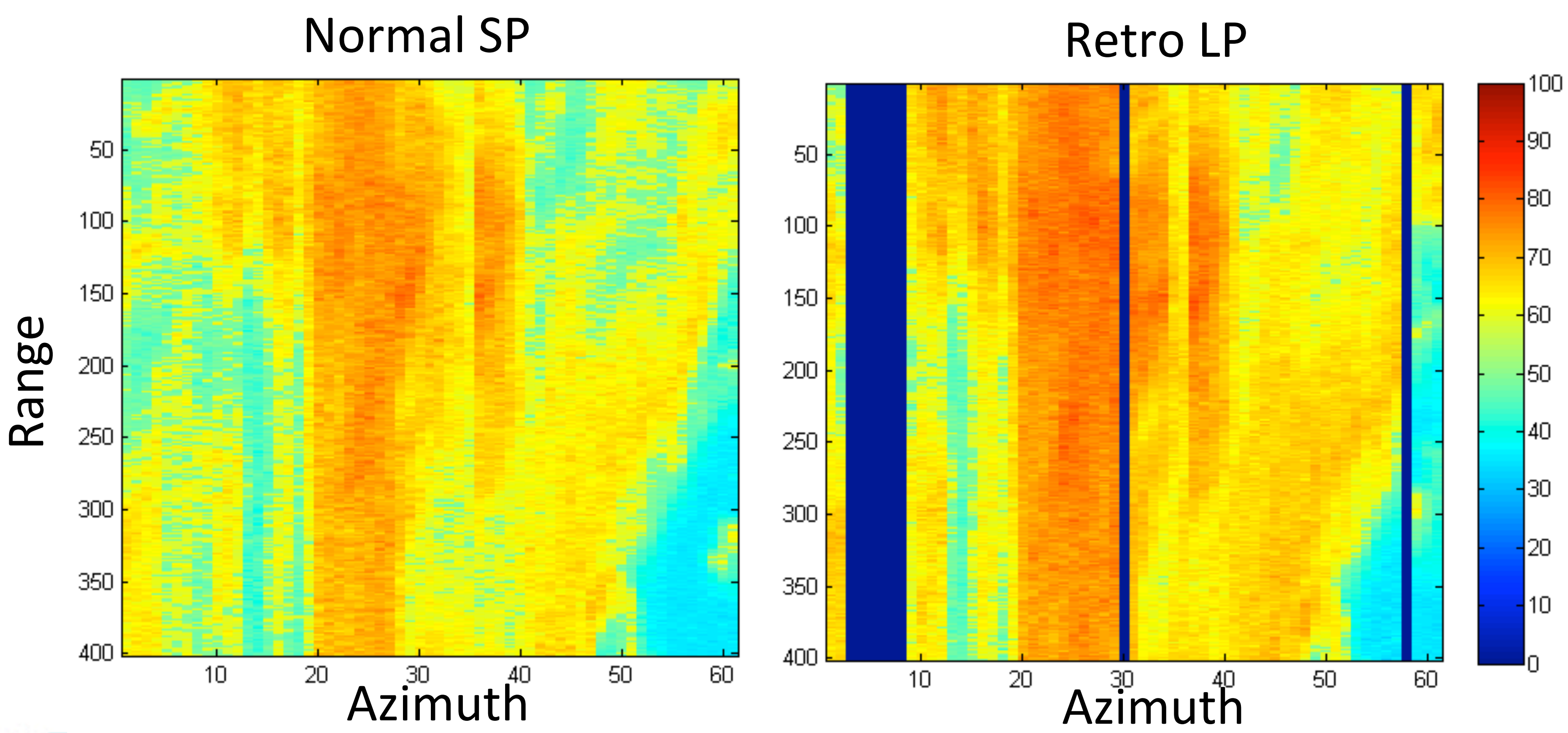
LP vs. Retro LP

More details can be generated from oversampled LP signals via Retro



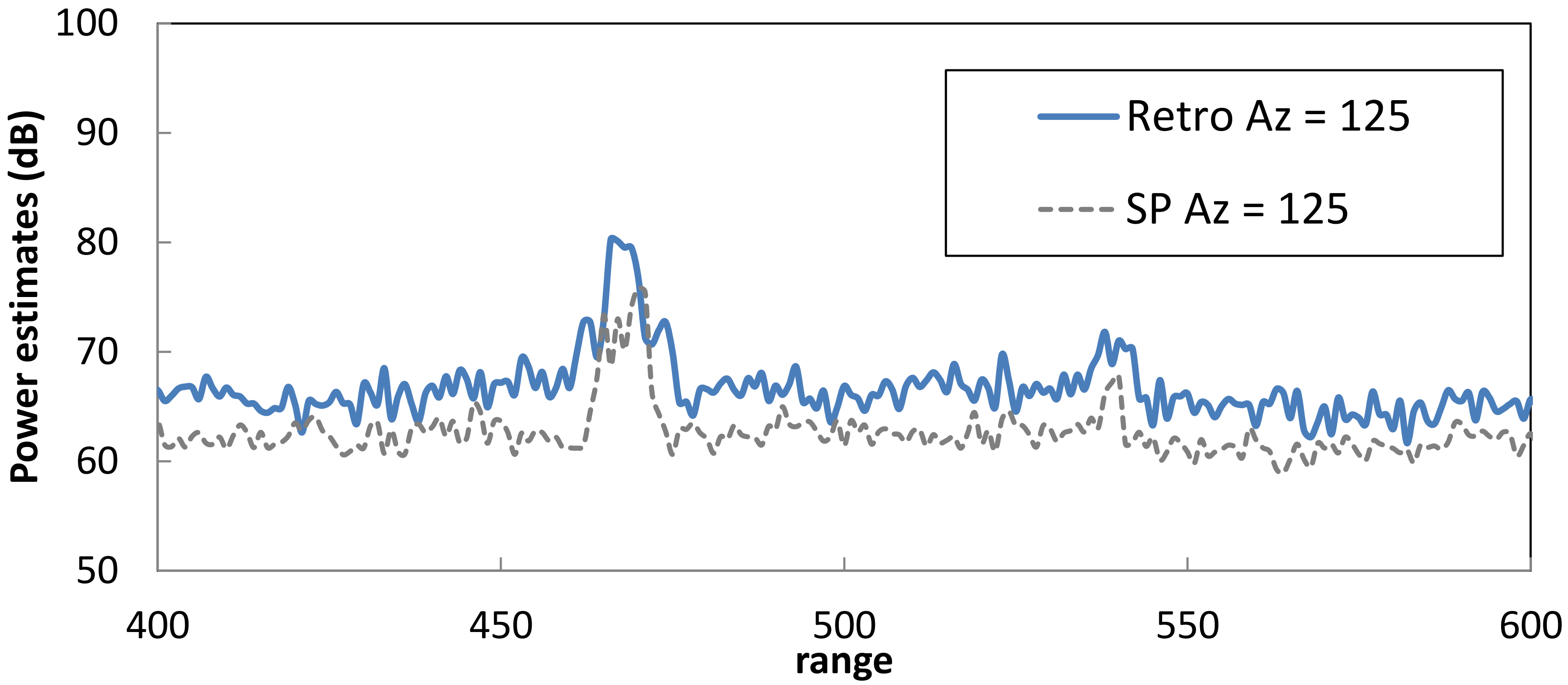
SP vs. Retro LP

Retro LPs show similar pattern to the SP signals, but some bias can be seen



SP vs. Retro LP

Retro LPs show similar pattern to the SP signals, but bias can be seen



Conclusions

- Range oversampling techniques can be used to improve radar signals in terms of accuracy and resolution.
- The whitening transformation can effectively reduce the measurement variance in both oversampled LP and the normally sampled SP signals as SNRs (signal-to-noise ratios) are large, but the variance largely increases as SNRs are small.
- The Retro de-convolution process can be used to generate finer-resolution data from long pulse signals, but bias needs to be corrected.
- Computational time of Retro is currently too long for real-time operation.

Follow-up Works

- Optimised and adaptive whitening transformation methods, which can handle the situation of low SNRs, have been implemented and is being tested.
- Implementation of the bias correction of the Retro signal estimates.
- Improve the computational efficiency of the Retro de-convolution process (GPU programming? Parallel Computing?)
- Compare with the coincidental rain gauge measurements.

Initial Analysis of the Possibility of improving QPFs through Dynamic Adjustment of Radar Rainfall Estimates

Susana Ochoa

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

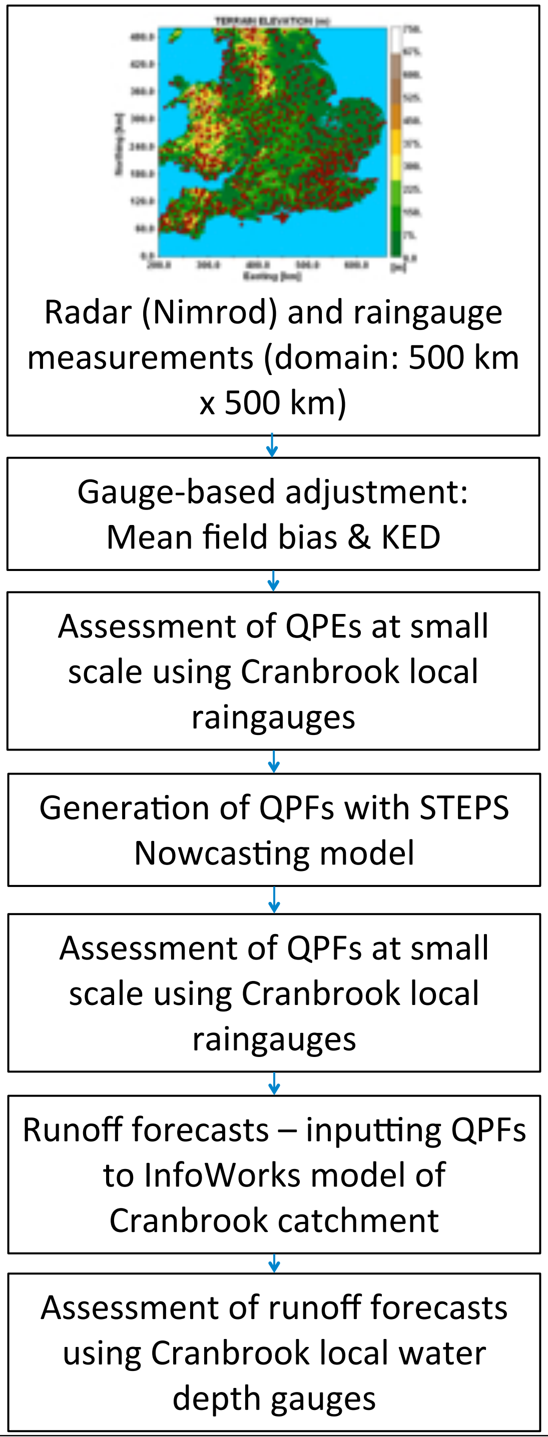
Possibility of improving QPFs through dynamic adjustment of radar rainfall estimates (initial analysis)

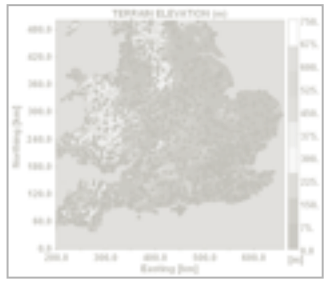
Sources of uncertainty in flood forecasting (Todini, 2004):

i. Uncertainties in input measurements

ii. Uncertainties in meteorological models, namely **radar nowcasting** or Numerical Weather Prediction models, used to generate Quantitative Precipitation Forecasts (QPFs);

iii. Uncertainties in hydrological models (parametric uncertainty, uncertainty in model structure and solution, and uncertainty in the measurement of responses used for calibration).


Radar (Nimrod) and raingauge measurements (domain: 500 km x 500 km)
Gauge-based adjustment: Mean field bias & KED
Assessment of QPEs at small scale using Cranbrook local raingauges
Generation of QPFs with STEPS Nowcasting model
Assessment of QPFs at small scale using Cranbrook local raingauges
Runoff forecasts – inputting QPFs to InfoWorks model of Cranbrook catchment
Assessment of runoff forecasts using Cranbrook local water depth gauges



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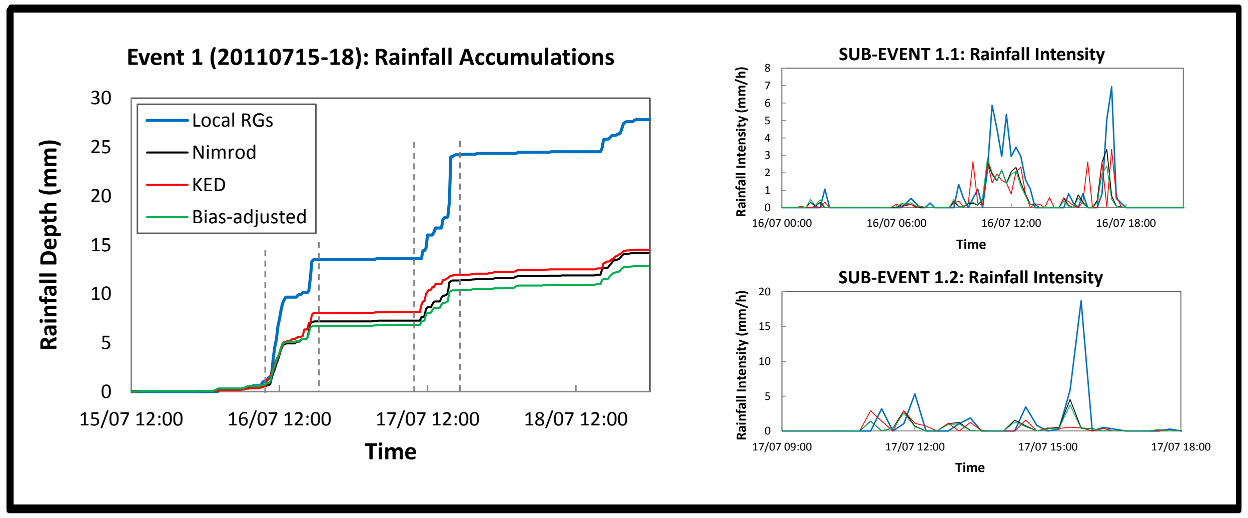
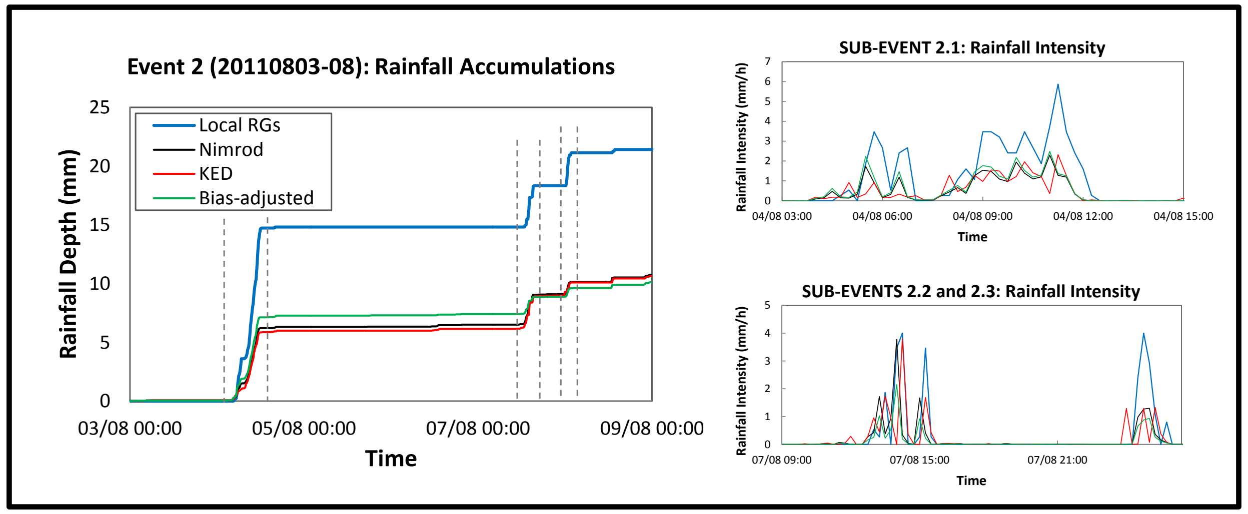
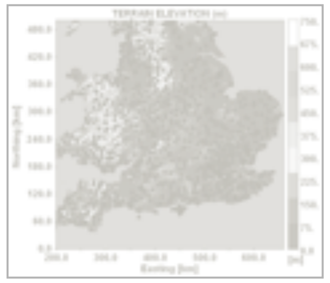




- Radar largely underestimate rainfall over the Cranbrook area (this seems to be due to radar beam blocking)
- Adjustments were done at too large scales and no improvements were achieved at the local scale of urban catchments
- Need to apply adjustment (both mean bias and KED) at smaller domains – our previous work supports this statement



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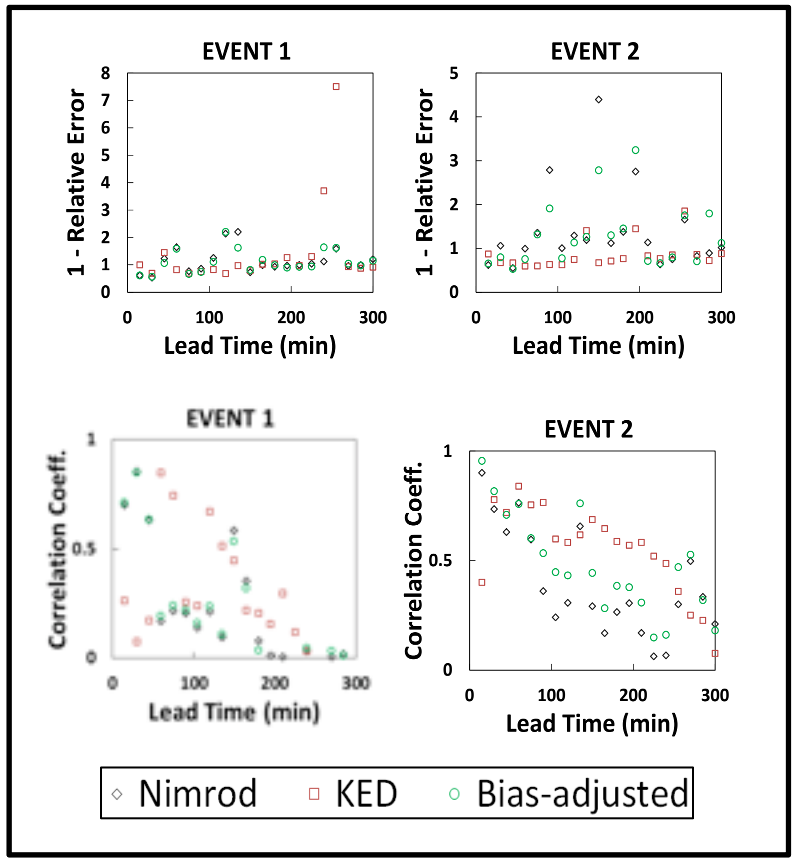
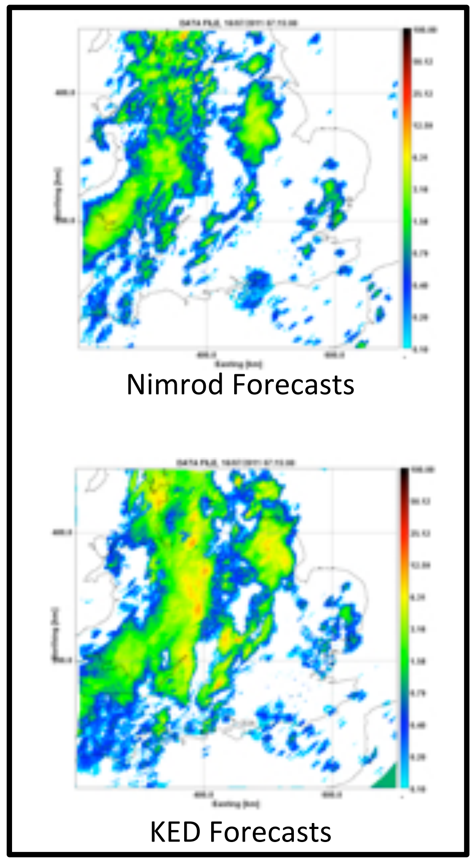
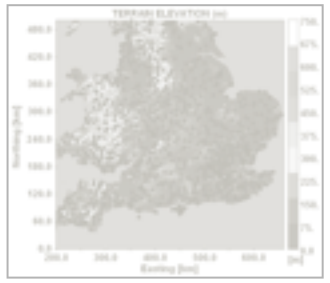




- **Quantitatively:** all QPFs perform badly – mainly due to underestimation of QPEs
- **In terms of correlation and storm movement:**
  - Nimrod and bias adjusted QPFs present consistent behaviour
  - KED QPFs present inconsistent behaviour, the storm even changes direction – reason: KED adjustment does not take into account the temporal correlation of the radar rainfall field; therefore, the adjustment affects the rain field in the time domain . Consequently, the nowcasting model is not able to properly capture the movement the storm



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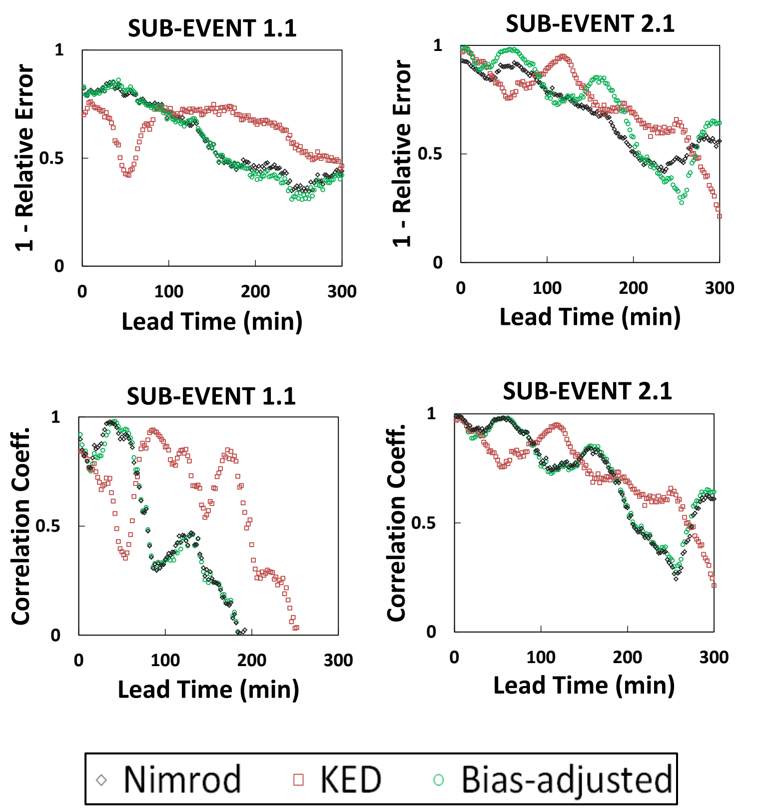
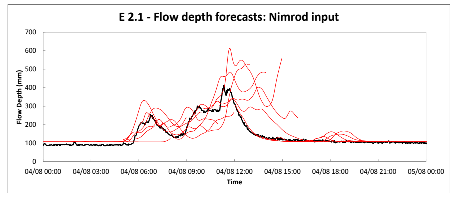
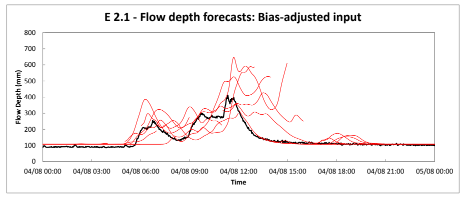
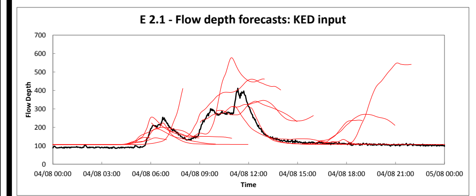




Water depth forecast – Nimrod QPFs



Water depth forecast – Bias-adj QPFs



Water depth forecast – KED QPFs

- **Quantitatively:** better results (than QPFs alone)
- **In terms of correlation and consistency:**
  - Nimrod and bias adjusted QPFs present consistent behaviour
  - KED QPFs present inconsistent behaviour

GENERAL CONCLUSIONS

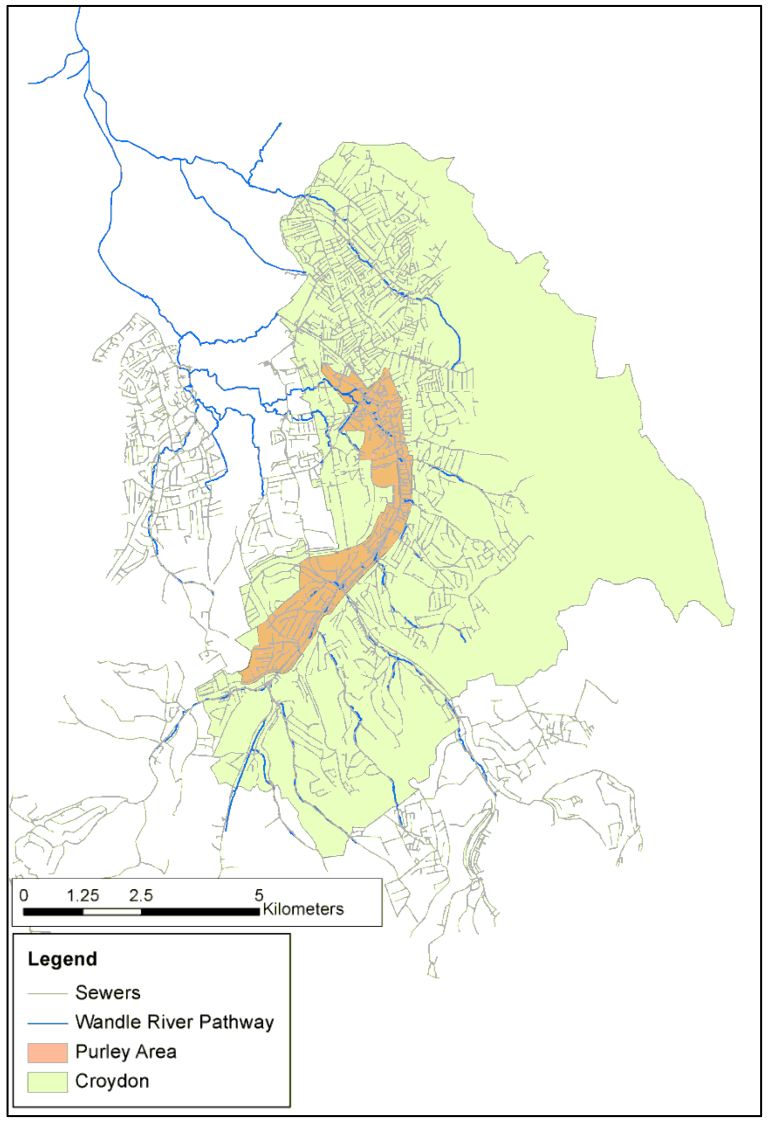
- Need to do adjustment at smaller domains
- KED adjusted radar rainfall fields may not be appropriate for generating QPFs
- Need to analyse more storms, adjustment methods and way of applying these

ACTIVITIES WITHIN WP3

- No changes in Cranbrook and Torquay models
- Upgrade of monitoring system of Cranbrook catchment
- Model of the sewer system of the Purley area has been acquired and refined
- First study has been conducted looking at the possibility of calibrating urban storm water drainage models using adjusted radar rainfall estimates
- Progress in the development of the forecasting platform

Model of the sewer system of the Purley Area

- Number of nodes: 10,205
- Number of links: 10,500
- Pipe length: 708 km
- Number of subcatchments: 5,185
- Mean subcatchment area: 1.2 km^2



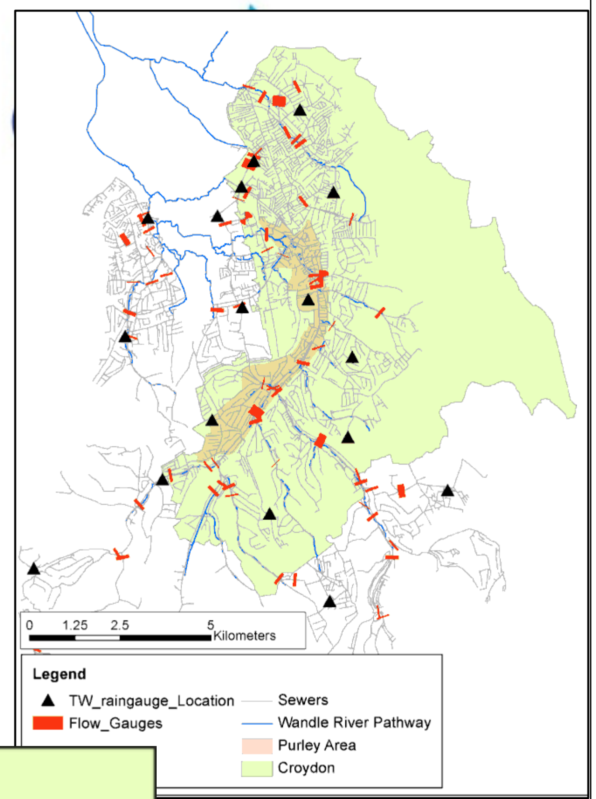
Sewer Network

Model description

- **Semi−distributed** model with **rainfall applied through subcatchments** associated to manholes
- Subcatchments split into different surface types:
  - Impervious areas: fixed runoff coefficient
  - Pervious areas: NewUK rainfall−runoff model
- **Fully hydrodynamic sewer flow model**
- **Verified in 2012 based on medium term flow survey**

Rainfall and flow monitoring data for model calibration

- **Medium term flow survey data:**
  - Carried out by TW between 28/01/11 and 13/07/11
  - 79 flow gauges
  - 18 rain gauges
  - 2 min resolution
- **Nimrod (radar) data available at 1 km – 5 min**



Testing of model for different rainfall inputs:

(3 storms were analysed – the same used for calibration)

1. Original raingauge data, applied using Thiessen Polygons
2. Block-kriged raingauge data
3. Original Nimrod (radar) data
4. Merged rainfall data (using Bayesian methodology)

ANALYSIS OF HYDRAULIC

	MEAN RELATIVE DIFFERENCE IN	
INPUT	EVENT 1	EVENT 2
RG	30.57%	40.56%
NIMROD	28.27%	36.96%
MERGED	24.91%	29.75%
BK	25.35%	27.69%

	MEAN RELATIVE DIFFERENCE IN	
INPUT	EVENT 1	EVENT 2
RG	90.96%	76.29%
NIMROD	46.21%	24.76%
MERGED	32.34%	21.12%
BK	31.88%	22.30%

	MEAN R^2 - FLOW	
INPUT	EVENT 1	EVENT 2
RG	69.43%	69.72%
NIMROD	66.58%	66.75%
MERGED	70.08%	70.30%
BK	69.94%	70.19%

	MEAN R^2 - DEPTH	
INPUT	EVENT 1	EVENT 2
RG	70.54%	70.15%
NIMROD	70.29%	65.62%
MERGED	74.84%	71.30%
BK	74.60%	71.67%

Conclusions & Future Work

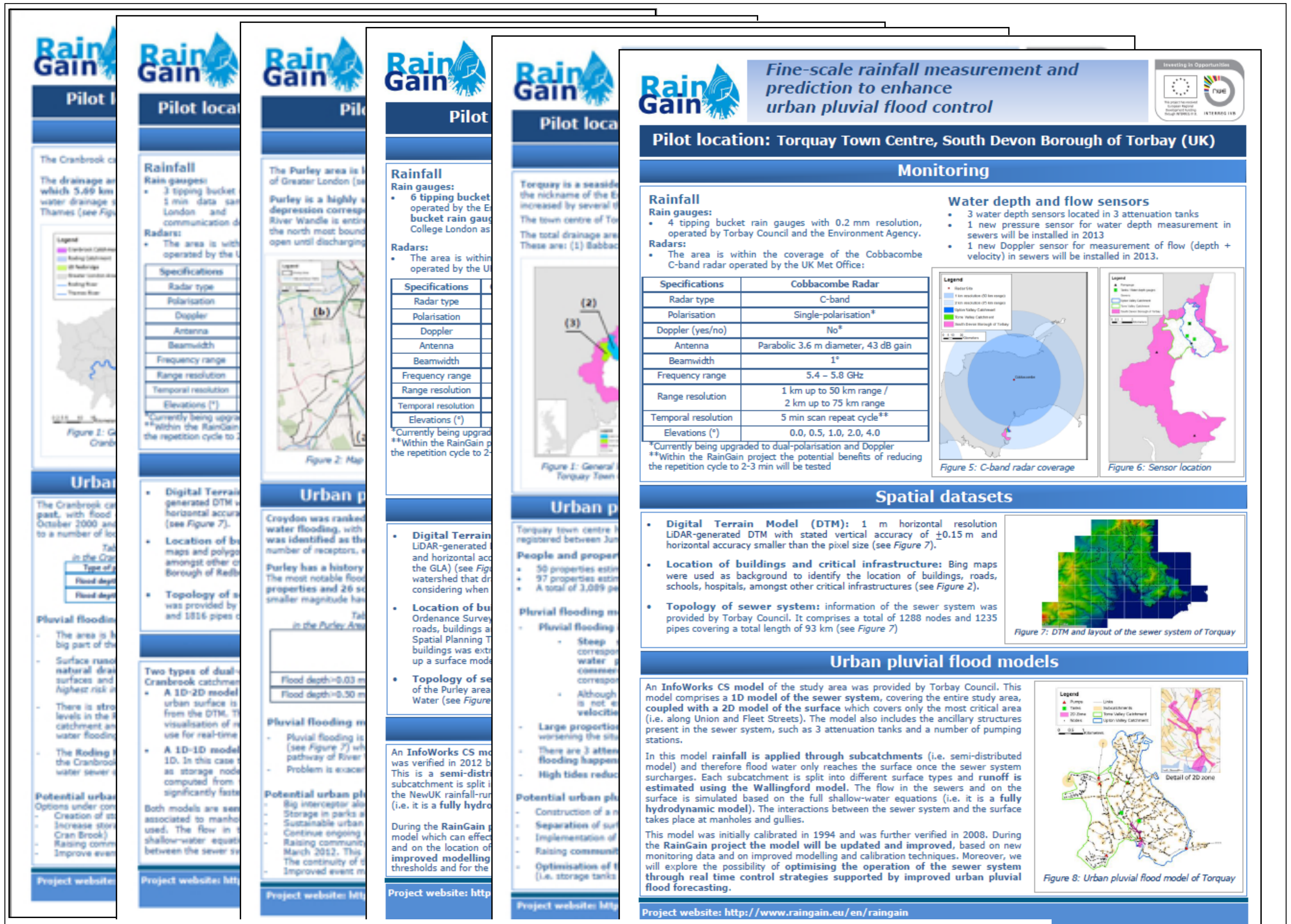
- It is possible to calibrate storm-water drainage models using gauge-based adjusted rainfall inputs
- In fact, better results may be achieved when using gauge-based adjusted rainfall inputs, as these can better capture the spatial structure and accuracy of rainfall fields
- **Future work:** Uncertainty-based calibration of storm water drainage models considering rainfall uncertainty explicitly – **will be done for all case studies**

Future work in WP3

- Uncertainty-based calibration of models for all pilot locations
- Possible: testing of different model structures at each pilot location
- Testing of different rainfall inputs as they become available (including data from X-band radar, improved C-band radar data, merged data, QPFs, etc.)
- Continue development of forecasting platform until it is operational

ACTIVITIES WITHIN WP4

- Upcoming NOG meeting – 60 confirmed attendees
- Implementation of factsheets for the 3 UK pilot locations
- Workshop pack for engagement of residents in local flood risk management has been finalised



RainGain

Fine-scale rainfall measurement and prediction to enhance urban pluvial flood control

Investing in Opportunities — INTERREG IVB

Pilot location: Torquay Town Centre, South Devon Borough of Torbay (UK)

Monitoring

Rainfall

Rain gauges:
- 4 tipping bucket rain gauges with 0.2 mm resolution, operated by Torbay Council and the Environment Agency.

Radars:
- The area is within the coverage of the Cobbacombe C-band radar operated by the UK Met Office:

Specifications	Cobbacombe Radar
Radar type	C-band
Polarisation	Single-polarisation*
Doppler (yes/no)	No*
Antenna	Parabolic 3.6 m diameter, 43 dB gain
Beamwidth	1°
Frequency range	5.4 – 5.8 GHz
Range resolution	1 km up to 50 km range / 2 km up to 75 km range
Temporal resolution	5 min scan repeat cycle**
Elevations (°)	0.0, 0.5, 1.0, 2.0, 4.0

*Currently being upgraded to dual-polarisation and Doppler
**Within the RainGain project the potential benefits of reducing the repetition cycle to 2-3 min will be tested

Water depth and flow sensors
- 3 water depth sensors located in 3 attenuation tanks
- 1 new pressure sensor for water depth measurement in sewers will be installed in 2013
- 1 new Doppler sensor for measurement of flow (depth + velocity) in sewers will be installed in 2013.

Figure 5: C-band radar coverage

Figure 6: Sensor location

Spatial datasets

- **Digital Terrain Model (DTM):** 1 m horizontal resolution LiDAR-generated DTM with stated vertical accuracy of ±0.15 m and horizontal accuracy smaller than the pixel size (see *Figure 7*).
- **Location of buildings and critical infrastructure:** Bing maps were used as background to identify the location of buildings, roads, schools, hospitals, amongst other critical infrastructures (see *Figure 2*).
- **Topology of sewer system:** information of the sewer system was provided by Torbay Council. It comprises a total of 1288 nodes and 1235 pipes covering a total length of 93 km (see *Figure 7*)

Figure 7: DTM and layout of the sewer system of Torquay

Urban pluvial flood models

An **InfoWorks CS model** of the study area was provided by Torbay Council. This model comprises a **1D model of the sewer system**, covering the entire study area, **coupled with a 2D model of the surface** which covers only the most critical area (i.e. along Union and Fleet Streets). The model also includes the ancillary structures present in the sewer system, such as 3 attenuation tanks and a number of pumping stations.

In this model **rainfall is applied through subcatchments** (i.e. semi-distributed model) and therefore flood water only reaches the surface once the sewer system surcharges. Each subcatchment is split into different surface types and **runoff is estimated using the Wallingford model**. The flow in the sewers and on the surface is simulated based on the full shallow-water equations (i.e. it is a **fully hydrodynamic model**). The interactions between the sewer system and the surface takes place at manholes and gullies.

This model was initially calibrated in 1994 and was further verified in 2008. During the **RainGain project the model will be updated and improved**, based on new monitoring data and on improved modelling and calibration techniques. Moreover, we will explore the possibility of **optimising the operation of the sewer system through real time control strategies supported by improved urban pluvial flood forecasting.**

Detail of 2D zone

Figure 8: Urban pluvial flood model of Torquay

Project website: http://www.raingain.eu/en/raingain

GENERAL AND TECHNICAL FACTSHEETS OF UK CASE STUDIES

Workshop pack for participatory management of