Radar technologies to obtain higher resolution rainfall estimates suitable for urban hydrological applications

by

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Some background information:

- Factors that limit resolution of radar rainfall estimates
- Types of radars
- Radar functionalities (single/dual pol, Doppler)

What is a weather radar?

For typical weather radar...

A parabolic antenna focuses radiation into a narrow pencil beam. (narrower beam = higher resolution)

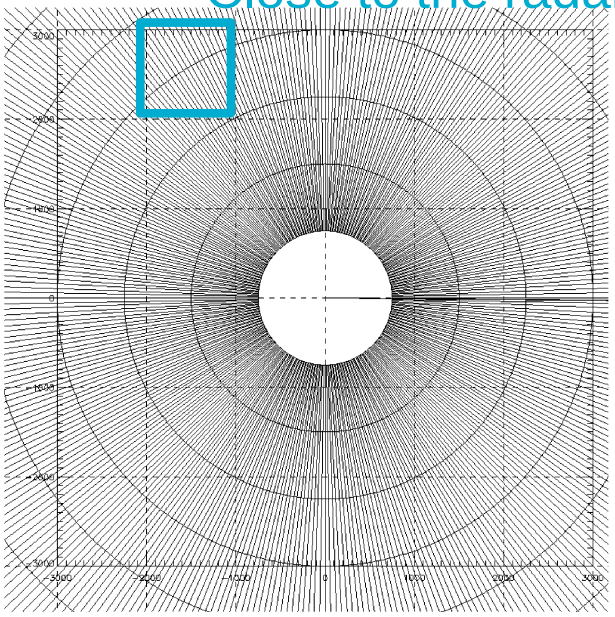
The radiation is “pulsed” –each pulse is back-scattered by precipitation it interacts with. Once the pulse has travelled to maximum range, another pulse is transmitted.

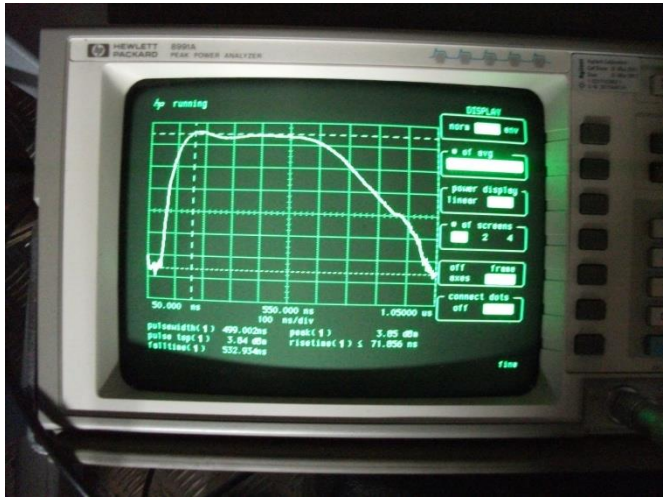
Some of the back-scattered radiation is received by the radar and is used to calculate the reflectivity.

Reflectivity is used to calculate the **rainfall intensity.**

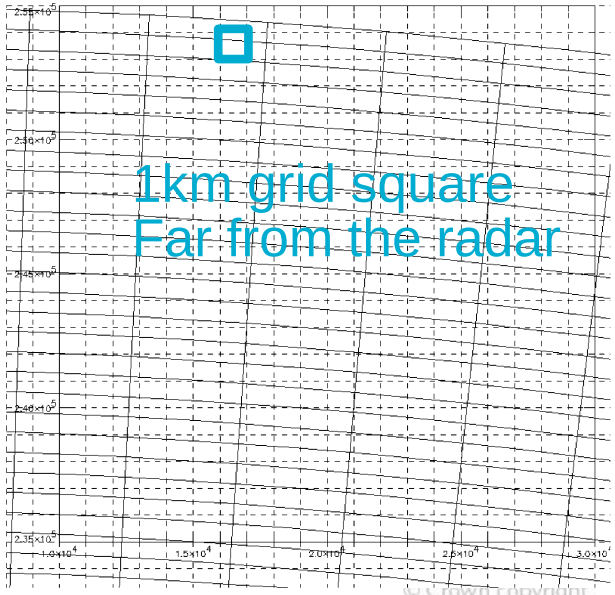
Resolution

1km grid square
Close to the radar





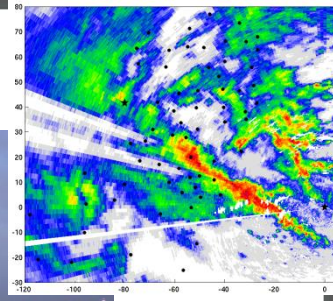
1km grid square
Far from the radar

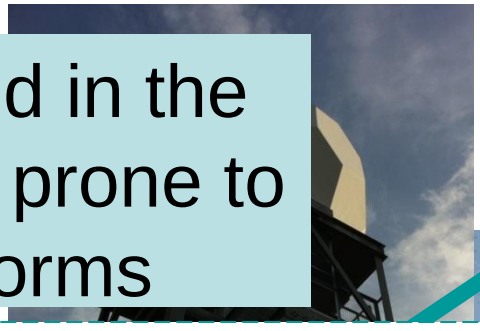


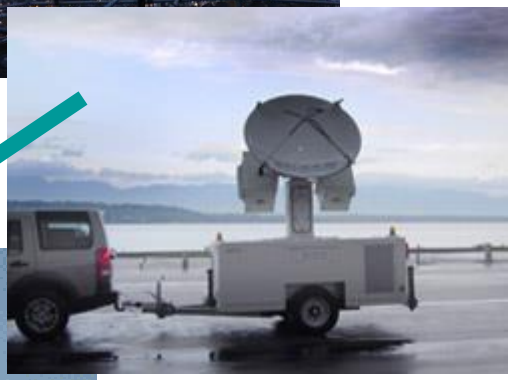
Met Office

So what is X-band?

What is X-band used for throughout Europe



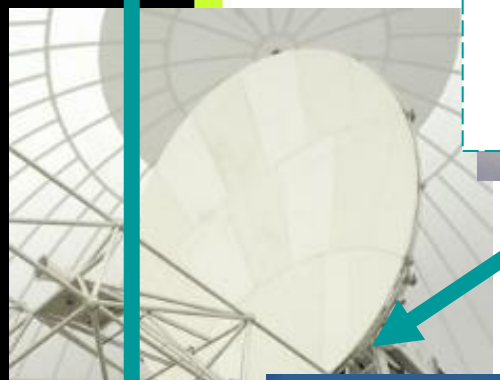




Attenuation

Primarily used in the US and areas prone to tropical storms

Increasing Antenna size (and cost)

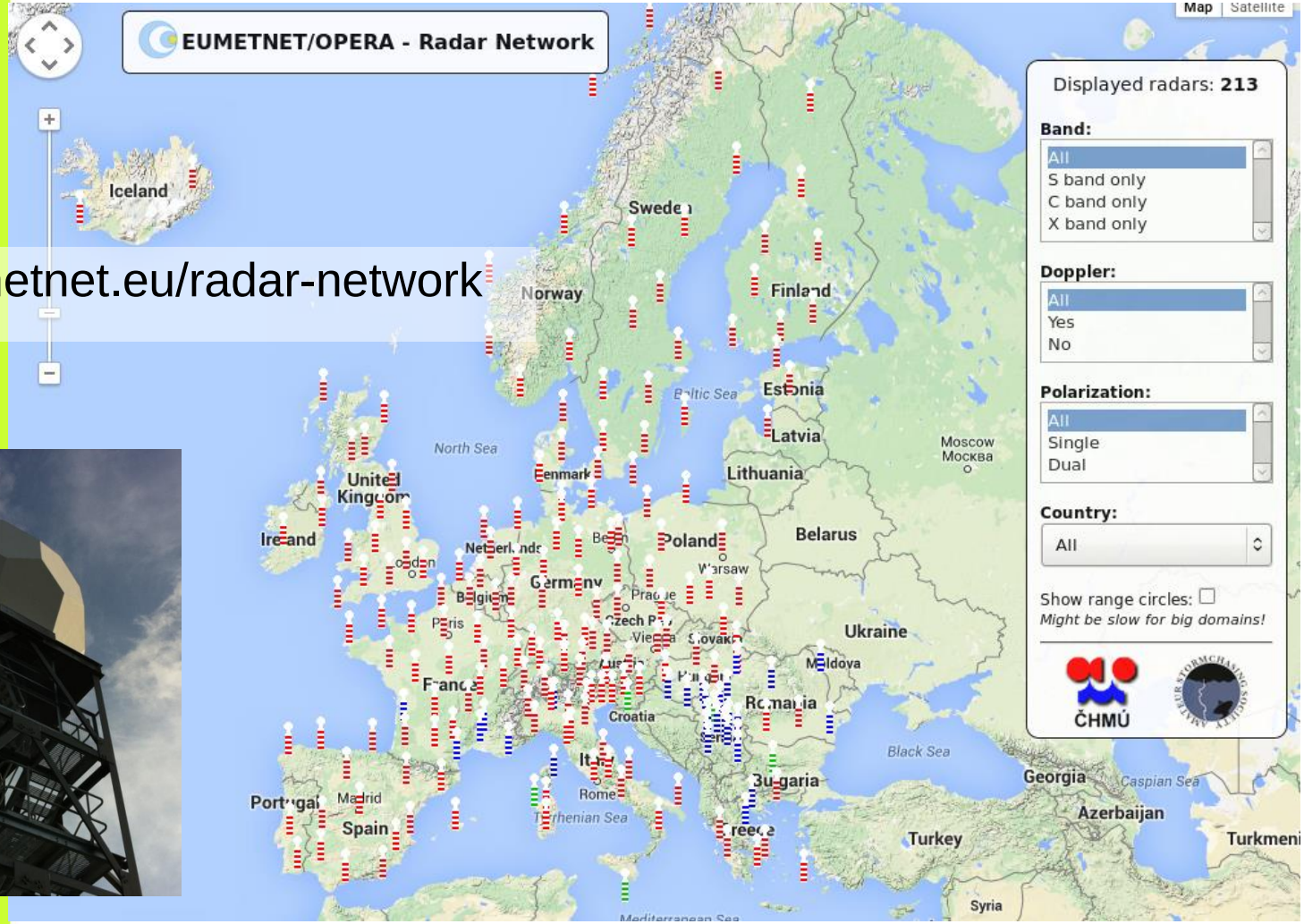


Used in mountainous and Urban areas and for portable applications such as research

Frequency

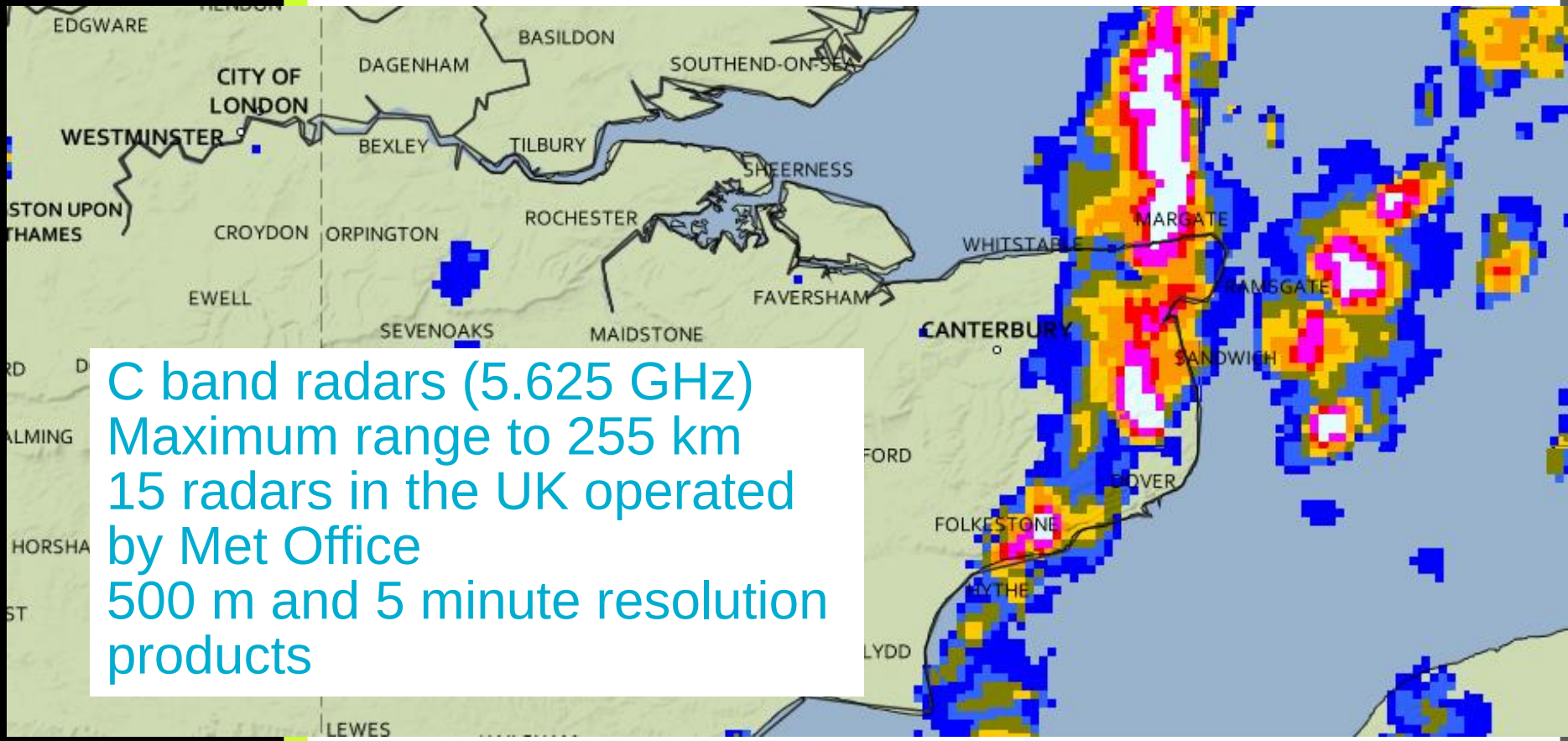
International networks

http://www.eumetnet.eu/radar-network



Data from national networks

Typically 1km / 5 min resolution

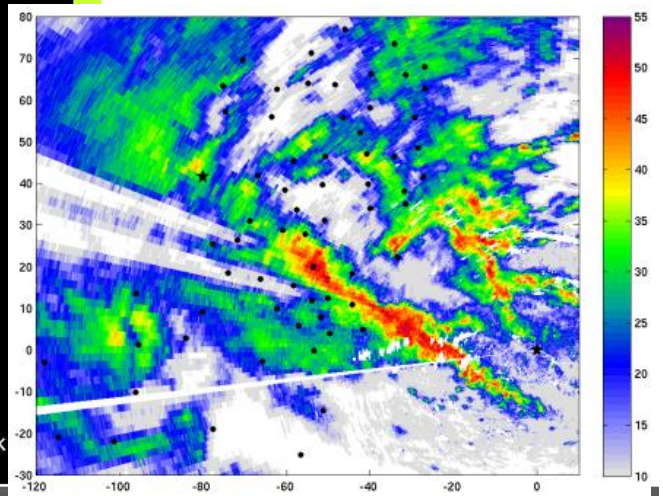


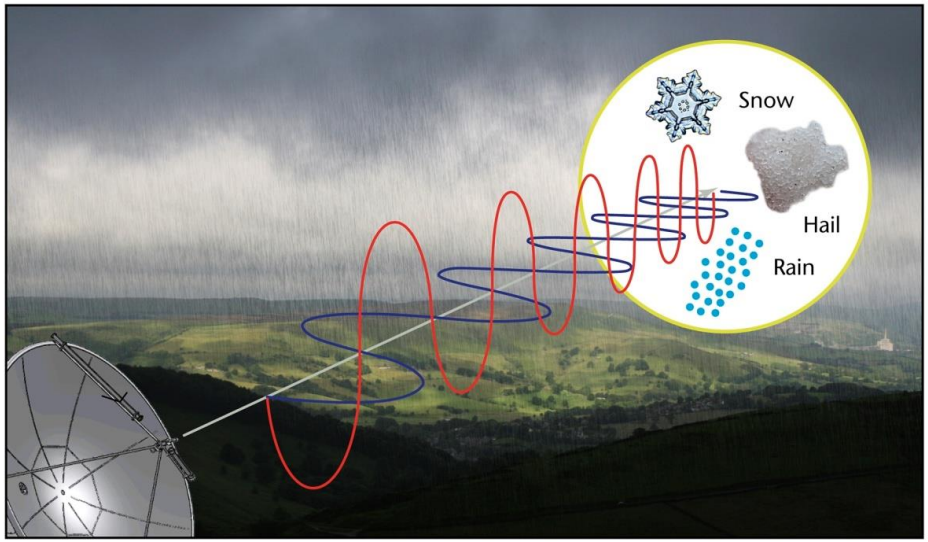
C band radars (5.625 GHz)
Maximum range to 255 km
15 radars in the UK operated by Met Office
500 m and 5 minute resolution products

This resolution may be insufficient for urban hydrology!

Dual Polarisation (S, C and X band)

- Send and receive pulses in both vertical and horizontal polarisations
- Provides 2D information about the hydrometeors (i.e. rain drops, snowflakes, ice crystals)
- Phase measurements from H and V can correct for attenuation much more effectively than single-polarisation methods and allow us to convert z->R with greater accuracy. (Current EA/MO/FFC project: Optimising the benefits of dual polarisation)

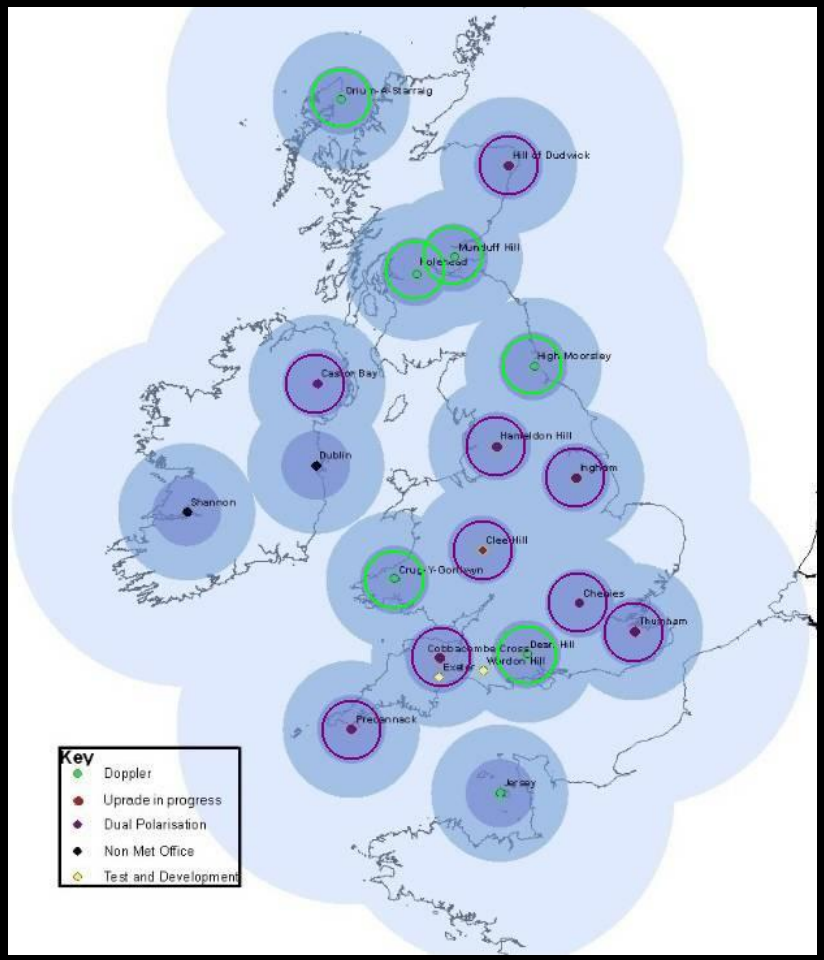




Met Office

Environment Agency

9/15 radars upgraded



Upgrade to dual polarisation

6 Doppler Radars to be upgraded

9 Dual Polarisation Radars

Met Office operates 15 C-band radars
Range: 250 km
Resolution: 500m composite over the British Isles
Updated every 5 minutes
Used to generate short-range forecasts of preciptiation out to 7 hours

X-band and C –band in the UK

Xband:

A **cheaper** installation cost for comparable spatial resolution

Attenuates in heavy rainfall, often with complete extinction

Dual Polarisation X-band radars can correct for attenuation in cases where the signal is not completely extinct

C-band:

A **large installation** for comparable spatial resolution.

Attenuates (but rarely complete extinction) in heavy rainfall

Dual Polarisation C-band radars can correct for heavy rainfall where the signal is not completely extinct

A network already operates in the UK, funded by the Public Weather Service and Environment Agency

Radar technologies explored throughout the RainGain Project to obtain higher resolution rainfall estimates

- Based upon Met Office C-band radars
- Based upon the use of local X-band radars

High resolution radar products from the UK weather C-band radar network

Katie Norman, Tim Darlington, Caroline Sandford, Steven Best, Nawal Husnoo, Sharon Jewell, Pat MacKenzie, Jacqueline Sugier, Malcolm Kitchen

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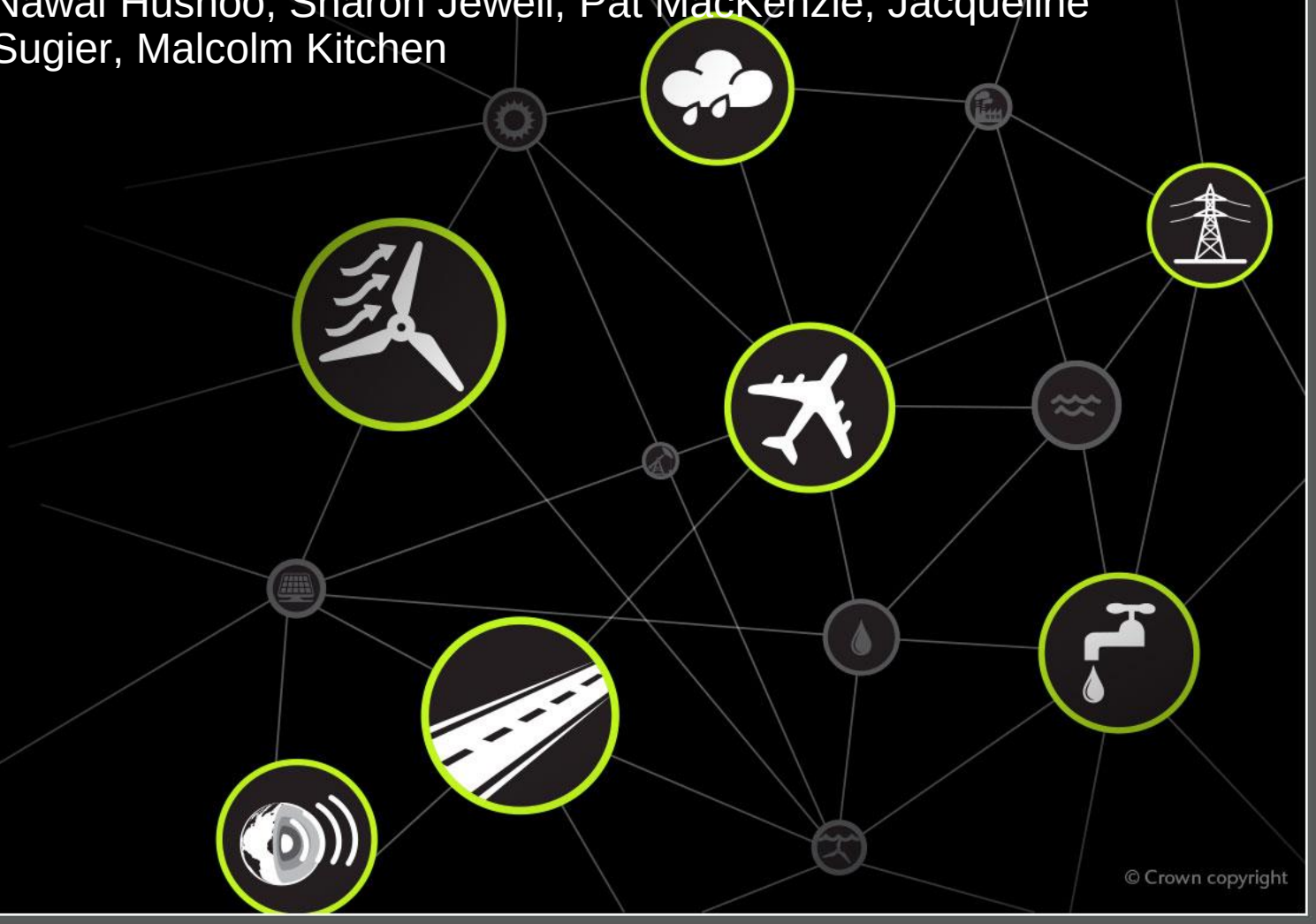
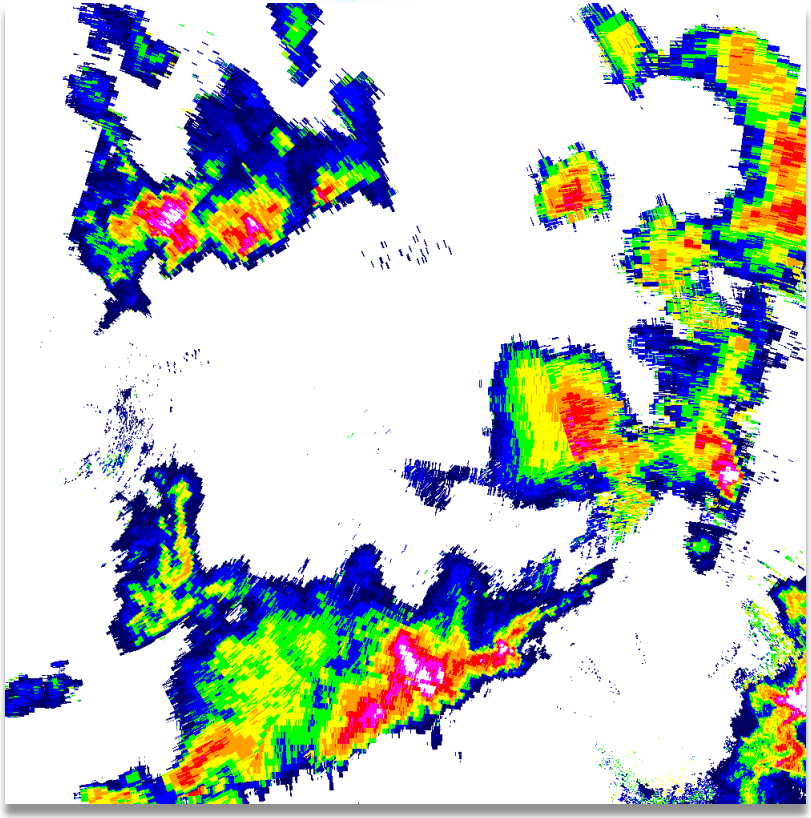
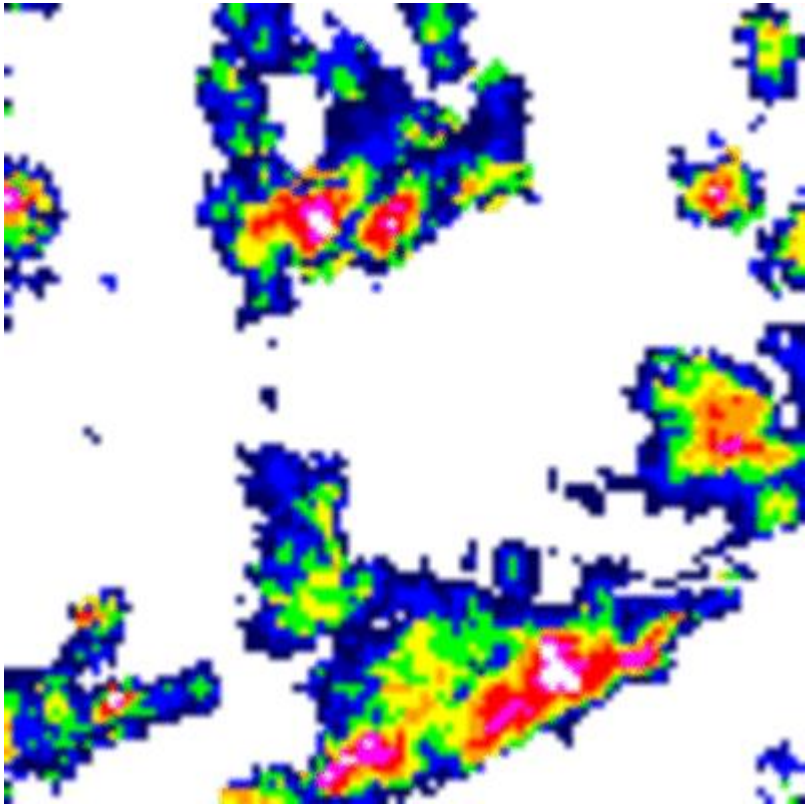


19th May 2015





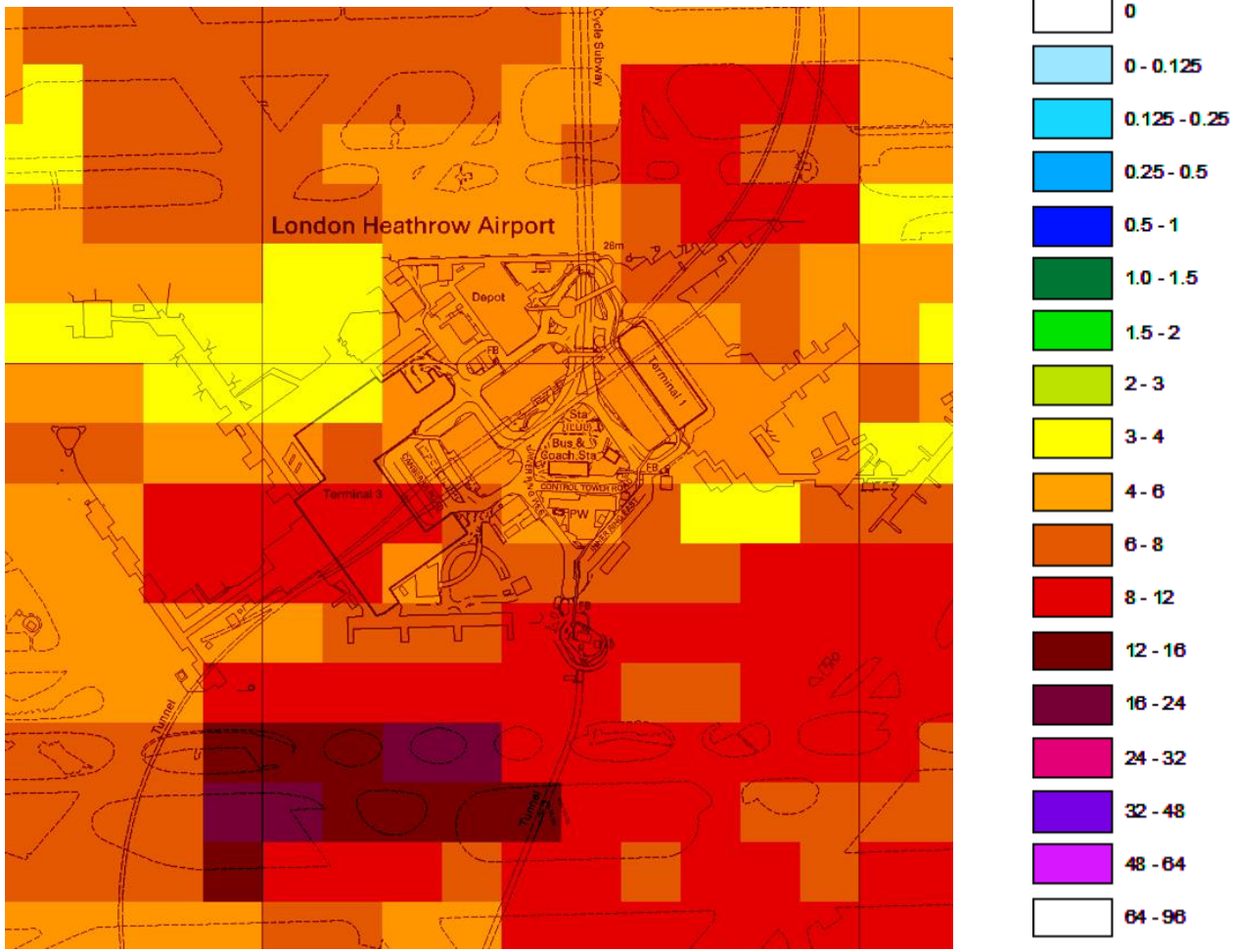
100 km by 100km - south East England including greater London area

100m Product uses radar data in short pulse (75 m) mode

1km Product uses radar data in long pulse mode (600m)

Rainfall at Heathrow Airport

100m Rainfall rate (mm/h) 1st March 2015 17:10



Areas of research: Products from Raw Data

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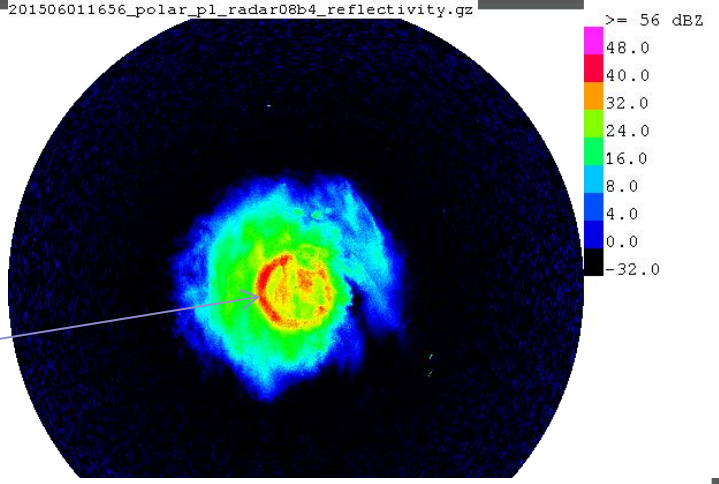
1) **Alternative signal processing** (beam sharpening, oversampling) – evaluation ongoing (Li-Pen Wang, KU Leuven and Steven Best)
2) **Dual polarisation quality control** – optimised for short pulse reflectivity data – Nawal Husnoo
3) **Beam blockage corrections** – optimised for high resolution – Dawn Harrison
4) **Vertical profile of reflectivity (VPR) correction** –better discrimination between convection and bright band
5) **Wind drift*** - Caroline Sandford
6) **Merging of radar and rain gauge data**** - Sharon Jewell

*Caroline Sandford, Correcting for wind drift in high resolution radar rainfall products: a feasibility study, Journal of Hydrology, Available online 18 March 2015 http://dx.doi.org/10.1016/j.jhydrol.2015.03.023 :
** Jewell, S. A. and Gaussiat, N. (2015), An assessment of kriging-based rain-gauge–radar merging techniques. Q.J.R. Meteorol. Soc.. doi: 10.1002/qj.2522

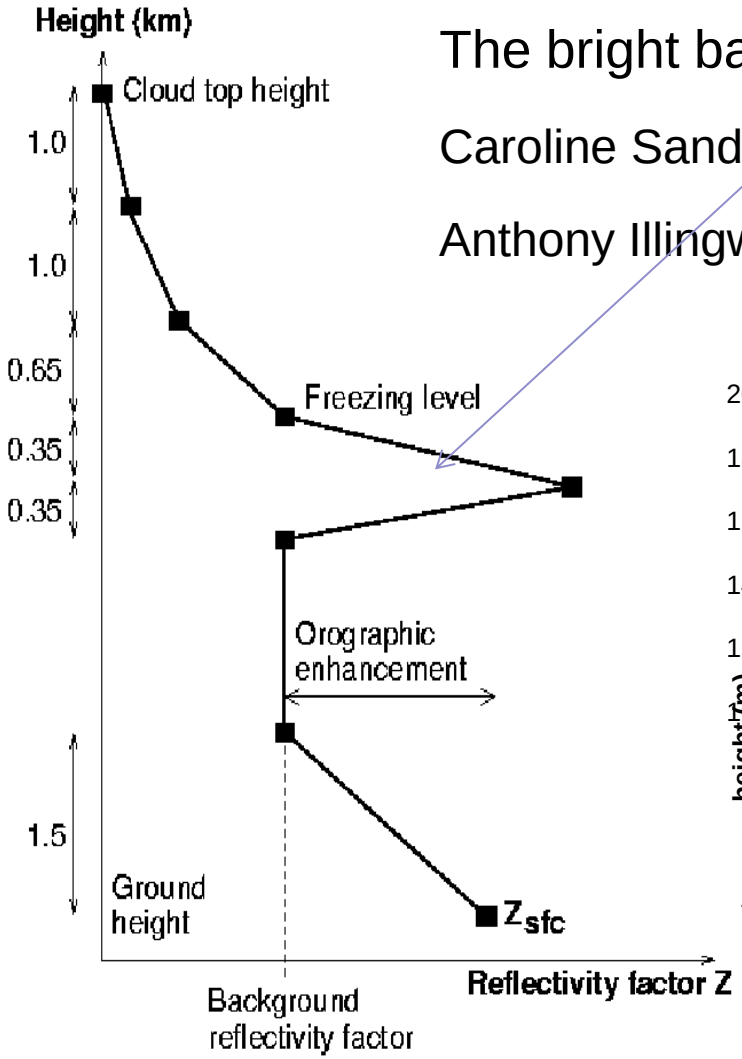
Vertical Profiles

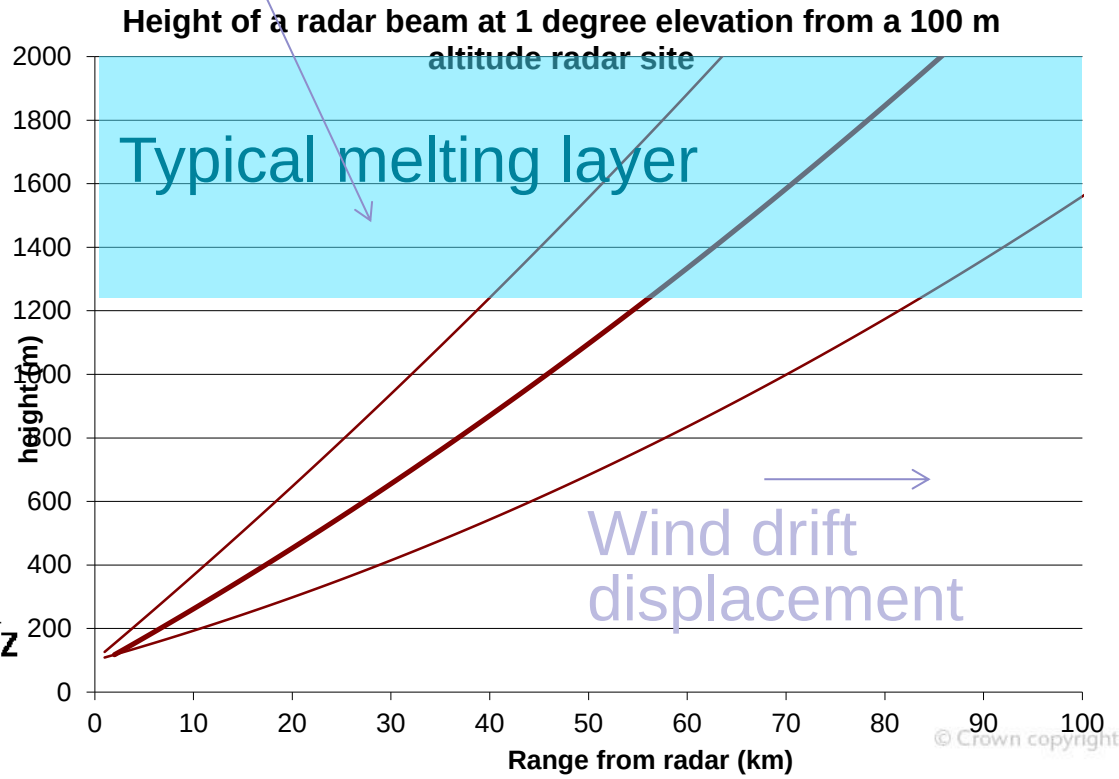


The bright band –

Caroline Sandford, Met Office and

Anthony Illingworth and Robert Thompson, University of Reading

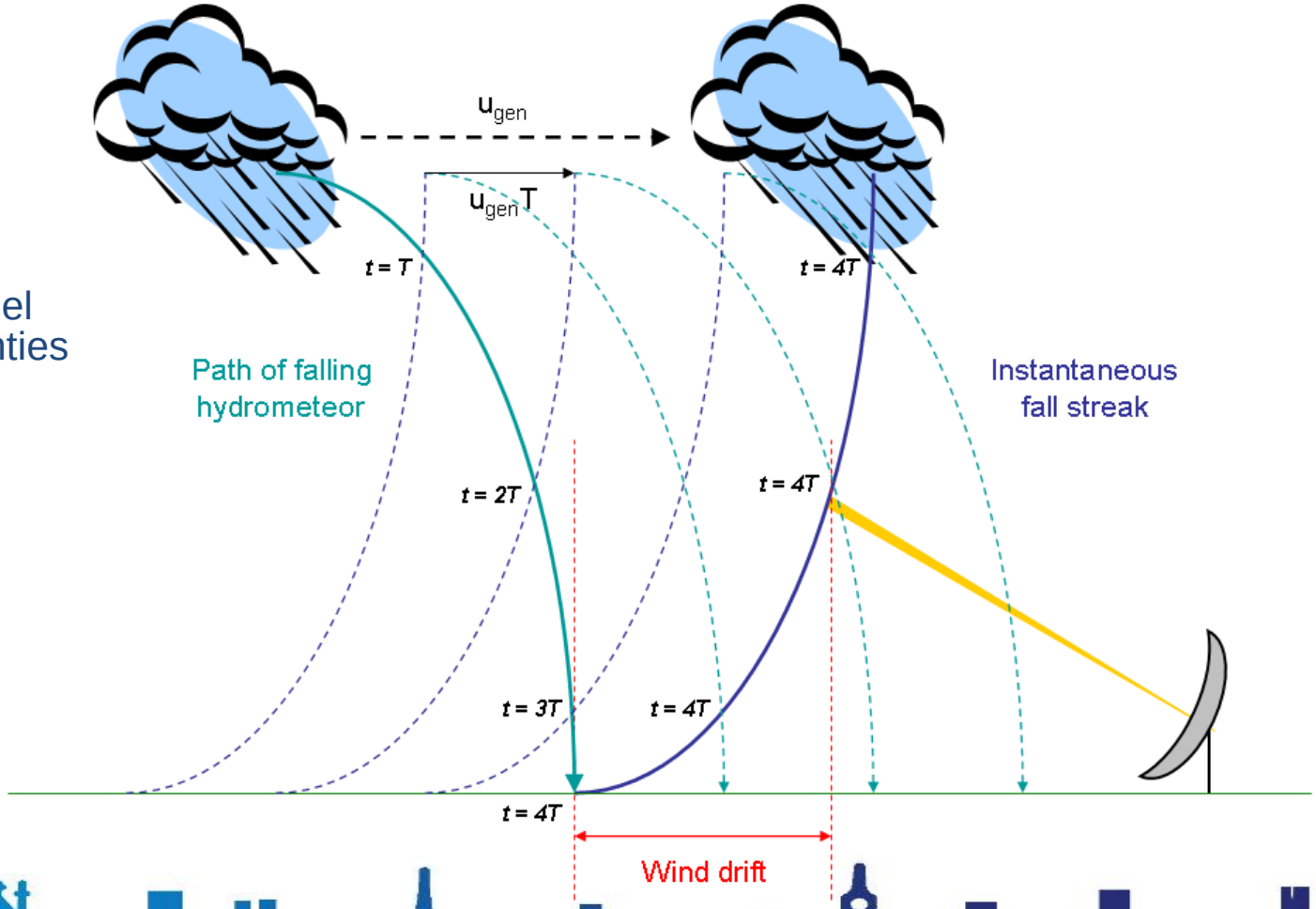




Vertical profiles

Wind drift – Caroline Sandford, Met Office

Wind drift correction by generating fall streak profiles from NWP model fields showed uncertainties of order 1km.



Performance of the high resolution rainfall product

Performance of the 100m product

Gauge comparison: March – June 2015
Gauge accumulations > 1.0 mm

100 m composite:

Bias = -0.20 mm
RMSE = 1.12 mm
>500 measurements

1 km single site rainfall rate product (out to 50 km range)
Bias = -0.51 mm
RMSE= 3.22 mm
>700 measurements

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Performance of the 100m product

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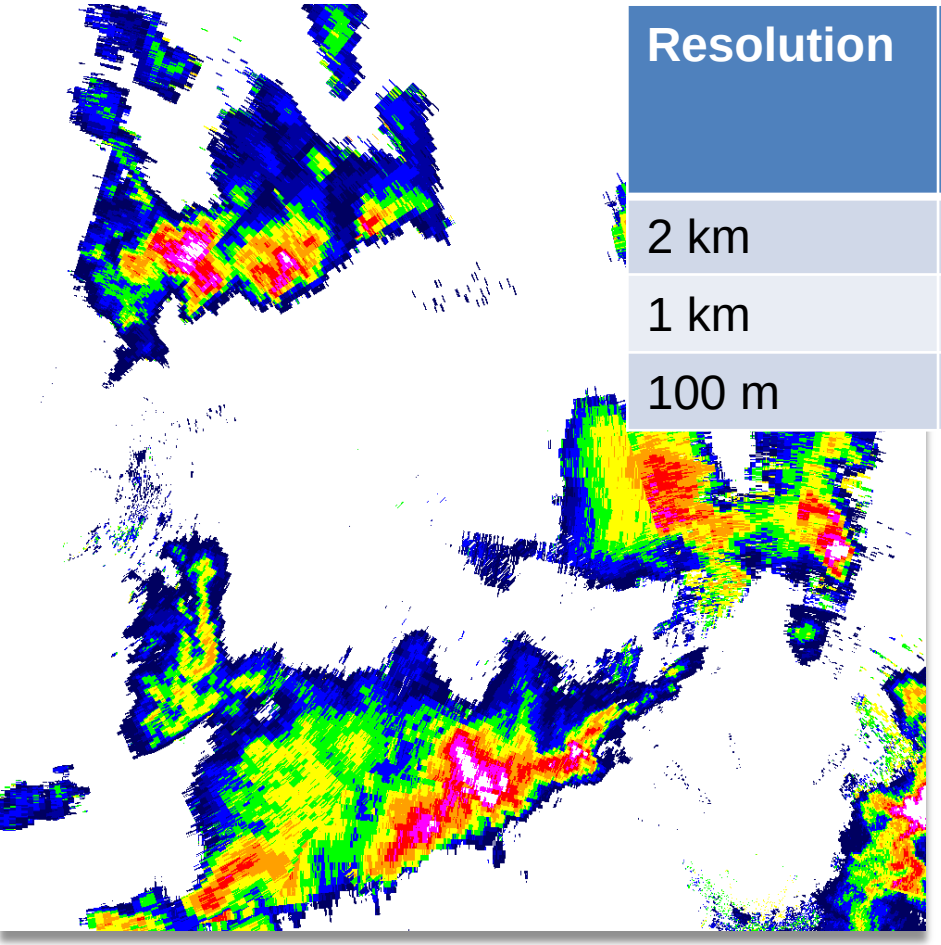


Resolution	Bias	RMSE	Number of events > 1 mm / hour
2 km	0.45	1.25	35
1 km	0.32	1.26	35
100 m	-0.07	1.00	35

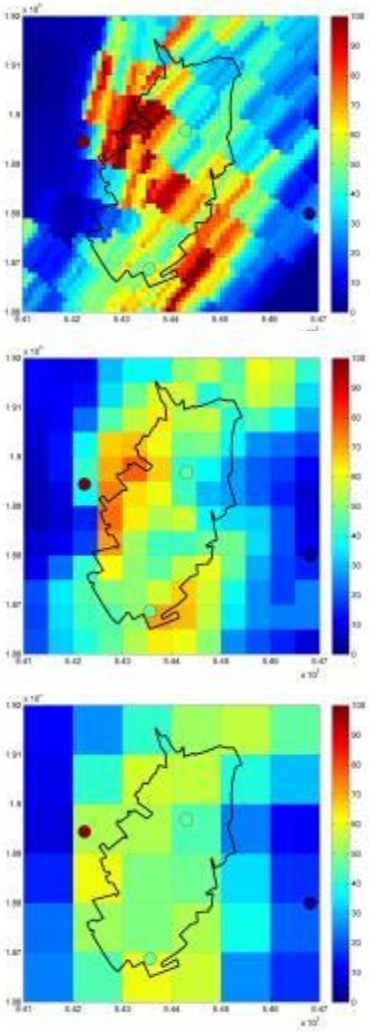
100m, 1km and 2km single radar products from Thurnham weather radar

19th May 2015

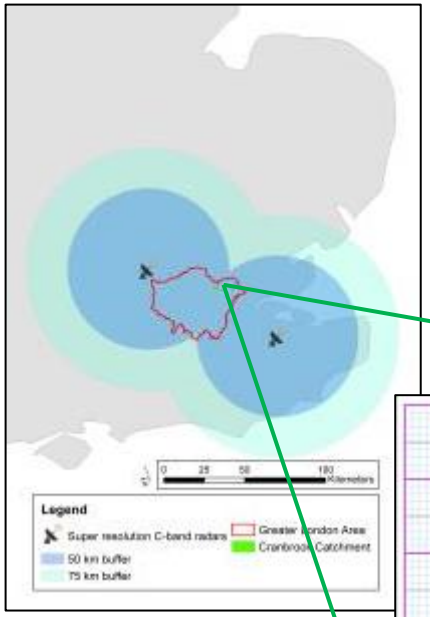
https://www.youtube.com/watch?v=w0YiatL6OeM

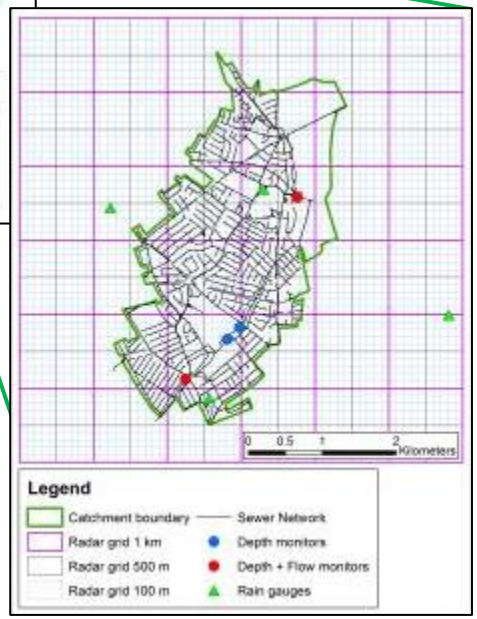
Performance of the 100 m product in a small (~9km^2) urban catchment in NE London

Max Intensity

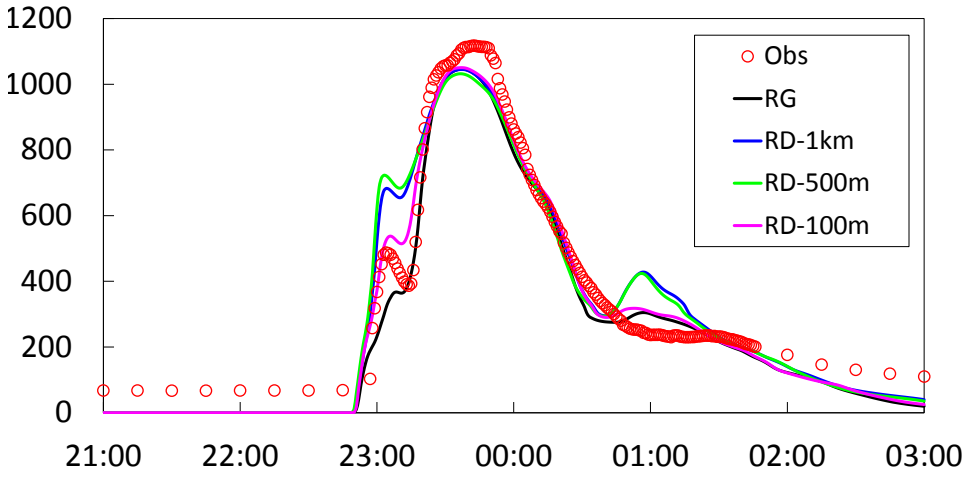


Convective storm on 03/07/2015





Observed vs. Simulated water depths



Conclusions

Investing in Opportunities
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- Demonstrated the feasibility of collecting high resolution data from a national weather radar network and generating high resolution radar rainfall estimates in urban areas.

- The accuracy of the 100m resolution estimates when compared to gauges is better than the 1 km resolution data over a 3 month period and for a case study.

Further work?

Investing in Opportunities
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Temporal sampling and resolution

(1) Getting the most from the radar hardware and

(2) Use of 4D processing to get best time synchronisation of information

Radar is uncertain

(3) Error models can be developed to understand this uncertainty and these can propagate into hydrological models

Engagement with national met services

(4) Many national Met services already gather data in short pulse mode – should future projects engage with EUMETNET to get the most out of existing infrastructure and data?

X-band radar technologies: Experiences from the RainGain project

X-Band Radars at RainGain Pilot Locations

Single-pol

Dual-pol
Doppler

Dual-pol
Doppler

Single-pol

Installation and testing of low cost X-Band radar in London (Mar-Oct'13)

- This campaign aimed at exploring:
  - The **potential benefits** of a low-cost, portable X-band radar for urban hydrological applications
  - The **challenges** associated to its installation and operation

- Potential benefits include:
  - High spatial and temporal-resolution rainfall estimates
  - Measurement of rainfall closer to the ground

London's low-cost X-band radar: Selex RainScanner RS90

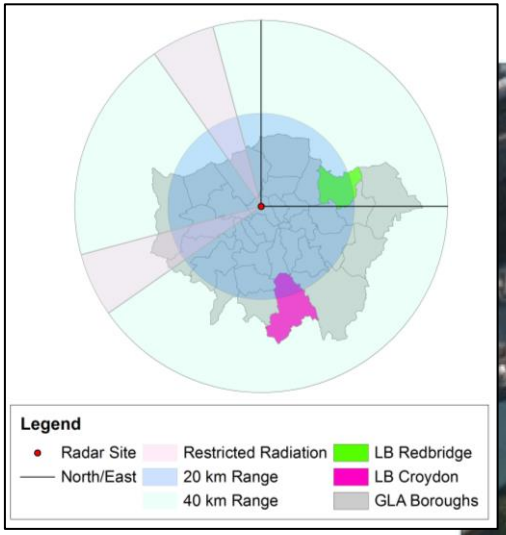
	Selex RainScanner RS90
Radar type	X-band
Polarisation	Single-polarisation
Doppler (yes/no)	No
Antenna	Parabolic, pencil beam antenna
Beamwidth	2°
Frequency range	8 to 12 GHz
Wave length	2.5 – 4 cm
Range resolution	30 m
Temporal resolution	1 min
Elevations (°)	2

Range: ~ 50 km

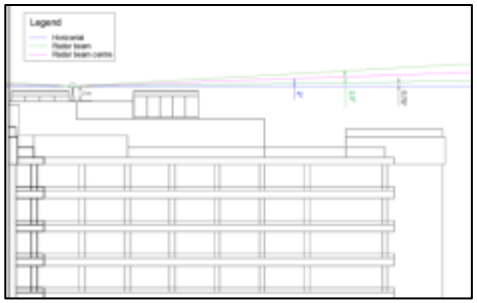
1. Preparatory stage

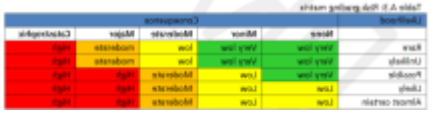
(June 2012 – February 2013)

a) Search of an appropriate location for the radar in terms of coverage, ‘visibility’ and permission!



b) Radar radiation permission, risk assessment and mitigation



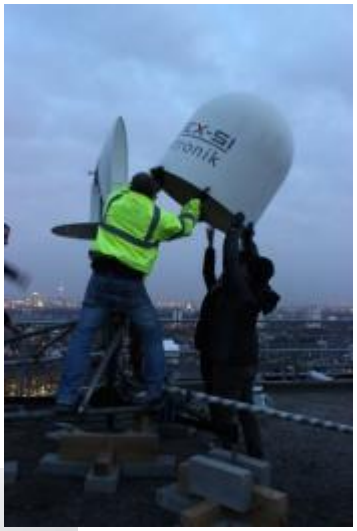


c) Training

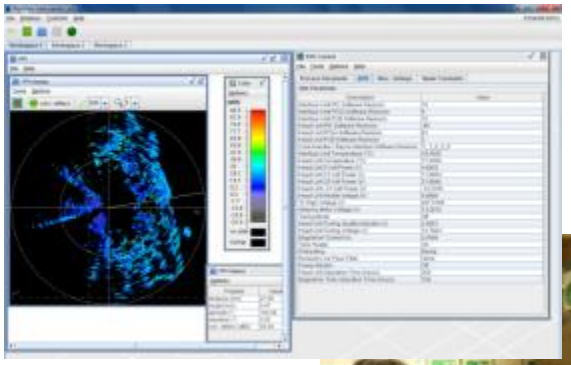
2. Installation & testing stage

(March 2013 – May 2013)

a) Radar installation



b) Software and hardware testing

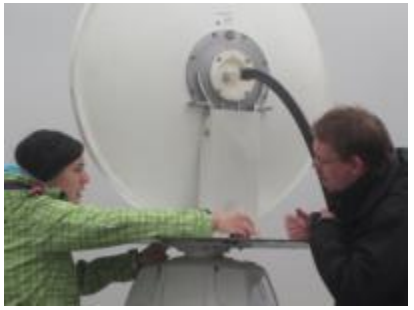


3. Operational stage

(June 2013 – October 2013)

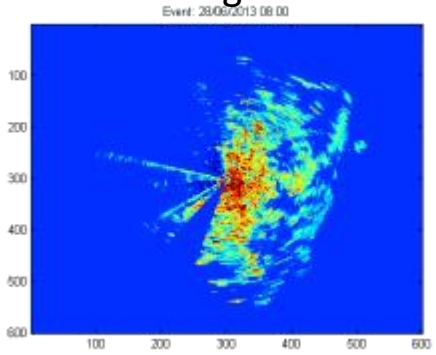
a) Raw data collection (8 ‘big’ storm events recorded)

b) Hardware adjustment and maintenance

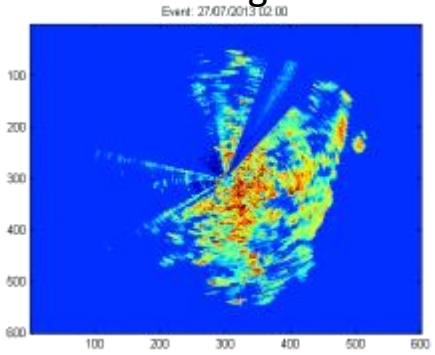


Physical increase of the elevation of the radar antenna was done twice after initial installation in order to reduce clutter interference

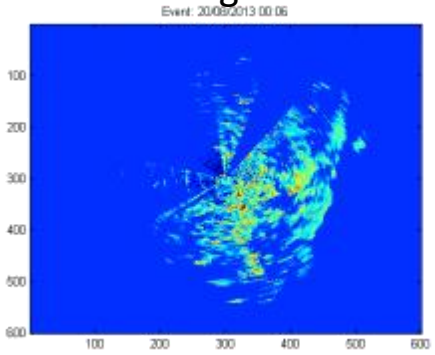
0.5 Degree



1.5 Degree



2.5 Degree



3. Operational stage

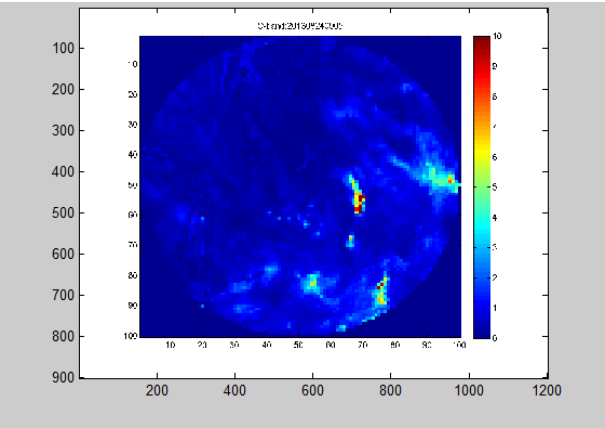
(June 2013 – October 2013)

c) Data processing

- Signal stability correction
- Clutter filtering
- (Range-dependent) Z-R conversion / calibration
- Attenuation correction
- Polar to Cartesian coordinate conversion
- Gauge-based adjustment

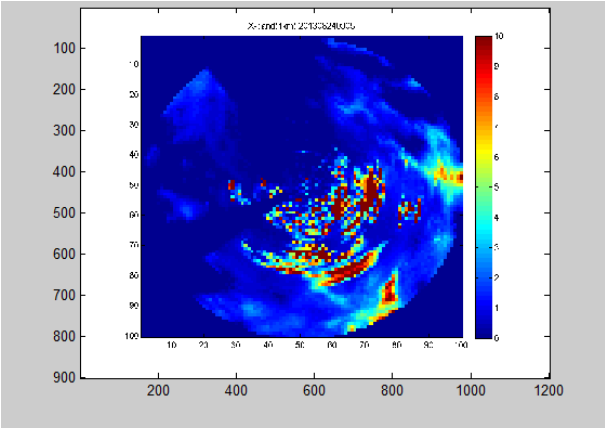
d) Data quality assessment (through comparison with C-band radar, raingauges and hydraulic outputs)

UKMO Nimrod Data
5 min / 1 km

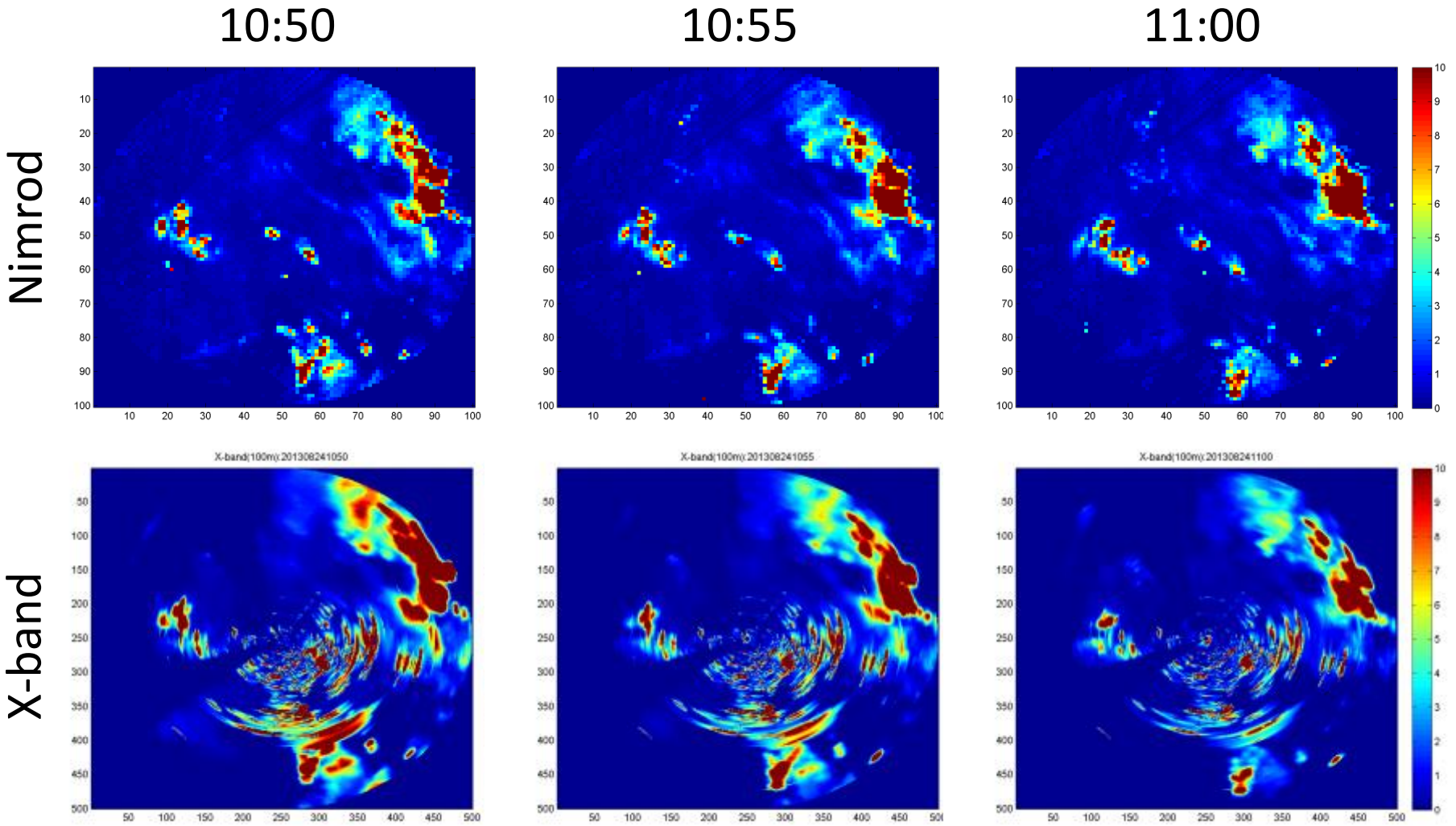


2013/08/24
09:00-11:00

X-band radar data
5 min / 100 m

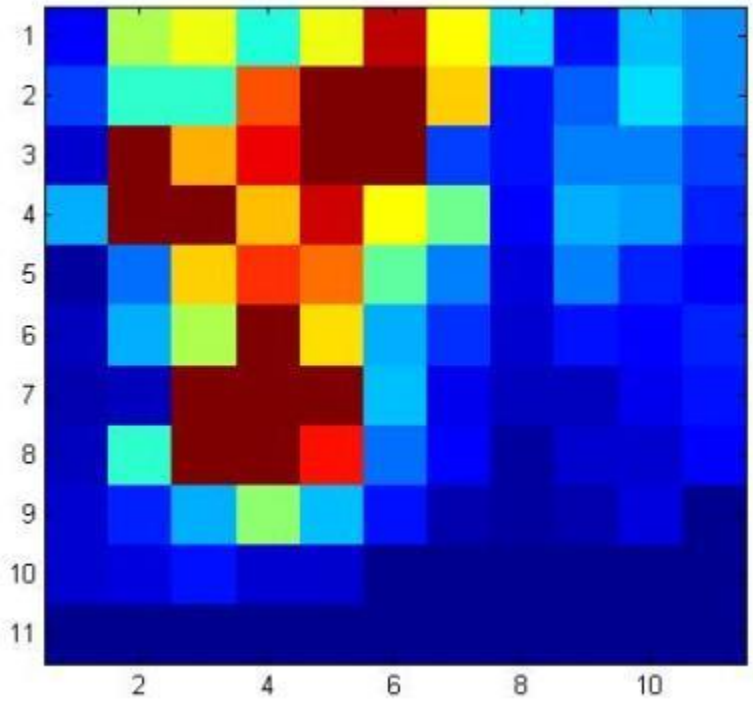


X-band radar can successfully capture storm cells (also captured by Nimrod) at higher resolution, but suffers from clutter and attenuation, leading to poor accuracy

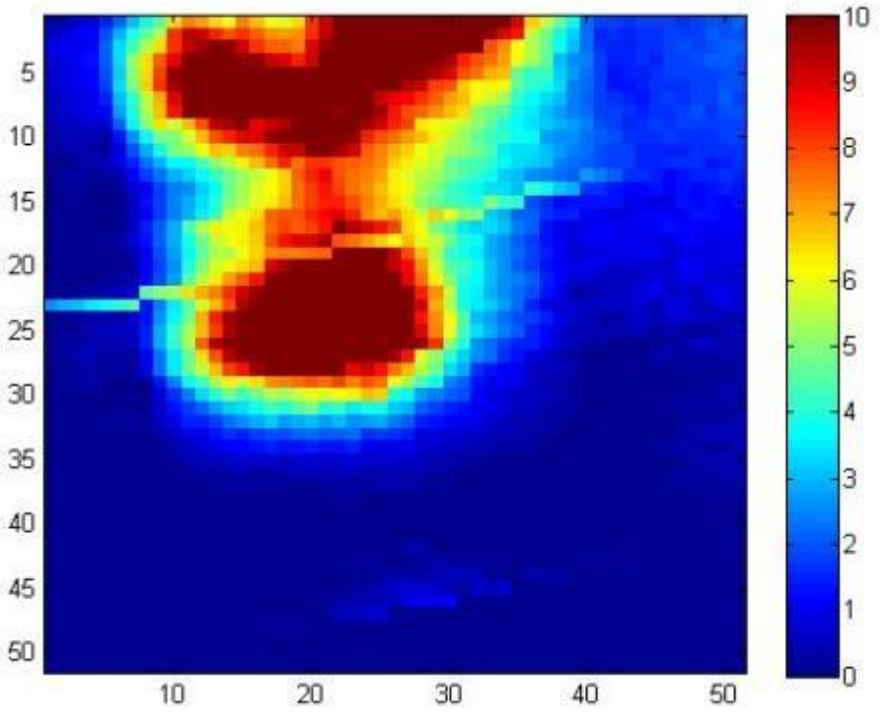


Low cost X-band radars have the potential to provide more detailed information of rainfall spatial structure, but their accuracy is rather poor

UKMO Nimrod Data
5 min / 1 km



X-band radar data
5 min / 100 m



Accuracy is hard to improve, given the limited parameters available for the low-cost radar

X-band radar monitoring campaign in Central London: Conclusions & Lessons learnt

- It is not easy to install a radar in the heart of a dense urban area such as London.
- In general: low cost X-Band radar can effectively capture storm cells and storm movement at high resolution; however, the accuracy of the estimates is rather poor.
- Main reasons for poor accuracy: clutter and attenuation.
- Accuracy can be improved based on complementary data from other sensors (e.g. C-band radar, raingauges); however, the need for data from multiple sensors to produce reliable estimates makes the added value of the low-cost X-band radar questionable, especially in areas such as London where C-band radar coverage and quality is quite good.
- Low cost X-bands could be useful for tracking and forecasting storm movements in areas where no other data area available. For example: in coastal areas.

X-Band Radars at RainGain Pilot Locations

Single-pol

Dual-pol
Doppler

Dual-pol
Doppler

Single-pol

Cost and availability of radar data in the UK

Your own radar
vs.
Buying data from UK radar network

OWN LOCAL X-BAND RADAR (range: ~ 40 km; area: 5,000 km²)	PURCHASING UKMO RADAR DATA (area: any)
COSTS	
• Investment cost radar: ~ £150k - £600k • Data handling (algorithms, QC): ~ £60k/yr (4 yrs) • Maintenance: ~ £20 / yr • Power, data transmission & storage: ~ £20k/yr	• 1 km resolution area cutout: ~£25 / yr • 500 m resolution area cutout: ~£30k/yr • Wholesale 1km composite ~£20k • 100 m res: not yet operational • Data handling & storage: ~£10k/yr • Forecasts (2km/15min): ~£5-20k (city-region)

OWN LOCAL X-BAND RADAR (range: ~ 40 km; area: 5,000 km²)	PURCHASING UKMO RADAR DATA (area: any)
COSTS	
• Investment cost radar: ~ £150k - £600k • Data handling (algorithms, QC): ~ £60k/yr (4 yrs) • Maintenance: ~ £20 / yr • Power, data transmission & storage: ~ £20k/yr	• 1 km resolution area cutout: ~£25 / yr • 500 m resolution area cutout: ~£30k/yr • Wholesale 1km composite ~£20k • 100 m res: not yet operational • Data handling & storage: ~£10k/yr • Forecasts (2km/15min): ~£5-20k (city-region)
PROS	
• Independence on operation and data handling • Opportunity to share costs with other users or to sell data to other users • Operational costs likely to decrease once radar has been deployed and algorithms have been developed	• Readily available • Robust processing and QC (reliable data) • No large initial investment required • No significant expertise needed

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CONS	
• Large initial investment required • Installation and operation requires specialised knowledge, staff and infrastructure • Coverage insufficient for nowcasting	• Constant running costs • Subject to prices set by provider • Little control over data quality

What to do?

- Clear benefit of having good quality radar rainfall estimates (in terms of hindcasting, real-time operation and nowcasting) – and same coverage is hard to achieve with rain gauges

- Decision to buy and operate new radar vs. purchasing radar data already available is a function of multiple variables:

f (current radar coverage including distance to nearest radar,

cost of accessing currently available radar data,

available budget - now and in future,

available in-house expertise and infrastructure,

envisaged application (hindcast, RT simulations, forecast?),

…)

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

Thank you

Questions – Q&A session!