Creating a world
fit for the future

AQ sensors and how best to use them

Welsh Air Quality Forum Annual Seminar
28th September 2021

www.ricardo.com

Introduction

- What is a low(er) cost sensor
- Pros and Cons
- Legislation / Standardisation
- Quality Assurance / Quality Control
- Applications

Definitions

- Sensor – a component that responds to a pollutant in some way

- Sensor system (or device) – a product built with sensors, with controlling firmware / hardware

- Reference analyser – an instrument with tested and quantified performance

Sensors - Pros and Cons

There are many factors to consider:

Pros	Cons
Low cost	
Low power	
Portable	
Deployability	
High time resolution	
Microenvironment mapping	
Ease of use?	

Sensors - Pros and Cons

There are many factors to consider:

Pros	Cons
Low cost	Data Quality
Low power	Drift
Portable	Noise
Deployability	Limit of detection
High time resolution	Repeatability
Microenvironment mapping	Uncertainty
Ease of use?	Ease of use?

Monitoring Legislation - Ambient

- EU / National Legislation / WHO guidance

Clearly defined measurement uncertainties:

Reference (or Equivalent) / Indicative

- NO_2 ±15% / 25%
- PM ±25% / 50%

(at the region of the Limit Value)

Monitoring Legislation - Ambient

- EU / National Legislation / **WHO guidance (very tough new Air Quality Guideline levels)**

Clearly defined measurement uncertainties:

Reference (or Equivalent) / Indicative

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(at the region of the Limit Value)

Table 0.1. Recommended AQG levels and interim targets

Pollutant	Averaging time	Interim target				AQG level
		1	2	3	4	
$PM_{2.5}$, µg/m³	Annual	35	25	15	10	5
	24-hour[a]	75	50	37.5	25	15
PM_{10}, µg/m³	Annual	70	50	30	20	15
	24-hour[a]	150	100	75	50	45
O_3, µg/m³	Peak season[b]	100	70	–	–	60
	8-hour[a]	160	120	–	–	100
NO_2, µg/m³	Annual	40	30	20	–	10
	24-hour[a]	120	50	–	–	25
SO_2, µg/m³	24-hour[a]	125	50	–	–	40
CO, mg/m³	24-hour[a]	7	–	–	–	4

[a] 99th percentile (i.e. 3–4 exceedance days per year).
[b] Average of daily maximum 8-hour mean O_3 concentration in the six consecutive months with the highest six-month running-average O_3 concentration.

Development of performance testing – CEN WG42 activity

- WG42 investigating how to test sensor systems
- Not working in isolation: wide consultation with interested parties
- Main challenges:
  - Cost of testing vs price of systems
  - Test sensors? Test end products?
  - Time required for test programme
  - Speed of sensor development
  - Where / when to test? Hot/Cold/Wet/Dry/UB/Traffic/Industrial
  - Software or algorithm updates

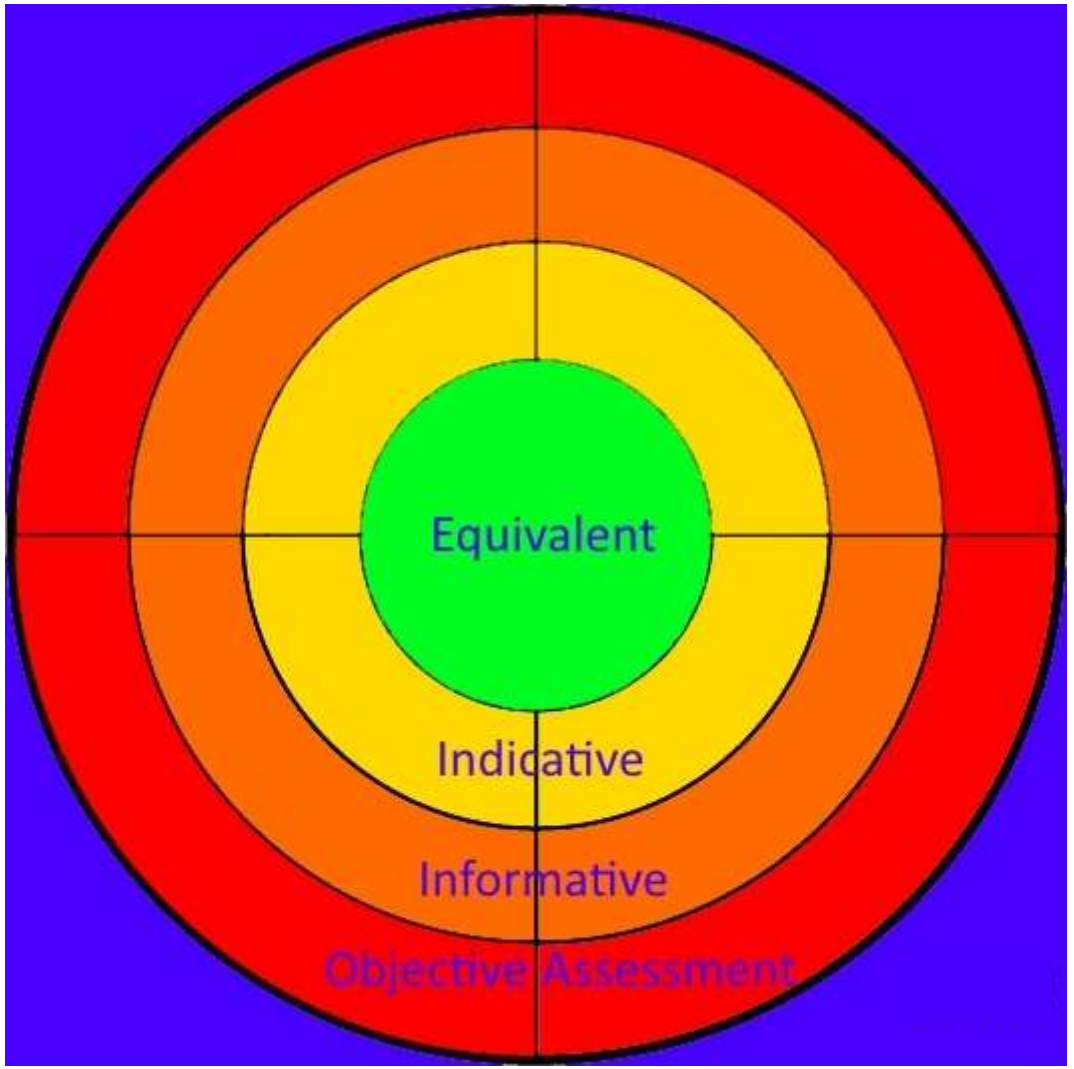
An EN specification document is nearly here…

Development of performance testing – fitness for purpose.

- Test programme needs to allow us to categorise performance.

- Already exists for Equivalence (and type testing for reference devices)

- EN specification:
  - Indicative (Class 1)
  - Informative (Class 2)
  - Objective Assessment (Class 3)

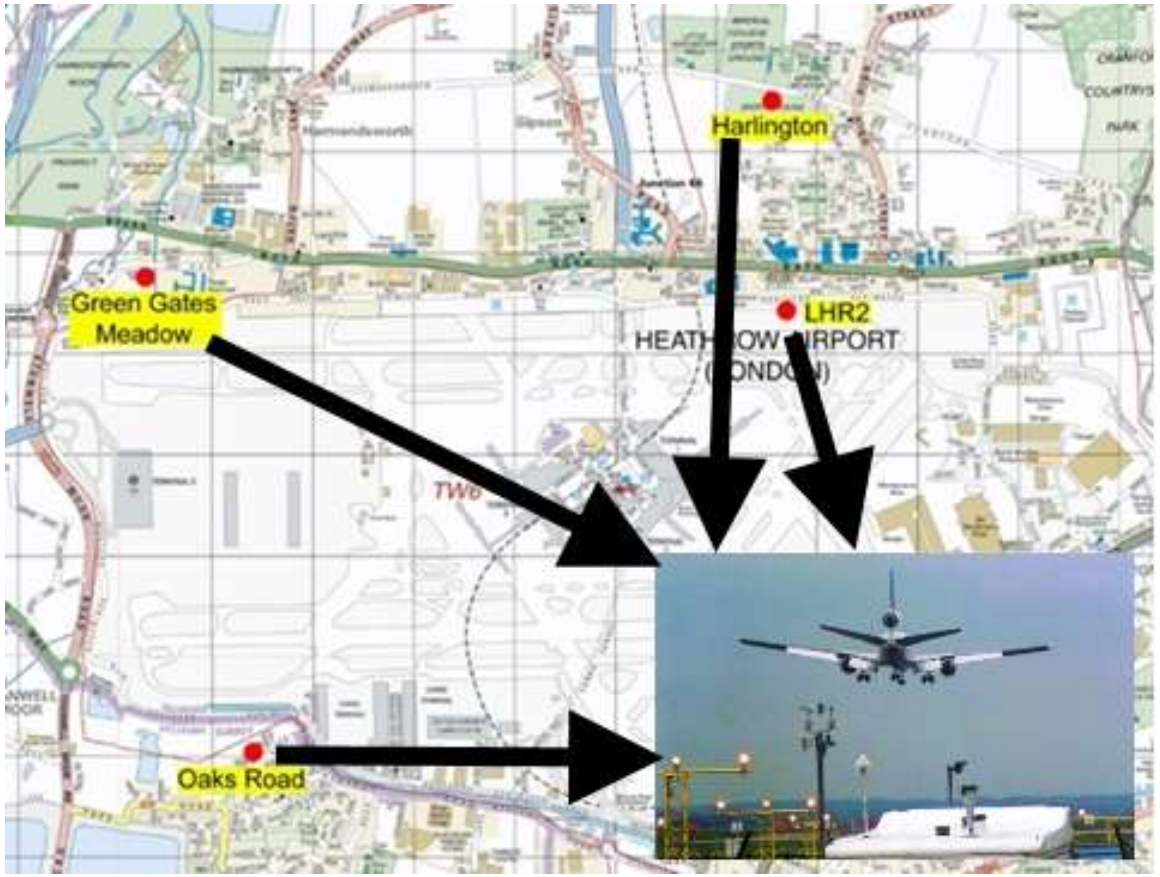


Ongoing QC – Method 1

Ongoing assessment probably more important than certification…

Methods include:

- All sensor systems regularly assessed against a true reference station

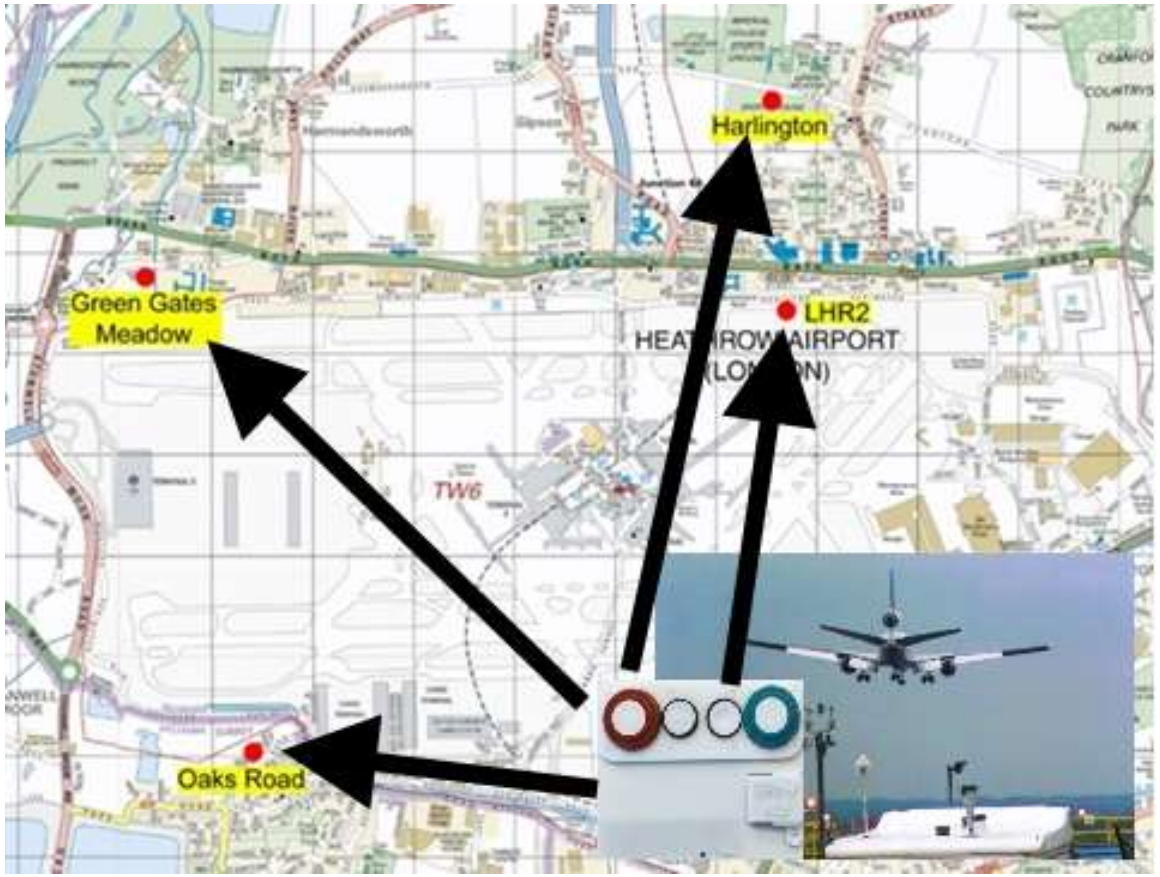


Ongoing QC – Method 2

Ongoing assessment probably more important than certification…

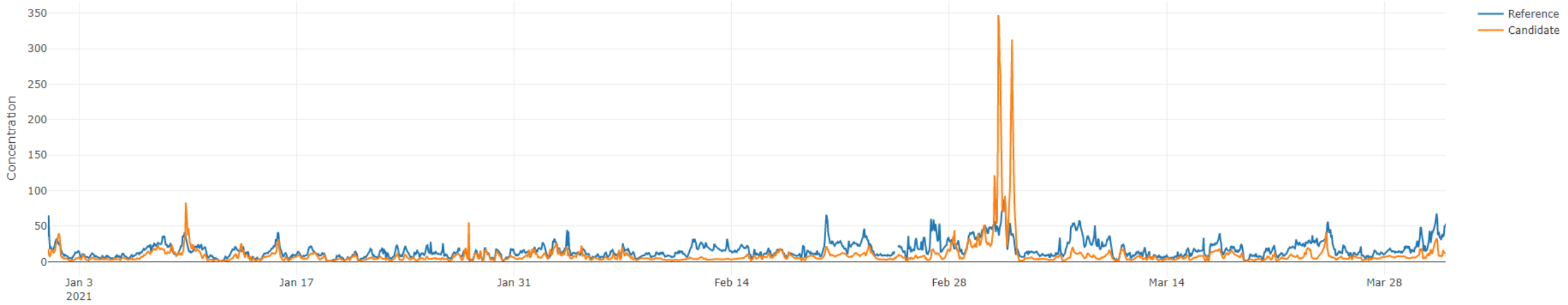
Methods include:

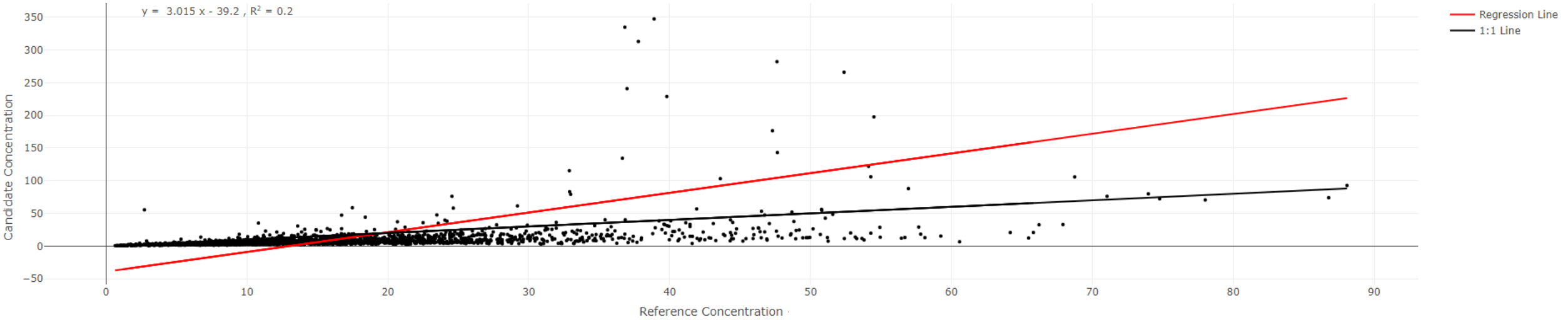
- All sensor systems regularly assessed against a true reference station
- One system regularly assessed against a reference station, then used as a transfer standard at other system locations



Example PM_{10} sensor system data

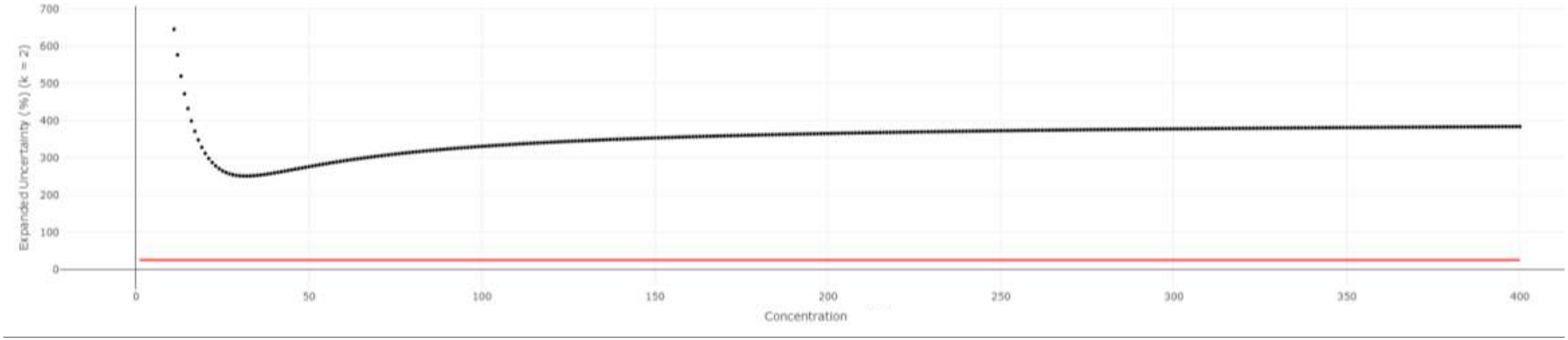
- Sensor data trends well with the reference analyse in some places but there are obvious outliers.
- Makes it difficult to derive a correction factor from linear regression analysis (poor correlation, $R^2 = 0.2$).
- PM_{10} peaks likely due to high relative humidity, not real PM.





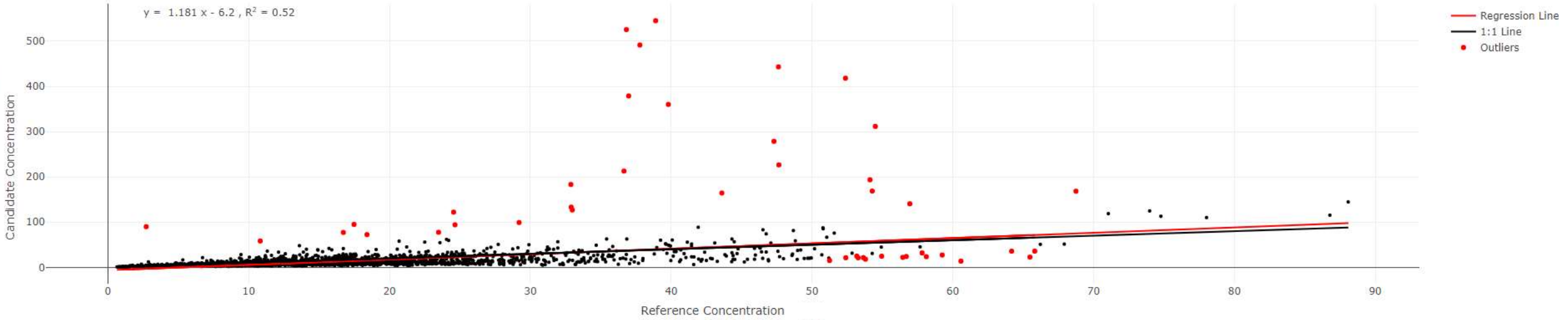
Example PM_{10} sensor system – uncorrected measurement uncertainty

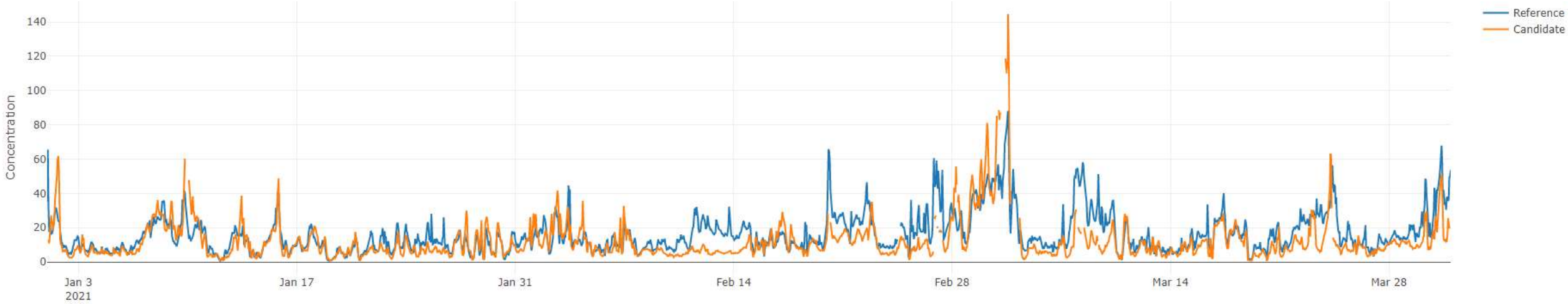
- Red line is ±25%.
- Uncertainty in hourly PM_{10} concentrations is ±276% at a limit value of 50 µg m^{-3}.
- If we use the regression results in the previous slide to correct the data the uncertainty is still ±143%
- Can we improve on this?



Example PM_{10} sensor system – corrected

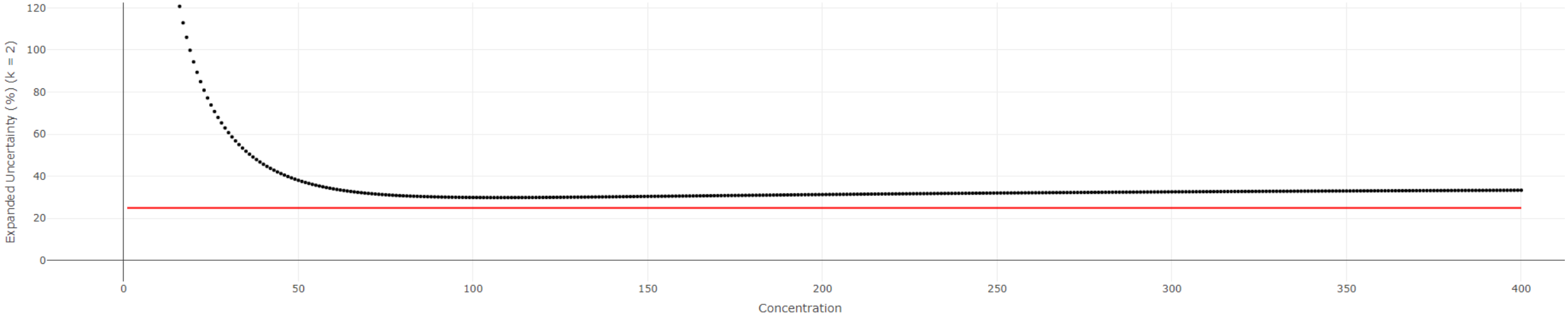
- Remove outliers through statistical analysis.
- Improved $R^2 = 0.52$.
- Correct data using new linear regression model.





Example PM_{10} sensor system – corrected measurement uncertainty

- Uncertainty in corrected hourly PM_{10} concentrations is now ±38% at a limit value of 50 µg m^{-3}!
- This indicates that the corrected measurements are indicative in this case e.g. U < ±50% for PM_{10} **with appropriate QA/QC applied.**
- Note that the measurement uncertainty is not constant throughout the measurement range, especially at low concentrations.
- Think back to the new PM_{10} WHO Air Quality Guideline of 10 µg m^{-3} - U = ±202% (*with the caveat that we are comparing hourly data with an annual mean*).



Ongoing QC – there is a 3rd method

Ongoing assessment probably more important than certification…

Methods include:

- All sensor systems regularly assessed against a true reference station
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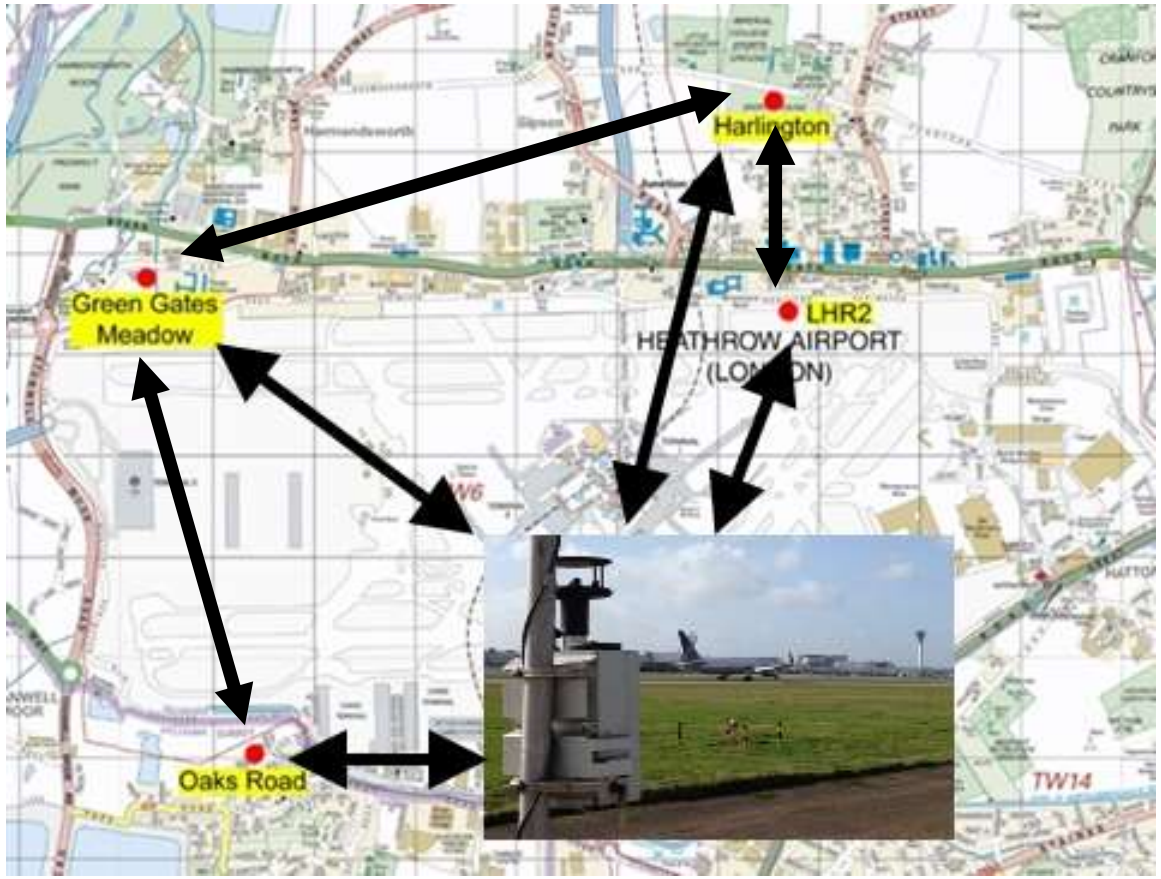
- Use of advanced processing protocols to compare system responses and scale datasets



Once you have comparison data, you can start to challenge and use the measurements

Machine learning / advanced data training

- Sensors of the same type typically behave similarly when exposed to the “same” weather.
- Means it is possible to look at large networks of sensor systems and process them for baseline and response profiles, either manually or using some form of AI
- Consistent internal QC – will be useful for building detailed pollution maps / clean routes to work, mitigation strategies etc.
- But: serious processing / communications requirements – not cheap.

Applications

Question	Answer
Can I use sensor systems instead of “proper” monitoring?	
Can I use sensor systems instead of diffusion tubes?	
Can I use sensor systems to identify hotspots?	
Can I use sensor systems to improve modelling data?	
What about mobile measurements?	
Can I use sensor systems to assess mitigation strategies?	
Can I use sensor systems at schools, indoors, in-car, etc?	
Can I “fit and forget”?	

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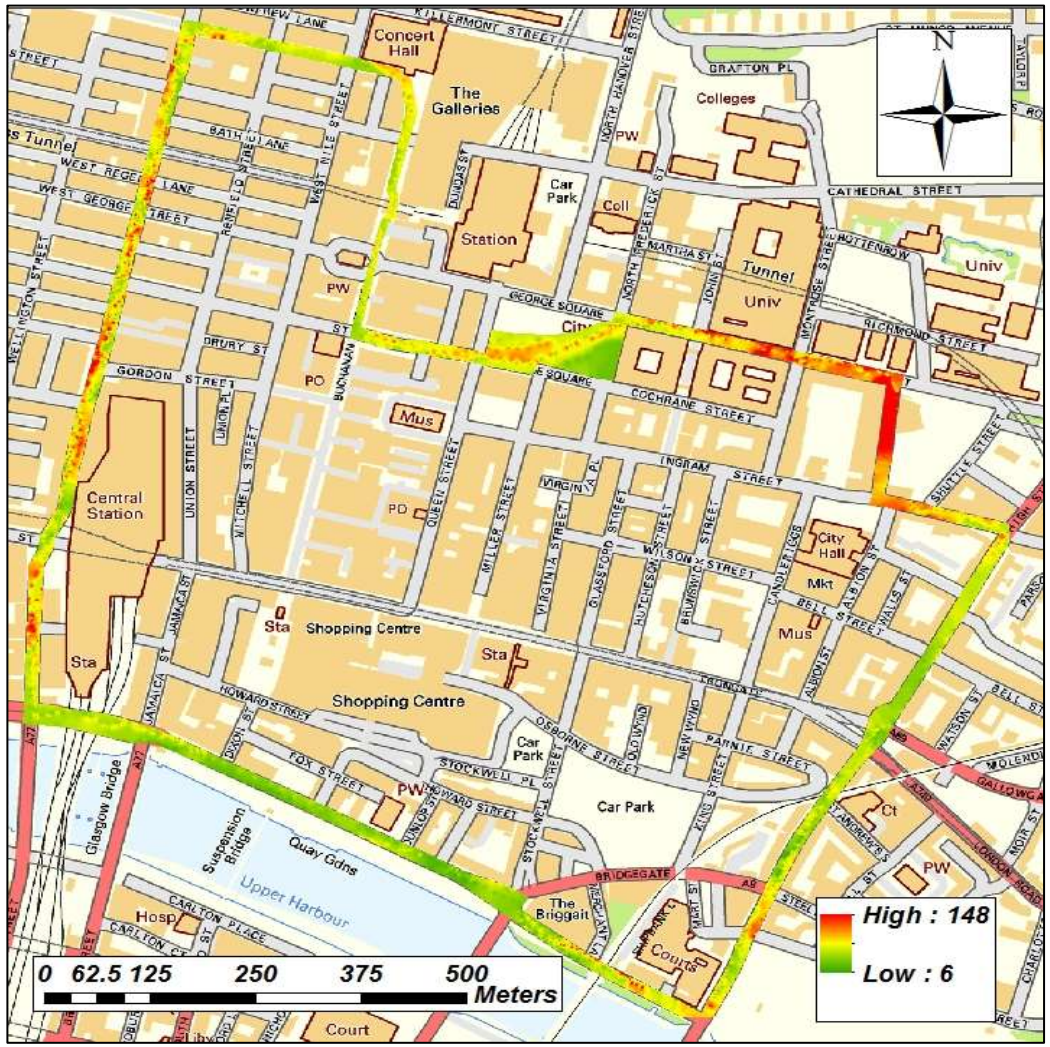
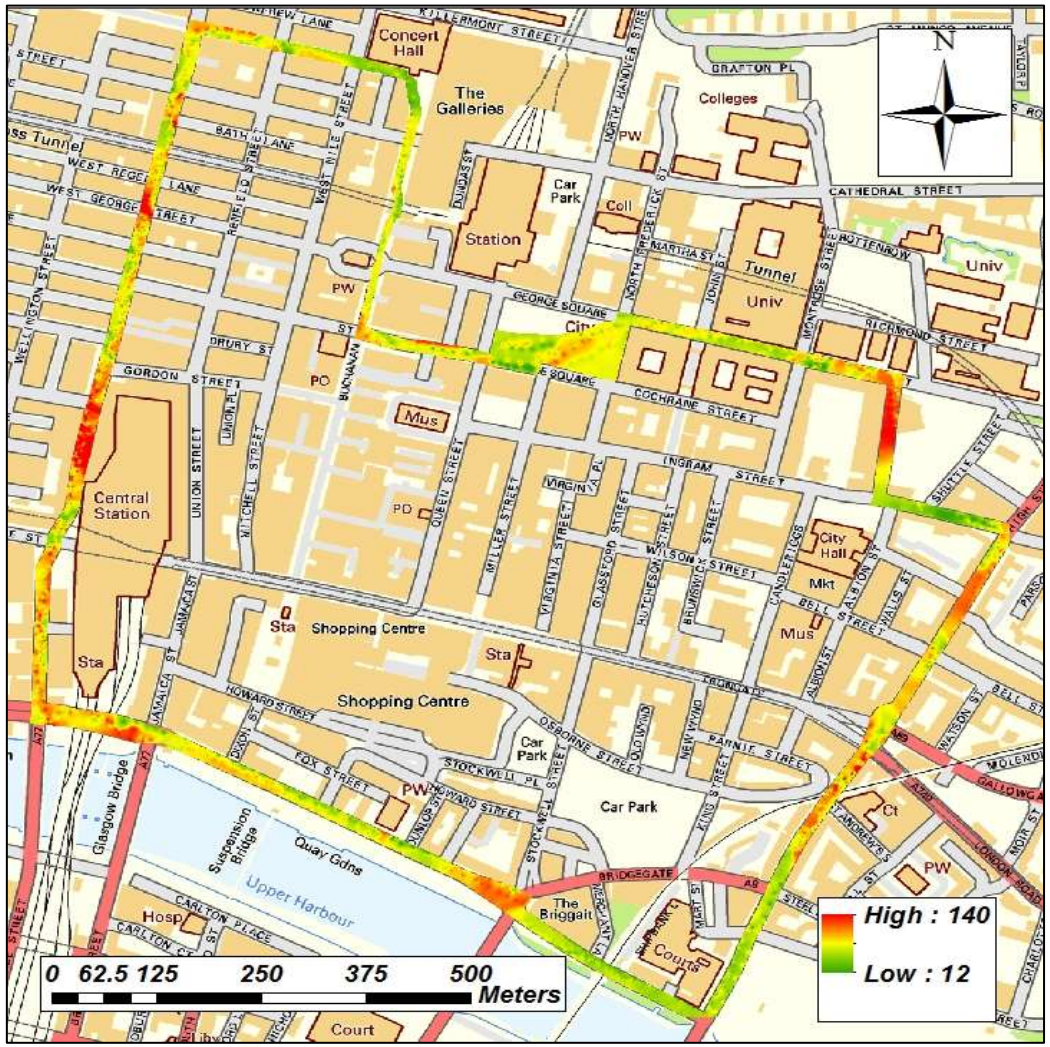
Applications – mobile and hotspot identification

Particulate Matter (PM_{10})



Nitrogen Dioxide (NO_2)



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Applications – awareness raising / education

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Can I use sensor systems at schools, indoors, in-car, etc?	**Yes**
Can I “fit and forget”?	**No/Maybe**

You’ll still need to keep a keen eye on QA/QC!

Questions