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Electrochemical Sensors for Environmental Monitoring in Cities

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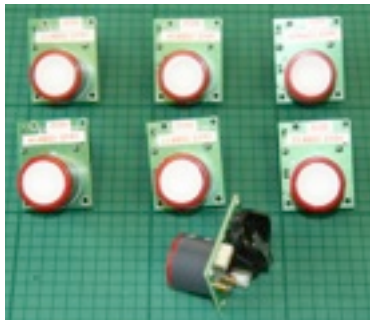
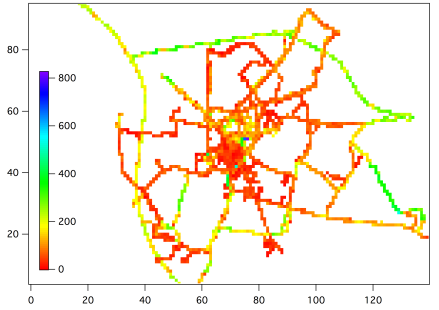
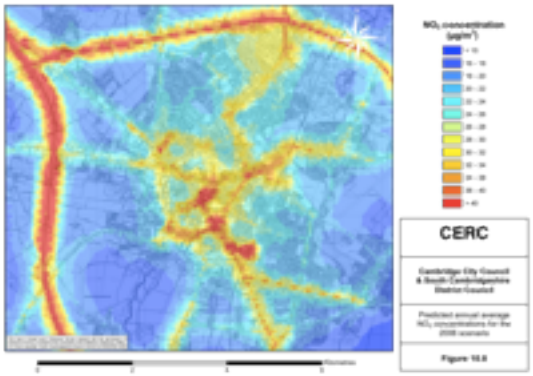


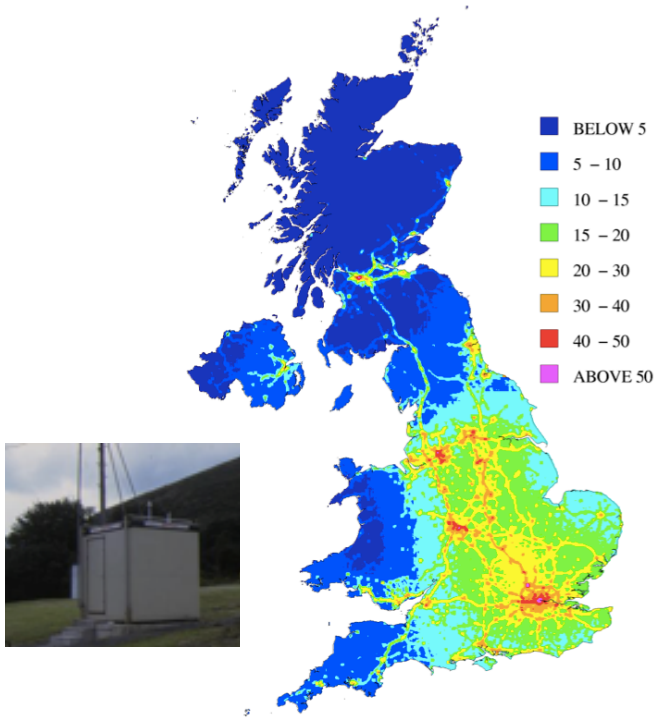


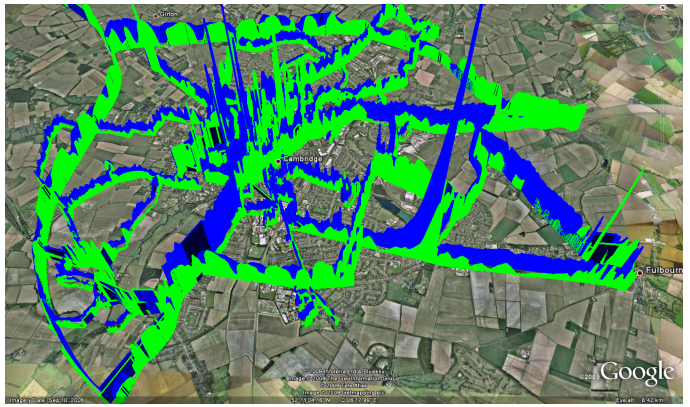


Motivation: granularity in urban air quality - on all scales

- Inhomogeneity in urban A/Q (sources, meteorology, chemistry)
- Non-linearity in chemical processes – *main atmospheric science driver*
- Precision (e.g. UK: AURN) monitoring sites costly and sparse (capture real variability?)
- Low cost solutions (e.g. NO_2 diffusion tubes) give coarse time (>bi-week) averages (precision?)

⇒ Alternative solutions?





AIM: Combine technologies to provide sensitive low cost sensor network system

Other data (met, traffic….)

archive

Real time data processing/ data assimilation

GPS (location)

GPRS (data transmission)

SENSORS

PRODUCTS

Environment…..

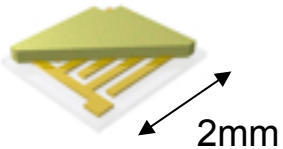
Regulation……

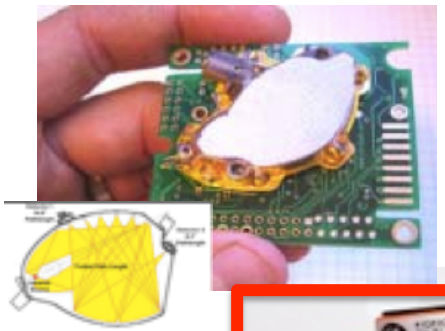
Exposure…..

Transport…..

Basis for sensor network system approach:

Low cost miniature gas sensor technologies





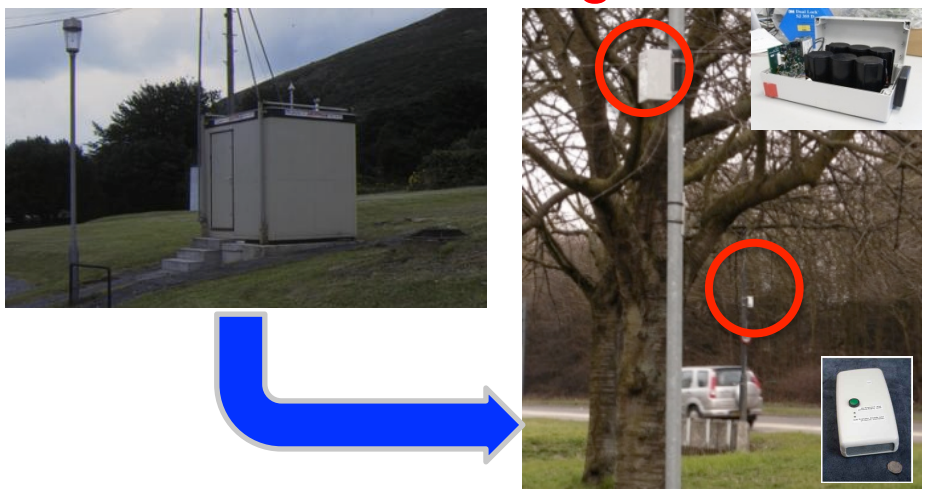
- Electrochemical
- Non Dispersive IR
- Photo-ionisation Detection
- Metal Oxide
- SAW
- ……..

>factor of 100 cheaper (and smaller) than traditional methods
- if they can be made sensitive enough

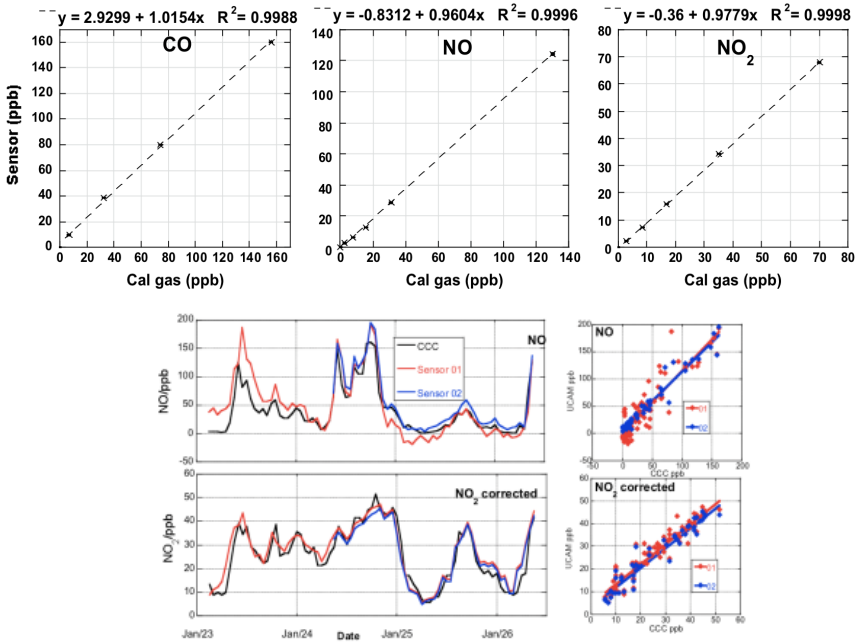
Development of *sensor networks* at the University of Cambridge*

Key Points

1). Miniaturisation/portability/ networking



2). Performance



3). Low Cost

50-100 fold reduction in cost per sensor node (also in size).

Potential new paradigm for air quality measurements

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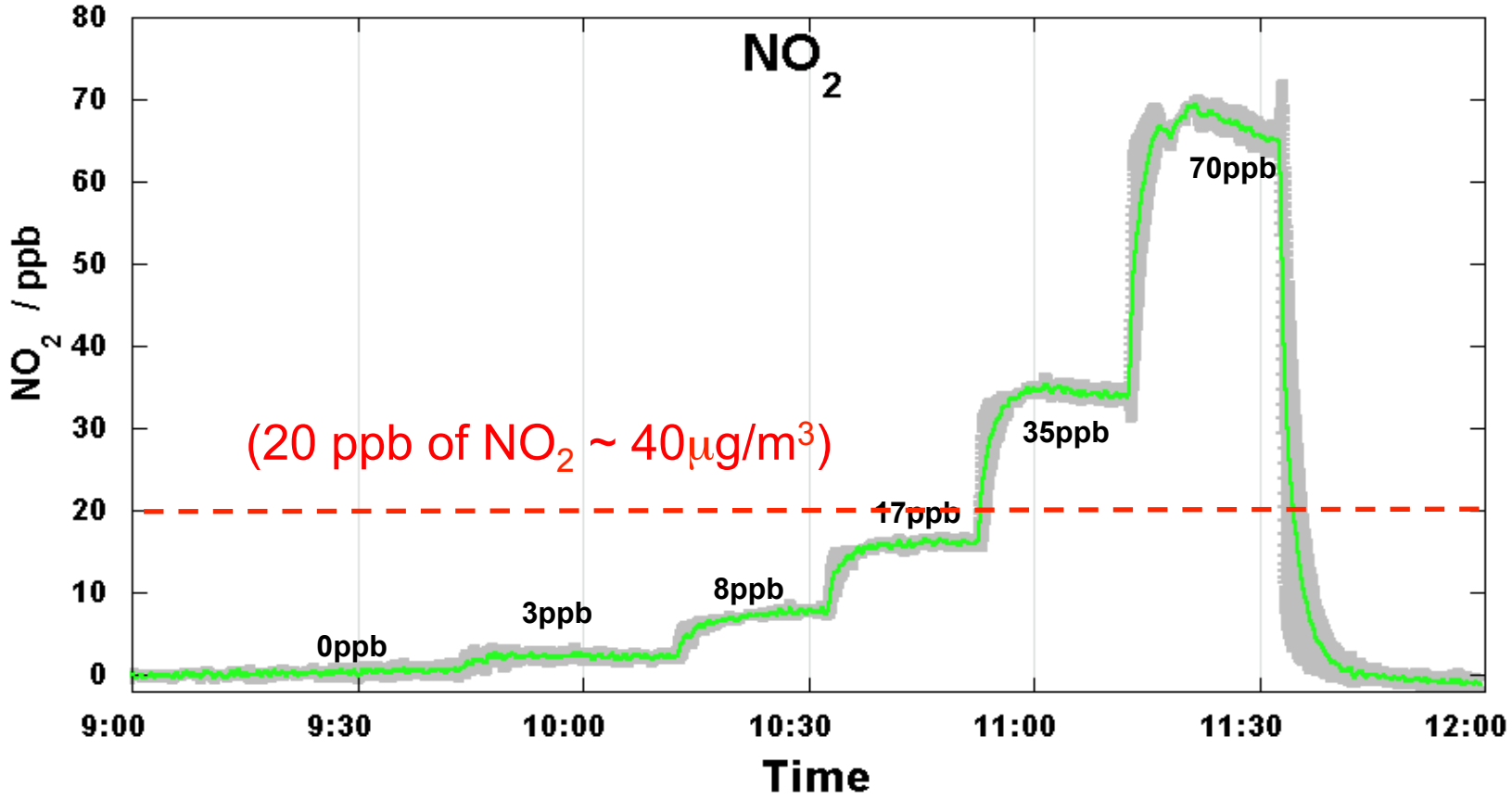
Performance of electrochemical sensors NO_2 sensitivity (laboratory)



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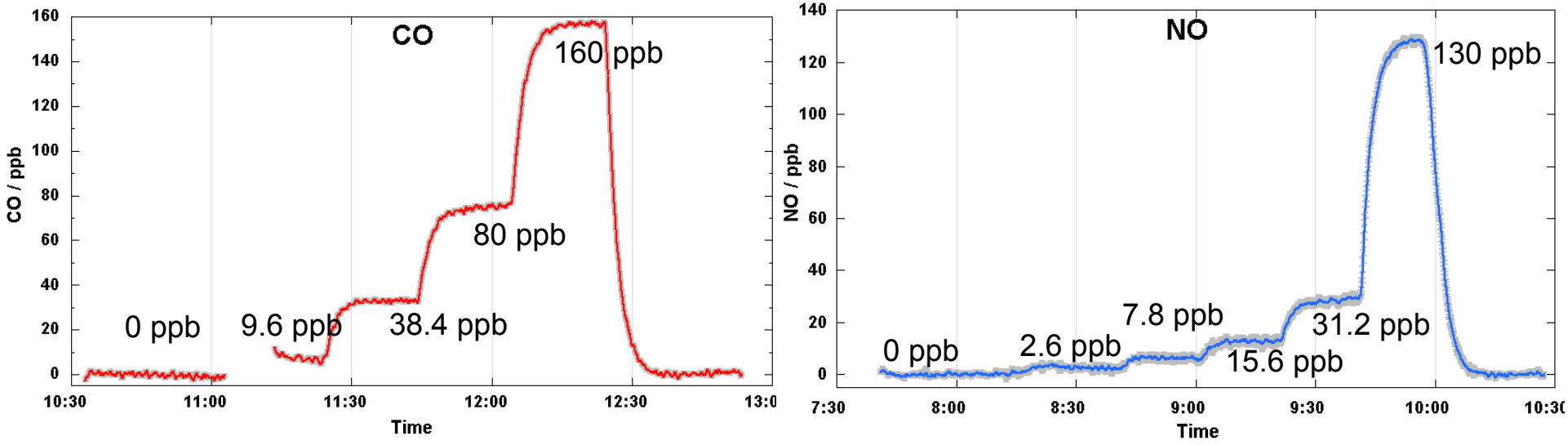
Indication of electrochemical sensor CO and NO sensitivity (laboratory)

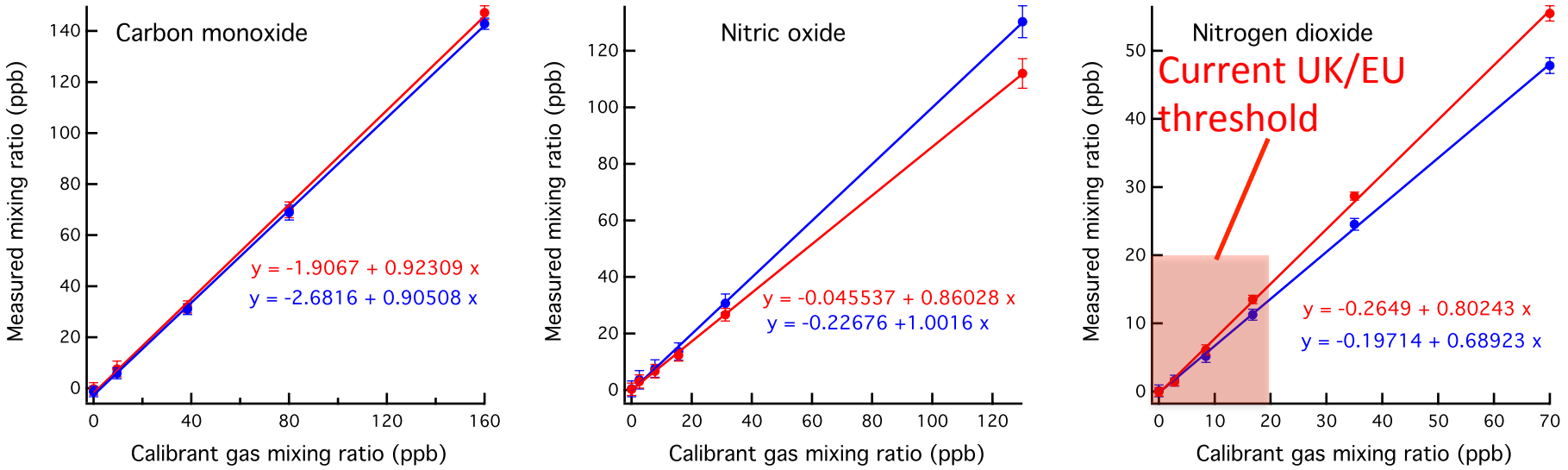


Improvements in: **Hardware**, control **electronics** and **analysis**

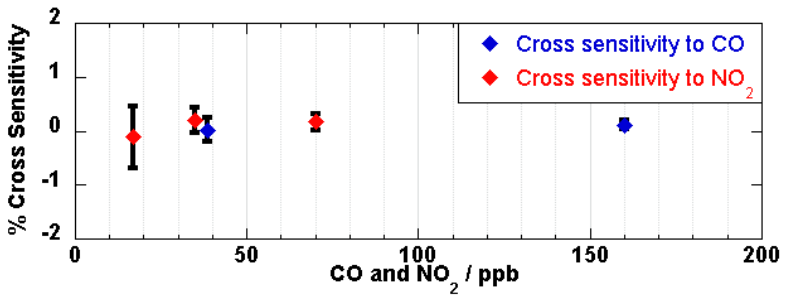
Viable tools for urban air quality monitoring.

Need to carefully consider data processing

Electrochemical sensor $CO/NO/NO_2$ sensitivity (laboratory)



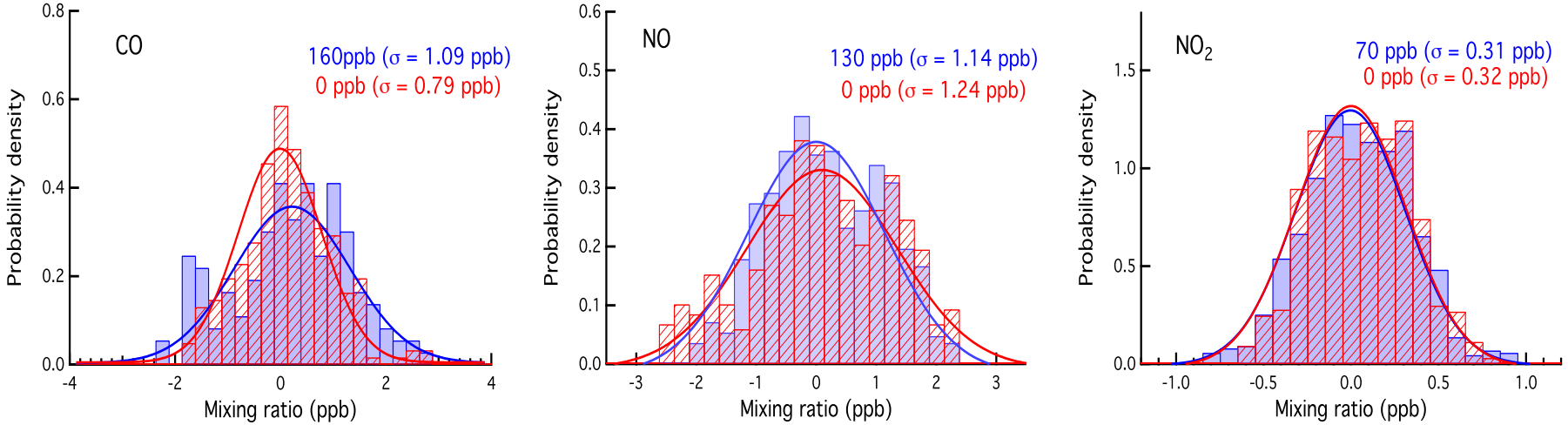
Sensitivity at the ppb level, (repeatability + selectivity*) in laboratory



* Some exceptions…

Electrochemical sensor performance (laboratory)

Limits of Detection (LoD) characteristics:



Typical sensor sensitivities/LoD are < 2ppb (< 4μg/m^3) for CO, 1-2 ppb (~2-4 μg/m^3) for NO and NO_2.

SO_2, O_3 have comparable performance to NOx.

Typical sensor T_{90} ~ 10-20s (determined by diffusion)
Very low power consumption (μW)

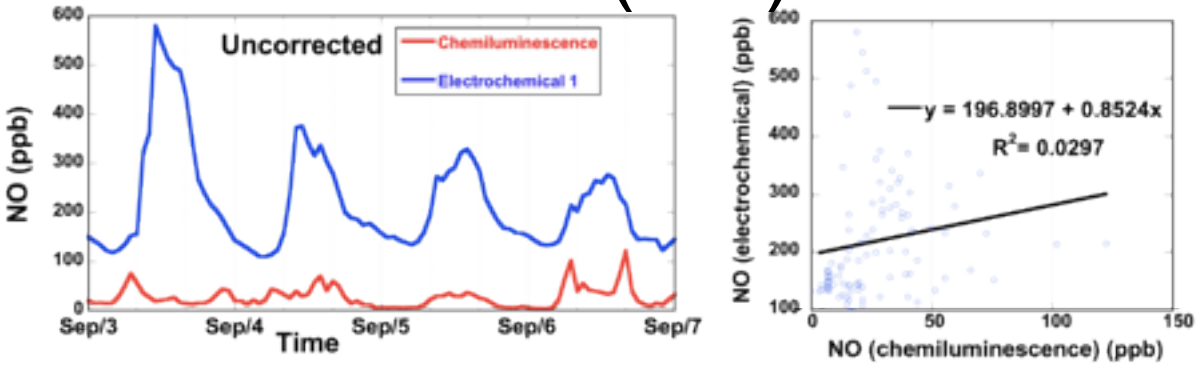
Electrochemical sensor performance:

Is laboratory performance replicated in the field?

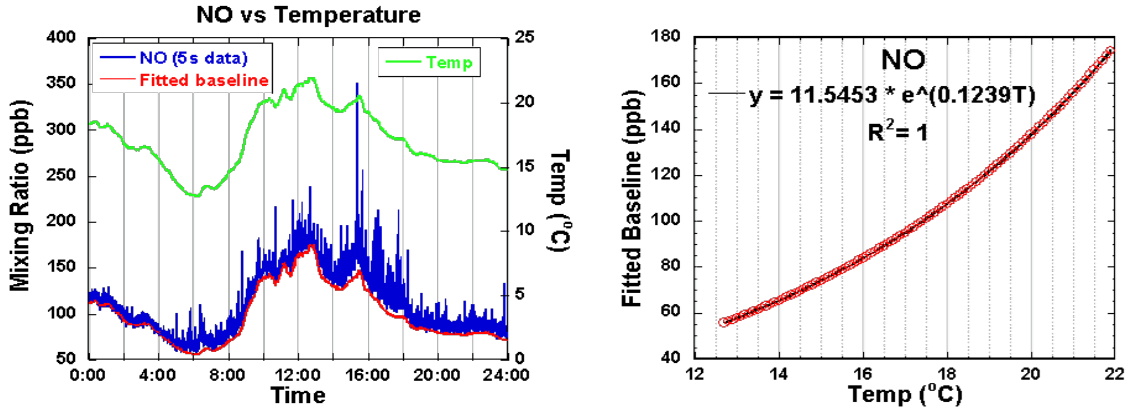
- Ambient T/RH corrections…
- Cross interferences…..
- …….
- …
- ..

Electrochemical sensor baseline temperature dependence correction (NO)

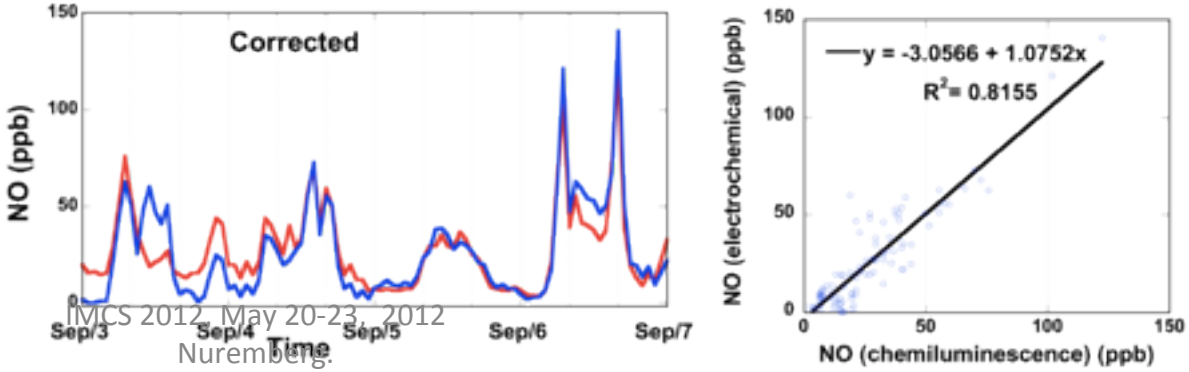
Raw data (electrochemical, chemiluminescence)



Sensor temperature/RH and baseline correction



Baseline temperature corrected (comparison with ratified data)



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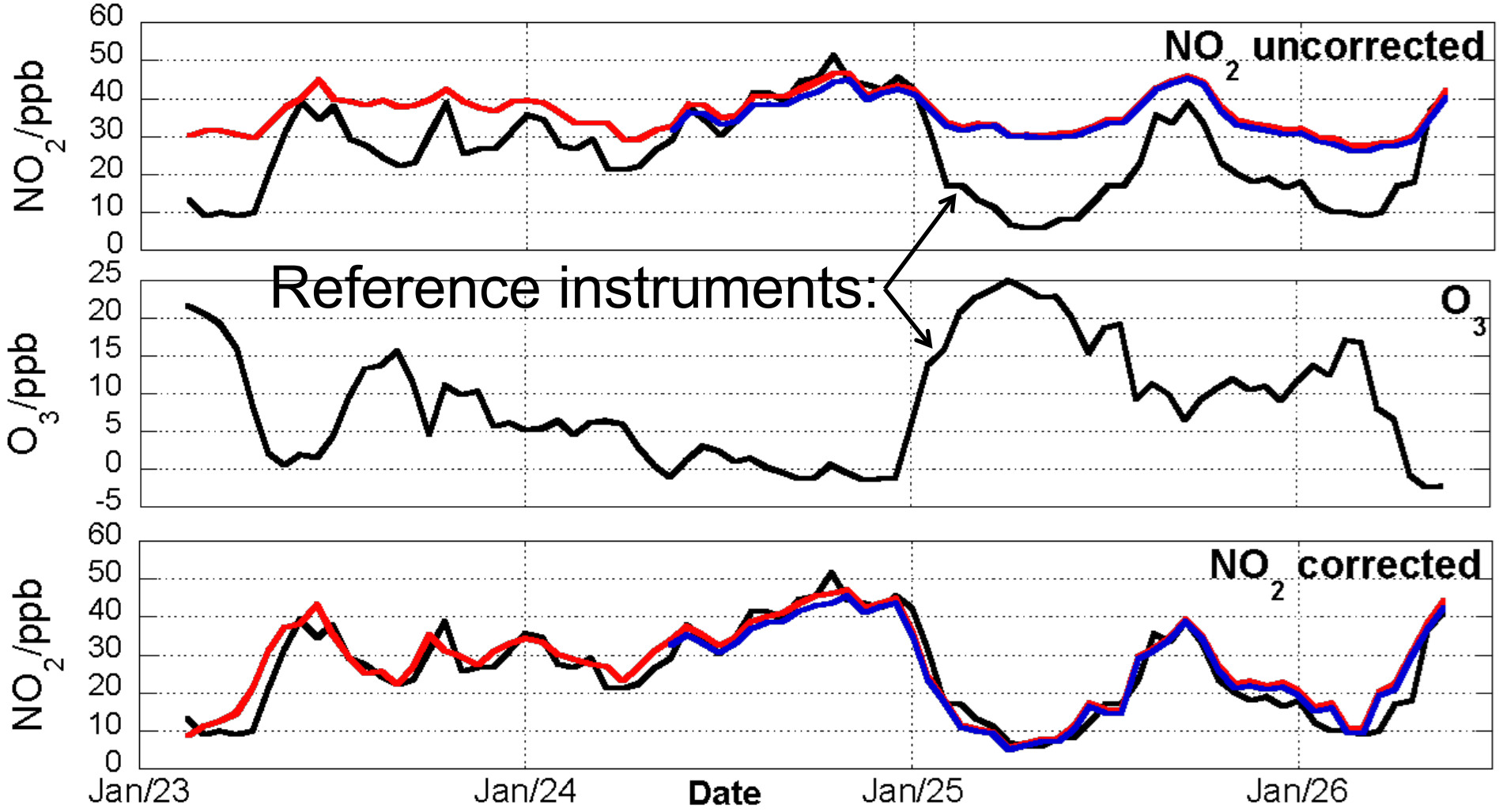
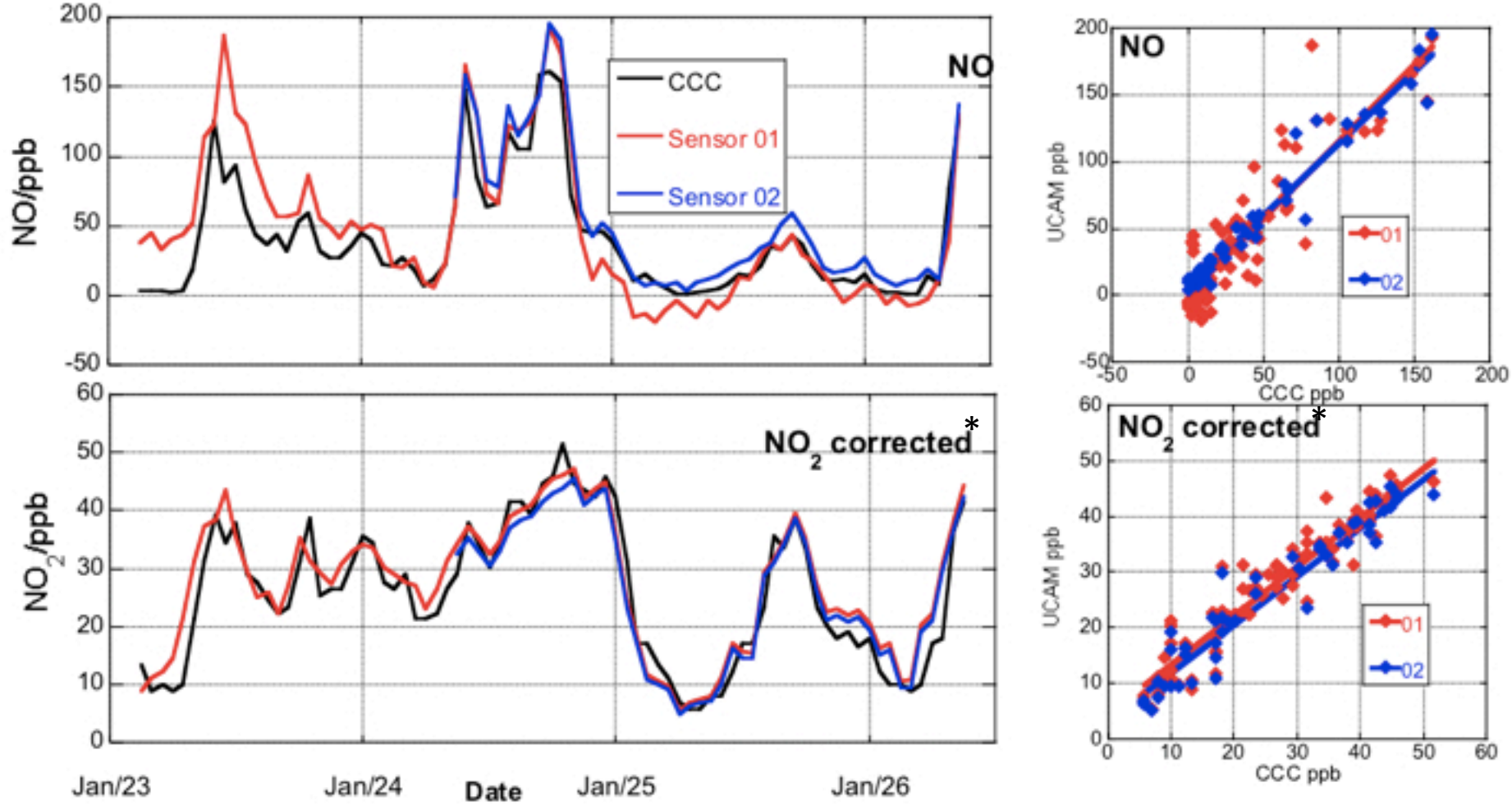
Cross interference (NO_2/O_3) + comparison with ratified site (hourly average)



Electrochemical instruments:

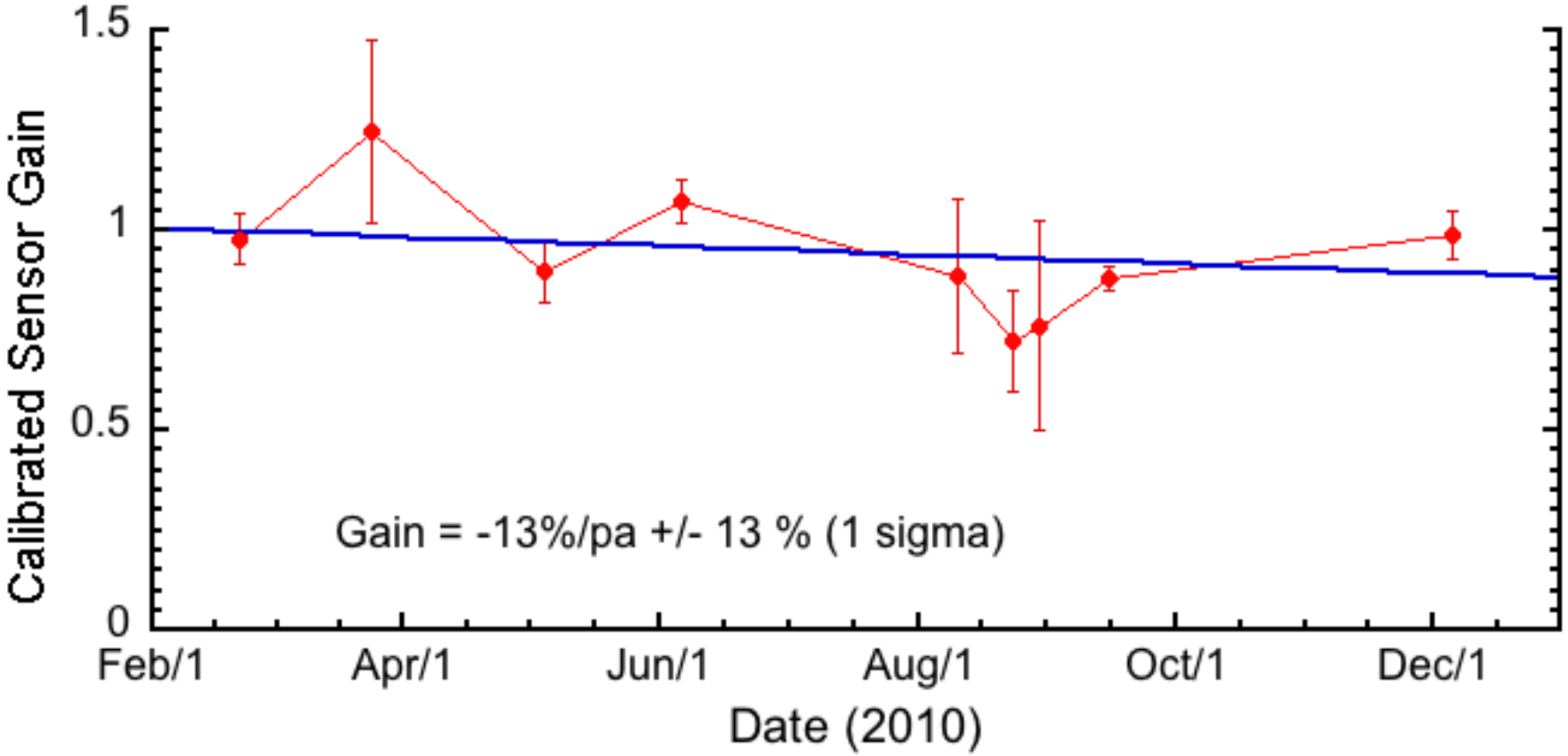
‘Real world’ comparison of NO_2 and NO with ratified AURN site



* Corrected for O_3 interference

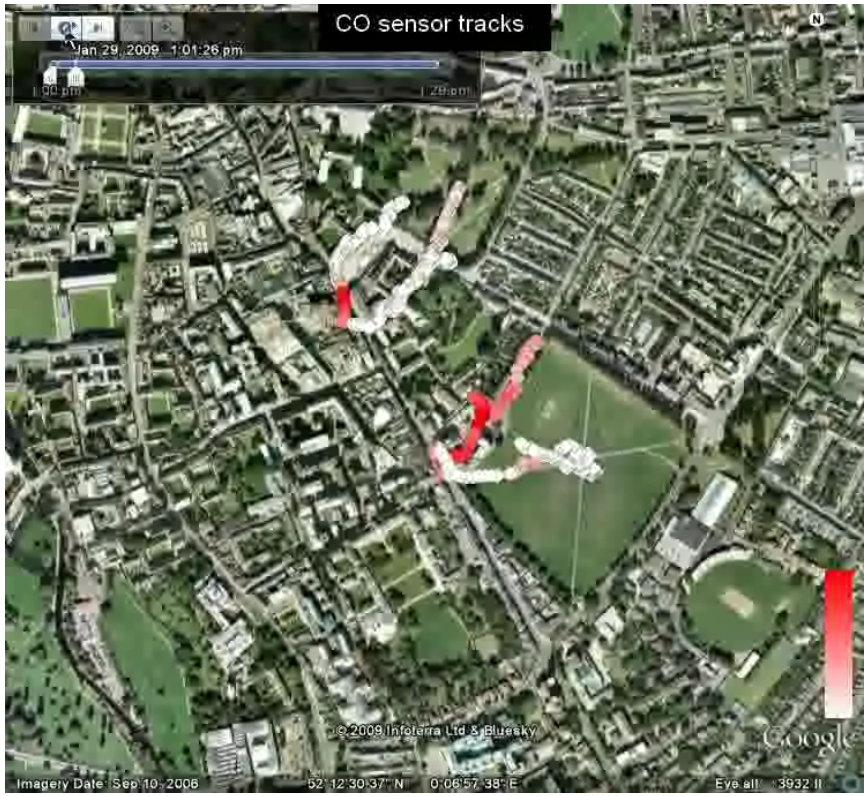
Performance replicated in the field….

‘Real world’ long term stability tests (NO) with ratified fixed site data



Calibration stability expected to exceed ~2 years

Multi-species real time mobile measurements of air quality in complex environments



Carbon Monoxide CO

Nitrogen Dioxide NO_2

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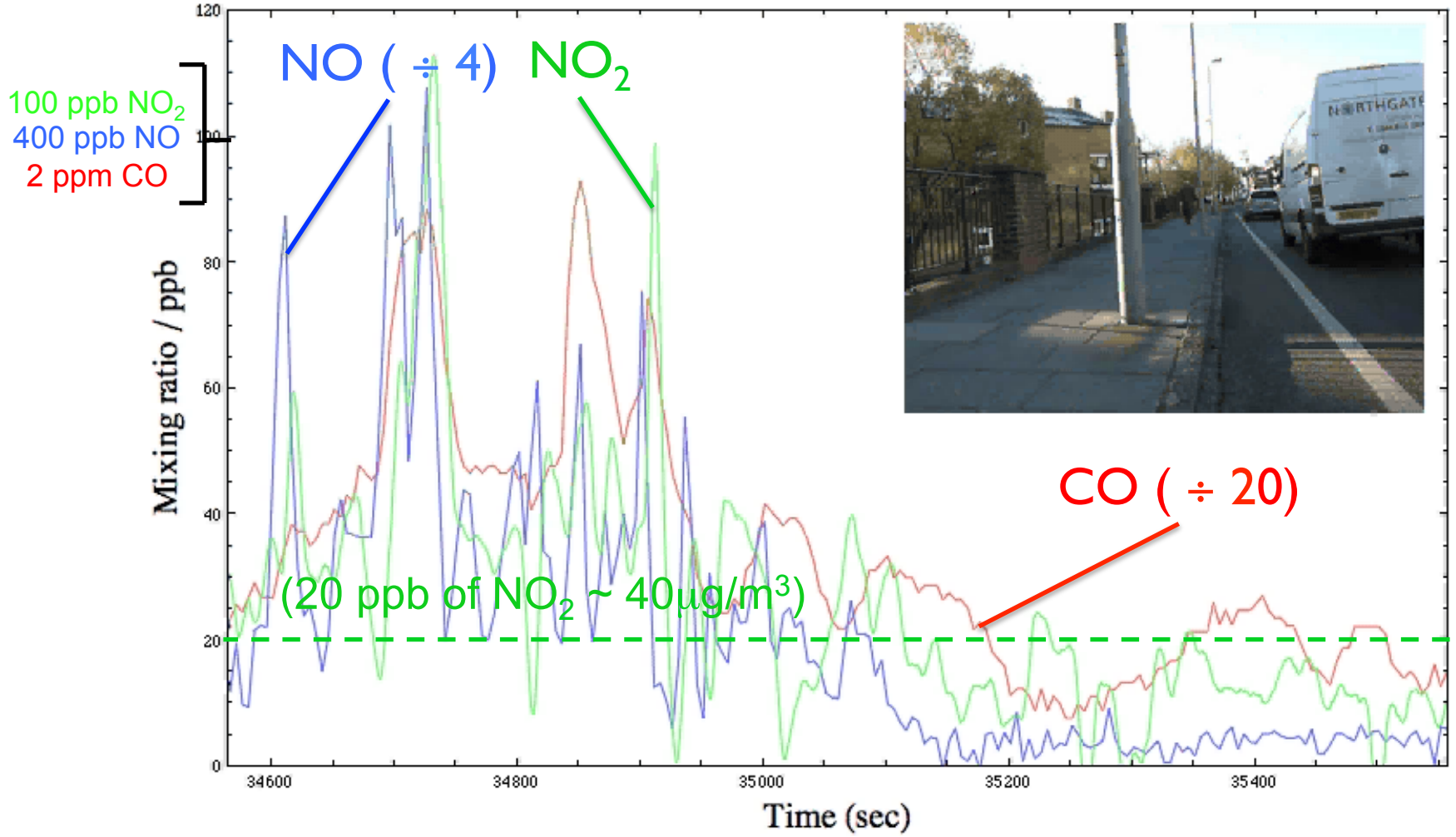
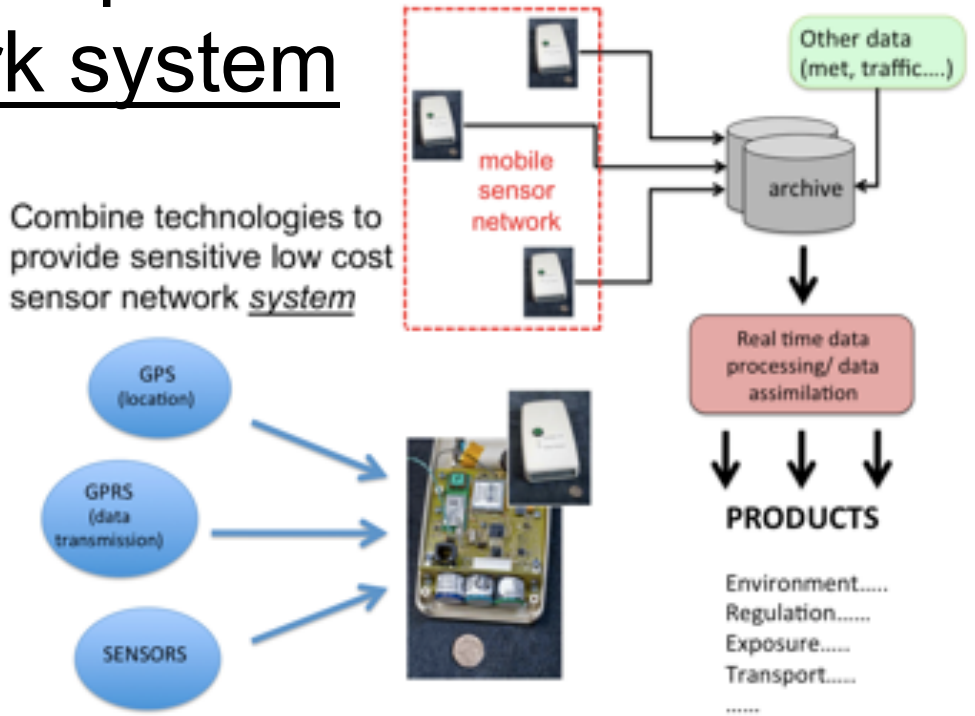
Multi-species real time mobile measurements of air quality in complex environments



Combine technologies to provide sensitive low cost sensor network system

- Real time location and data transmission by coupling sensor technology to GPS and GPRS



- Real time data processing including analysis/interpretation and visualisation (Imperial College)

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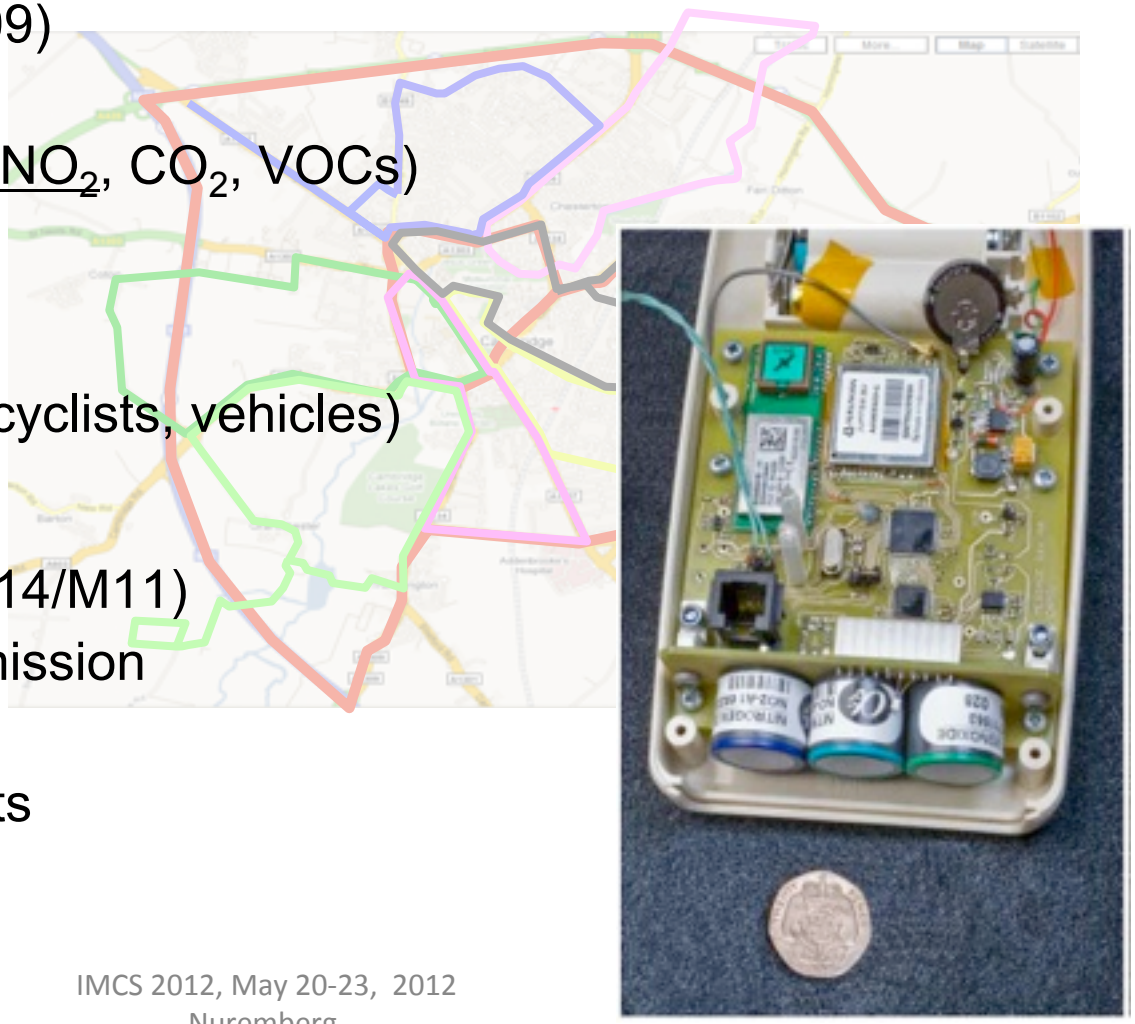
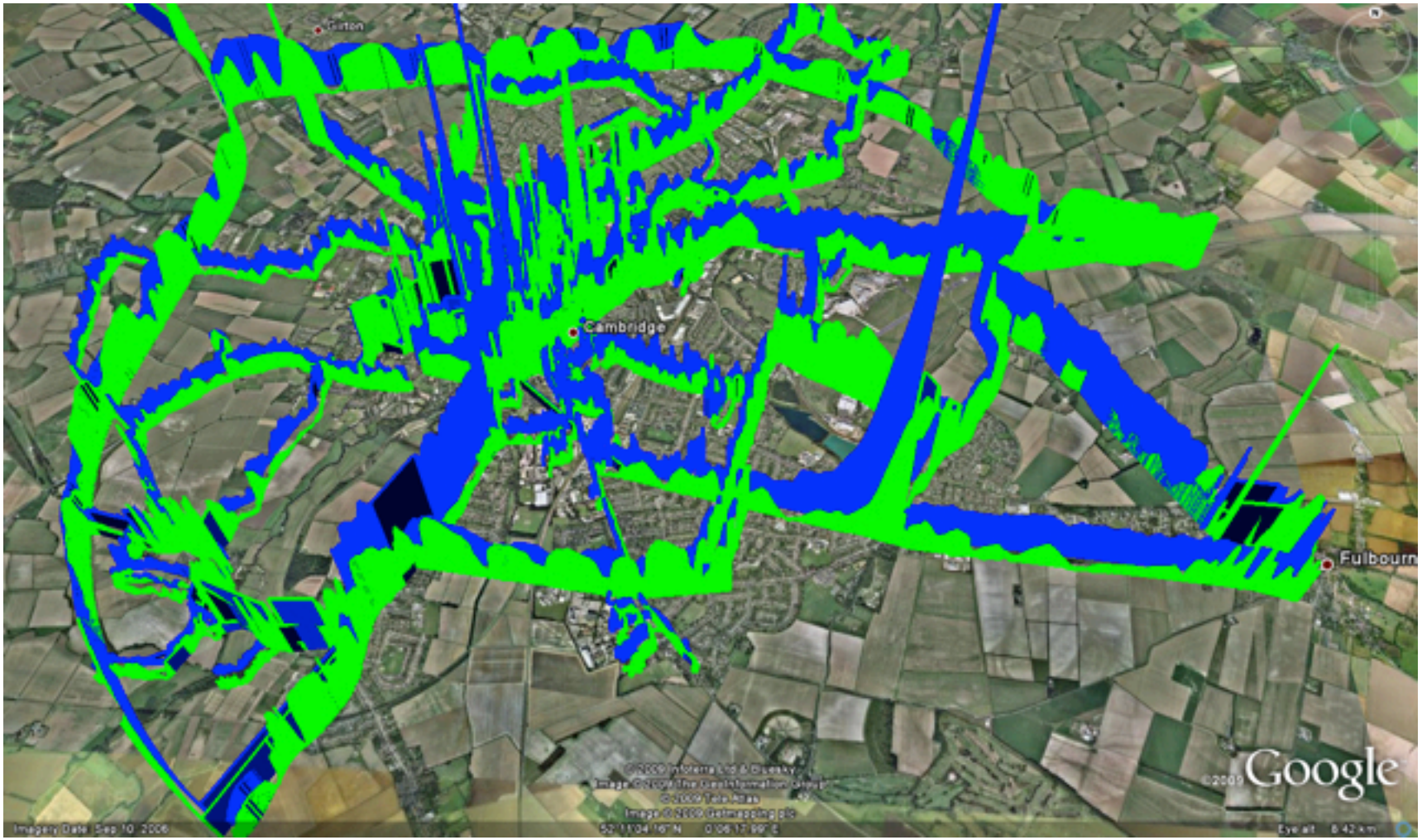
Mobile sensor network deployment: Cambridge (UK)

- 4 hour deployment (2009)
- > 40 sensors (CO, NO, NO_2, CO_2, VOCs)
- 3 transport modes
  (walkers, cyclists, vehicles)
- Inner city, outer loop (A14/M11)
- Real time GPRS transmission
- >200,000 measurements

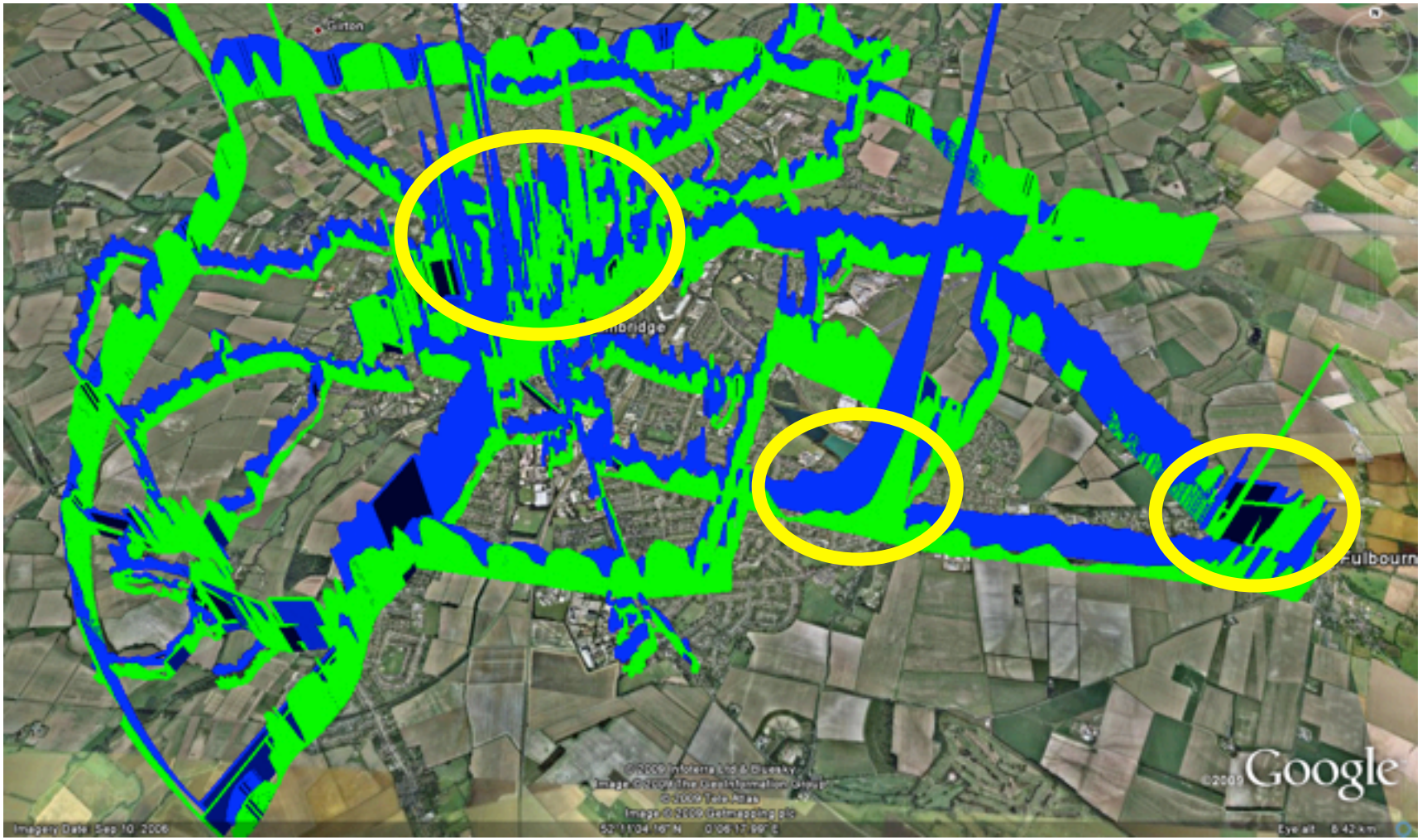


Three-species mobile sensor node

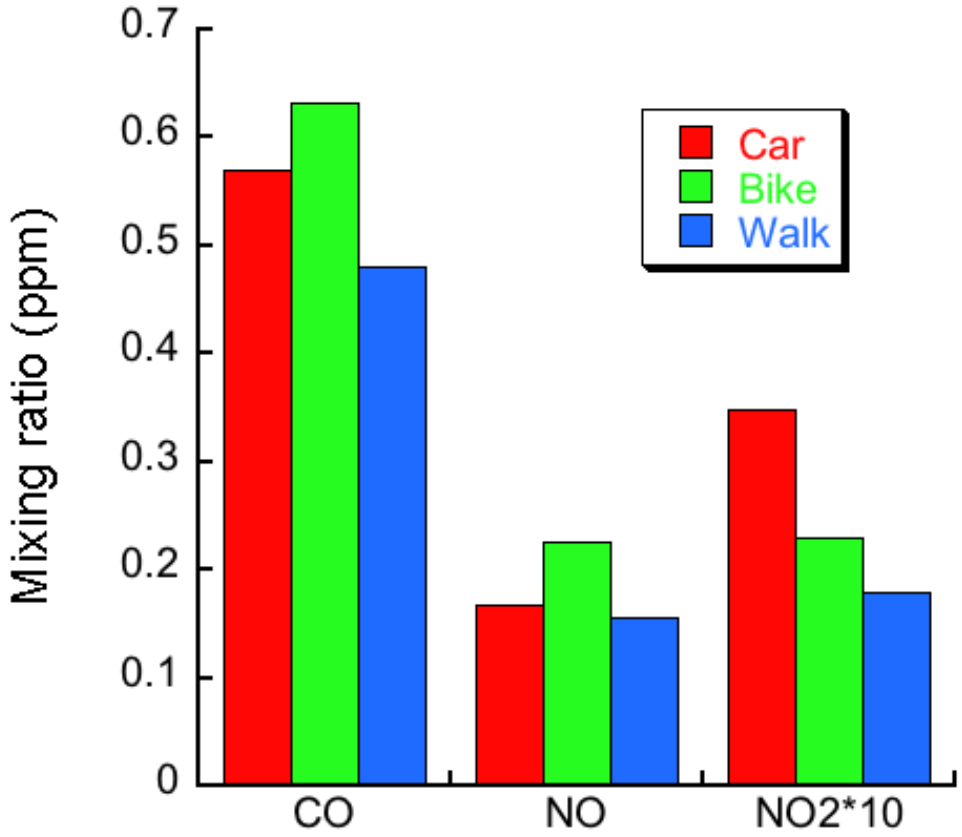
Cambridge deployment September 2009: NOx



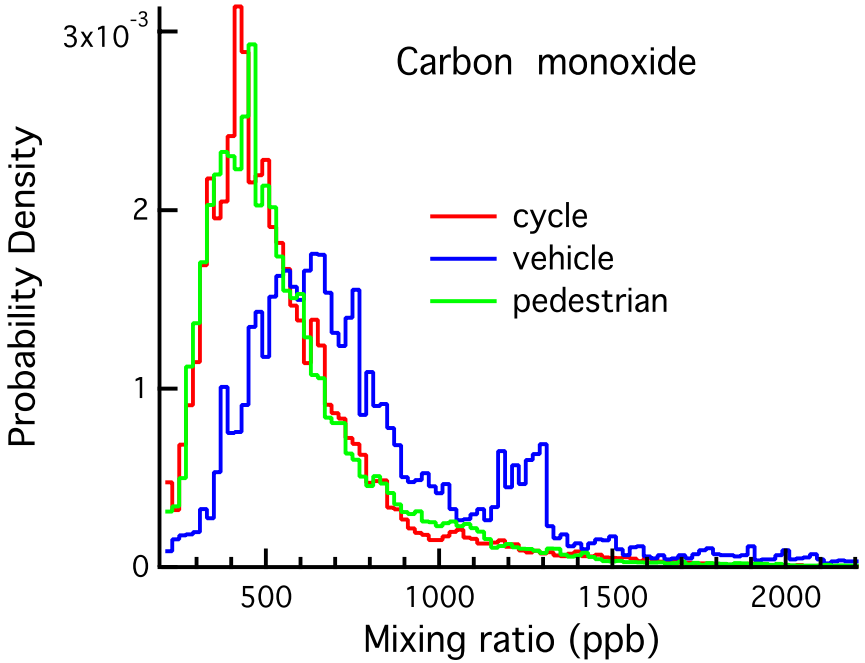
Visual determination of pollution hotspots – not possible with static sites

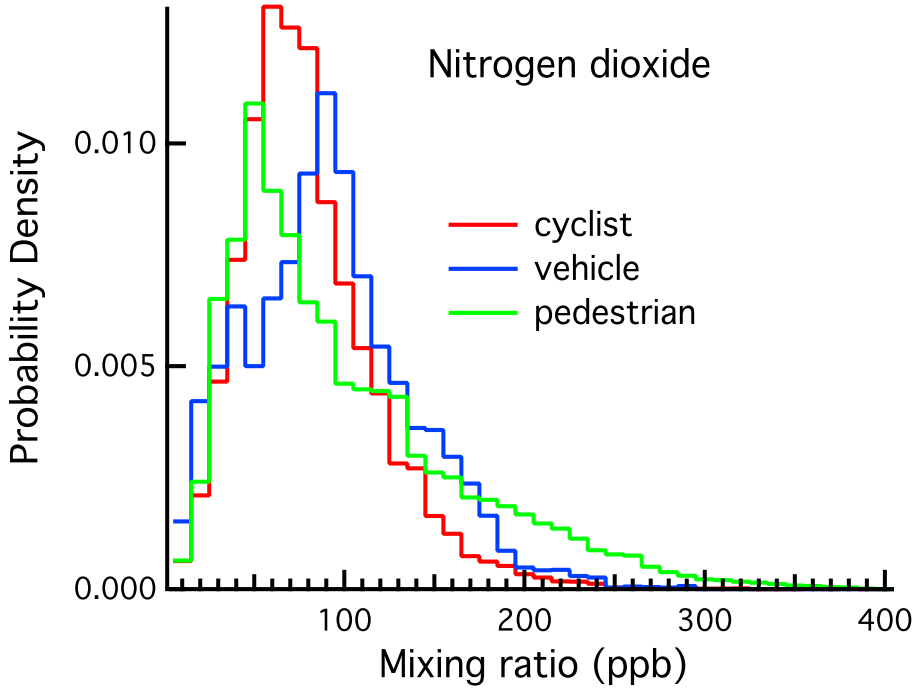


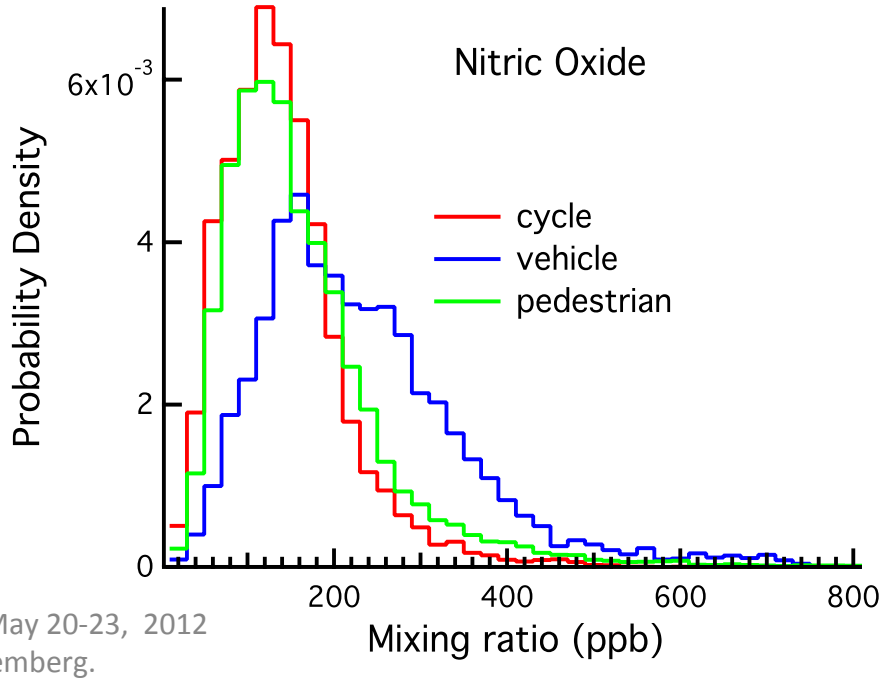
Statistical assessment of mobile A/Q data by transport mode (simplest possible!)



Derive ensemble averaged statistics – distinguish between transport modes:







Snapshots……

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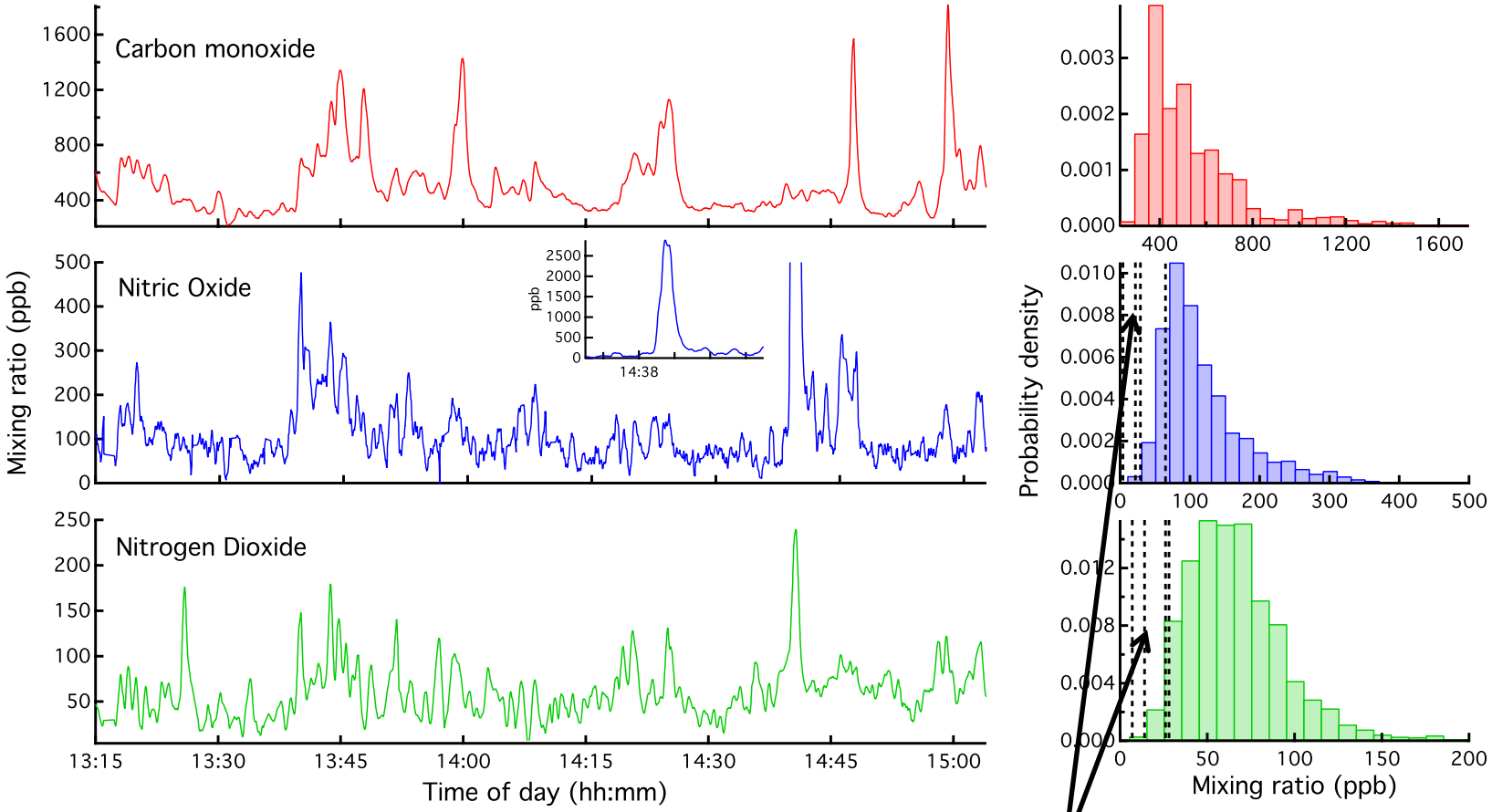
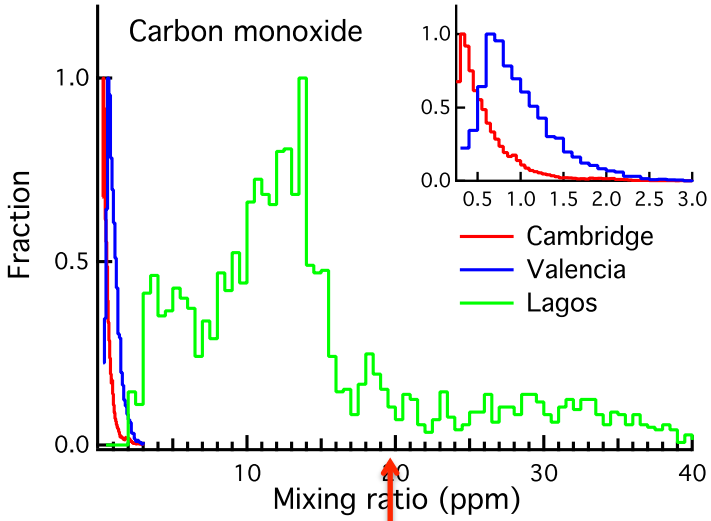
Individual exposure: are fixed site measurements representative?



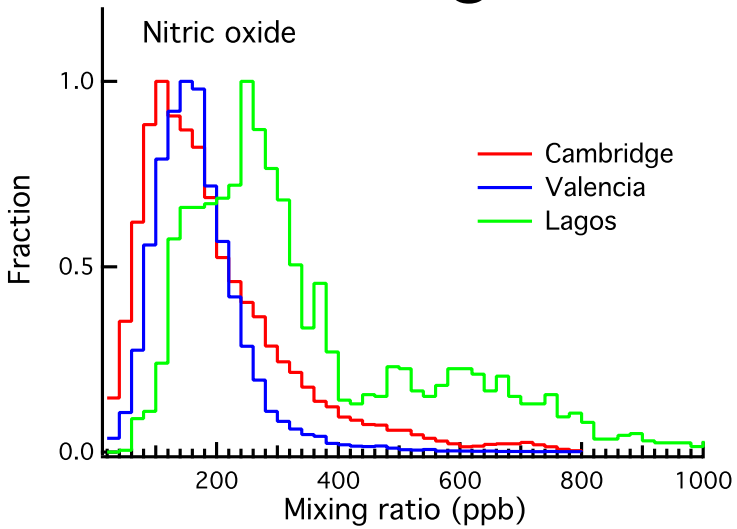
Fixed site hourly averages (dashed lines)

Answer: no……

Air quality in different regions (snapshots): Cambridge, Valencia, Lagos

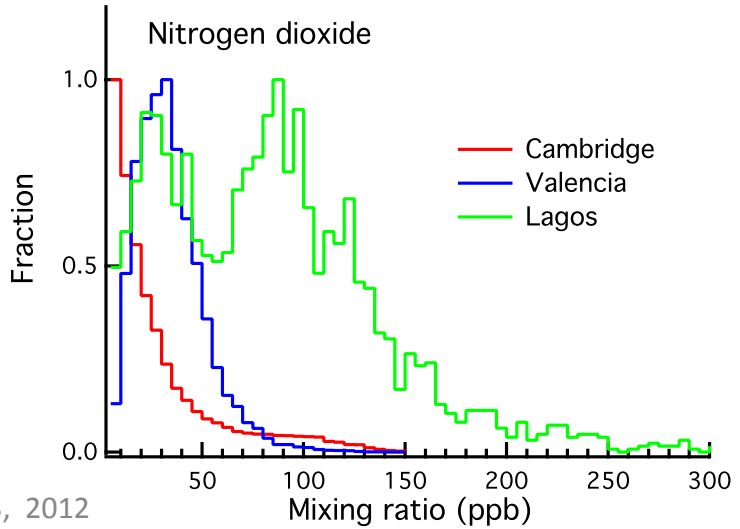


20 ppm



Dramatic differences…….

Flexible low cost way of characterising A/Q



Static Sensor Deployment, Cambridge (UK)

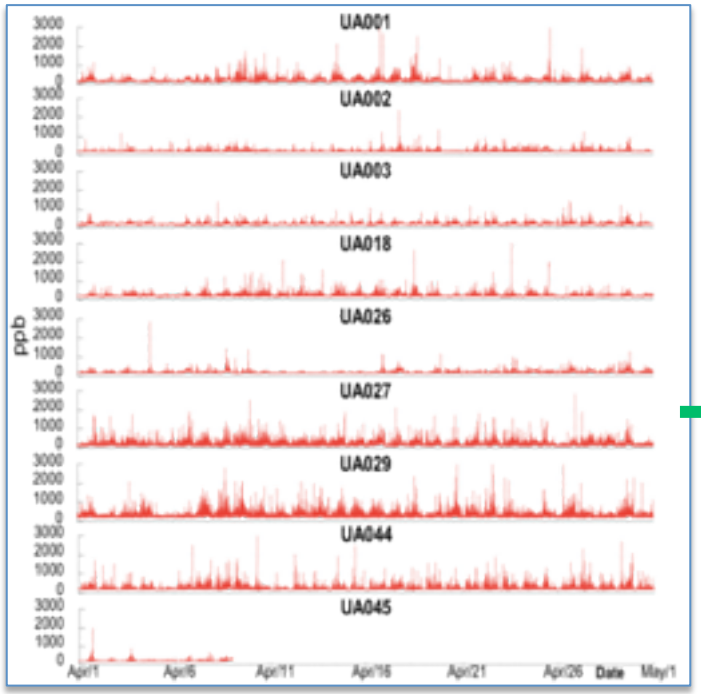
- >2 month deployment (May-July 2010)
- >40 sensors (CO, NO, NO_2) , T, RH
- Lamp post mounted, GPRS (GPS)
- Inner city, mixed urban, rural
- Real time GPRS transmission

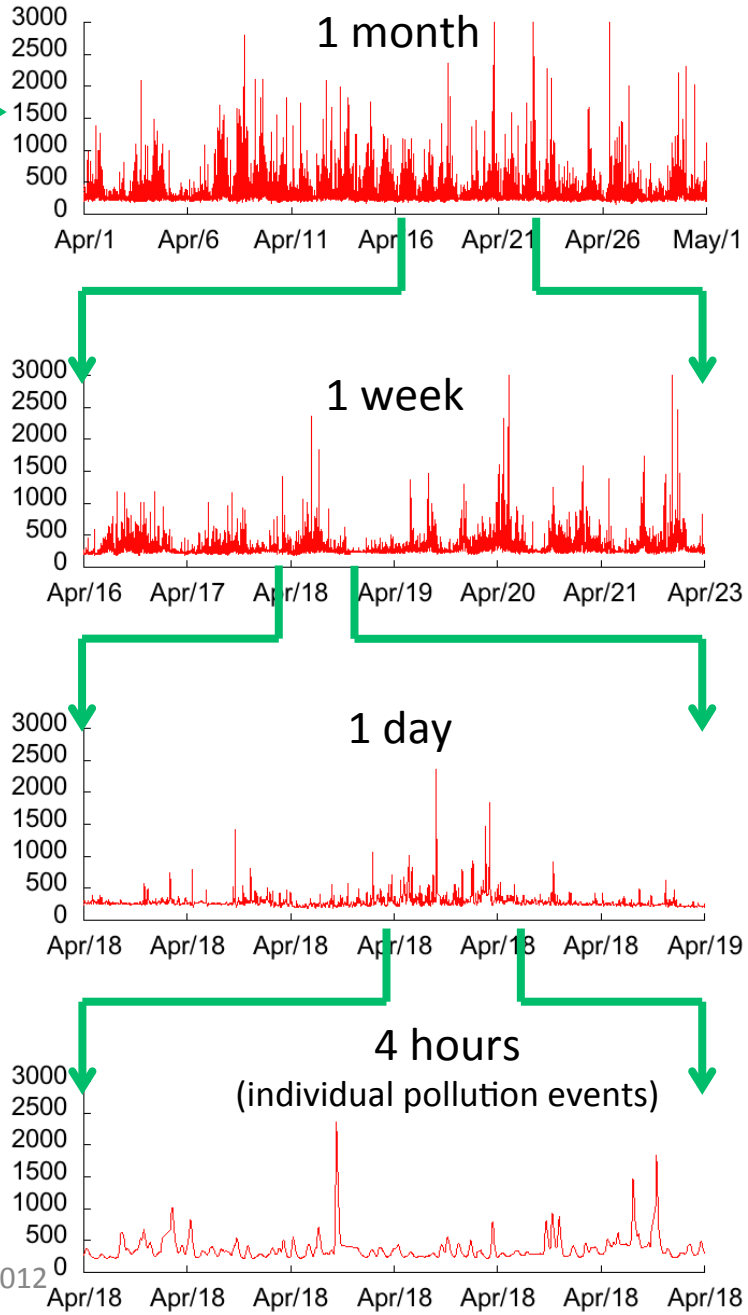
- >25,000,000 measurements

Static deployments (carbon monoxide)

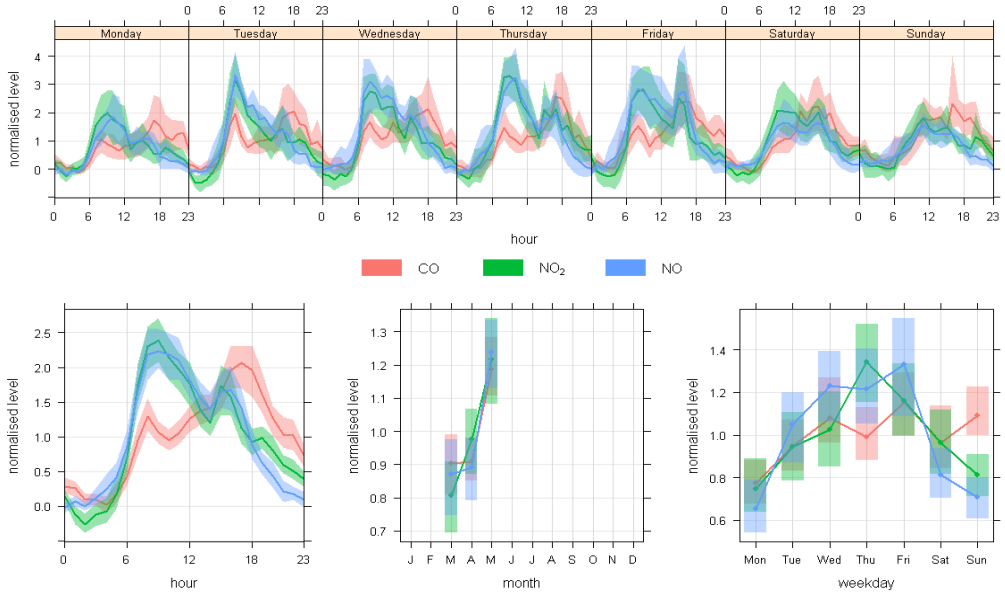
Grid
(46 sites)

vs

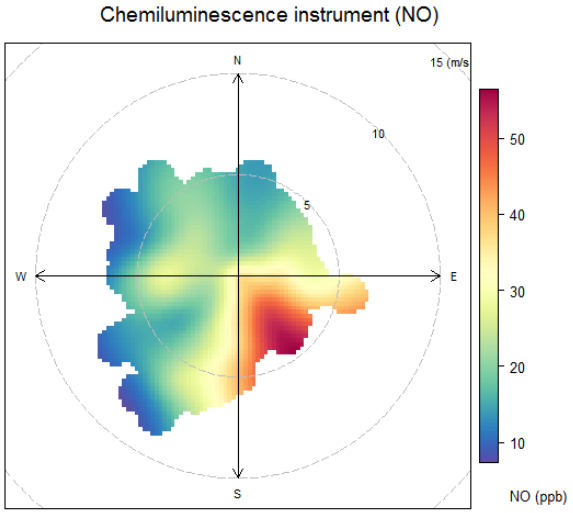




Statistical Studies



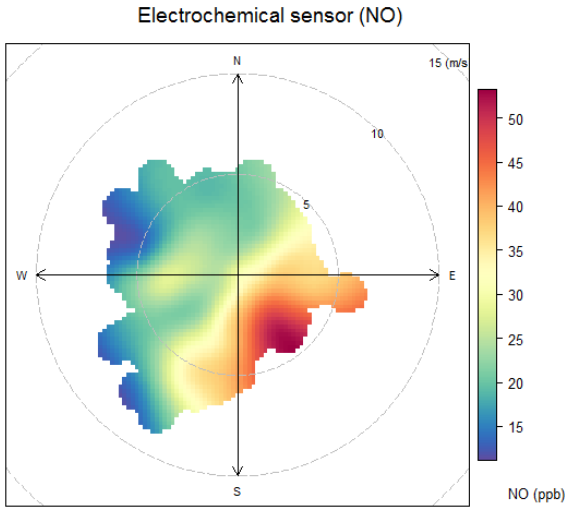
Electrochemical



Reference instrument

Diurnal patterns, weekend effects…

Bivariate plots (source attribution)



Electrochemical

OpenAir open source air quality analysis tool (OpenAir 2010)),

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High-density mapping

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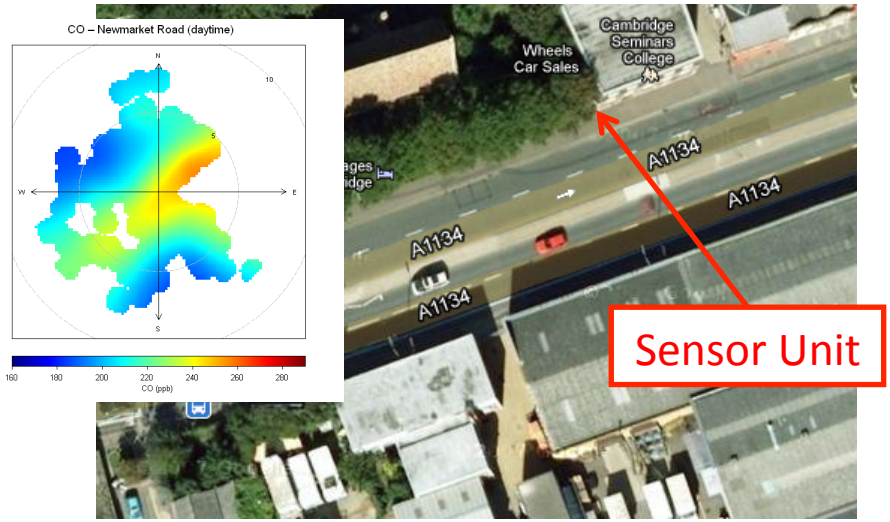
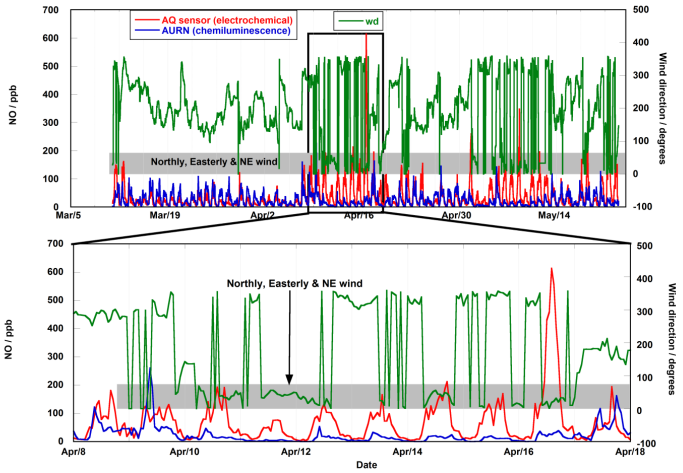
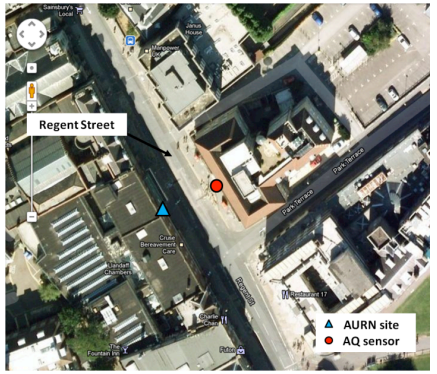
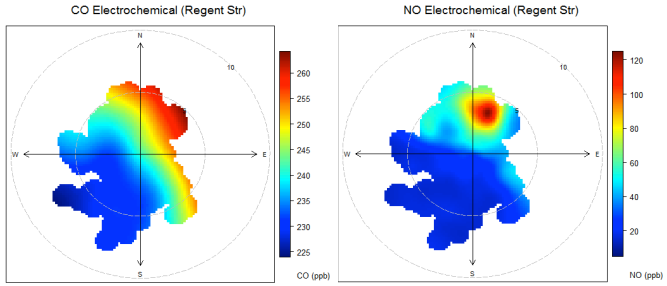
Street canyon effects: wind direction and re-circulation









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Where next?: High density sensor network system at UK Heathrow airport (2011-2013)

(Electrochemical, NDIR, PID, Optical)

- 50 sensor nodes, real time data transfer
- NO, NO_2, CO, CO_2, SO_2, O_3, VOCs and size-speciated PM.
- Source attribution/model validation for area.
- Novel software tools for calibration, data-mining, visualisation/interpretation.
- Methodology for optimising sensor network design.

Key aim is to assess added information content from sensor networks…

Conclusions

Electrochemical sensors can now provide highly sensitive, linear and in many case highly selective measurements of urban pollutants at the parts-per-billion level.

- Developed low cost portable and static multi-sensor node networks incl. GPS/GPRS for air quality measurements traditionally viewed as only achievable by costly and sparse fixed site monitoring stations.

- Demonstrated use in urban environment in portable/static networks, personal exposure, regional differences, canyon effects, comparisons with fixed site (more to be done……..)

- *Obvious applicability also to indoor air quality*

Sensor networks are new measurement paradigm?

Acknowledgements

Sensors and Sensor Networks

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John Polak, IC
Paul Kaye and UH team
David Carruthers (CERC)

Earlier work

Imperial College
Peter Landshoff
…….