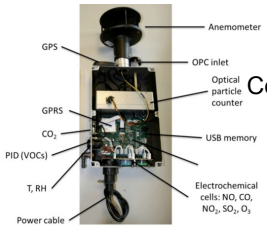
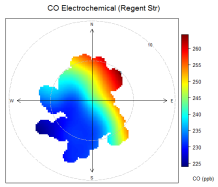
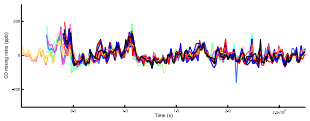
Small is beautiful: Low cost sensor networks start to show what they can do



Rod Jones
Centre for Atmospheric Science
University of Cambridge
rlj1001@cam.ac.uk





Outline:

- What can electrochemical sensors do?
- Mobile networks
- Static networks
  - Electrochemical
  - Other sensors: PID, PM….
- Network calibration
- Summary (brief!)

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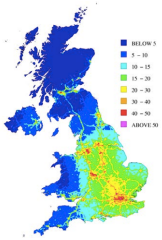
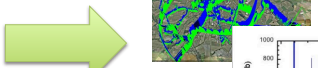
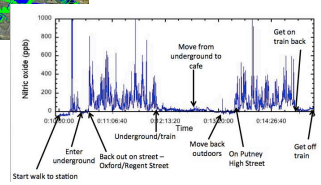
Development of sensors and sensor *networks*

- *Cost/ease of deployment*
- *Information content (location)*







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Examples of current miniature sensor methodologies

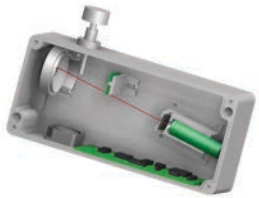
Electrochemical: e.g. NO_2, NO, CO, O_3, SO_2…

Spectroscopic: e.g. CO_2, CH_4…

Photo-ionisation: Σ hydrocarbons

Optical: particulates PM_{10}, $PM_{2.5}$

Others……



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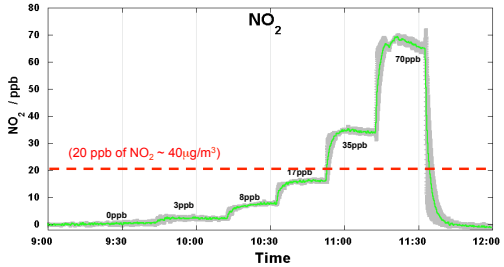
Challenges: enhance performance of sensors (e.g. electrochemical NO_2, laboratory)

ppm → ppb level response



Improvements in: **hardware**, control **electronics** and **analysis (data post processing)**

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Is laboratory performance replicated in the field?

Use *software* to account for sensor limitations

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

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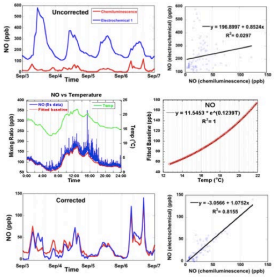
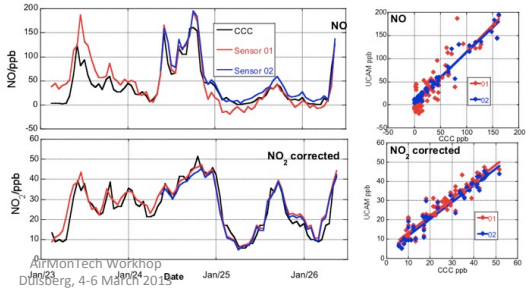
Correction of sensor artifacts in data post processing

- Temperature/ RH dependence
- Cross interferences
- Offsets/biases
- ……
- …



Field measurements of NOx measurements after post processing



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Three-species mobile sensor node

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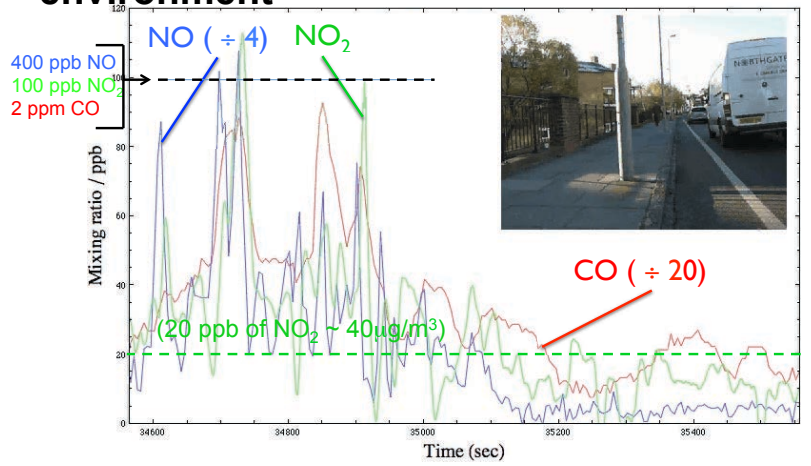
Multi-species real time mobile measurements of air quality in complex environment



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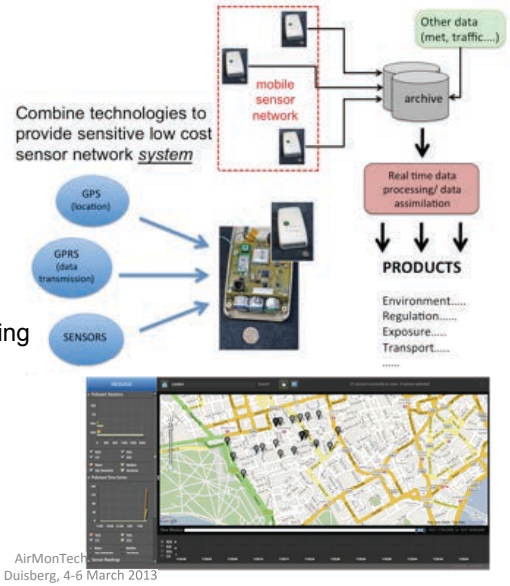
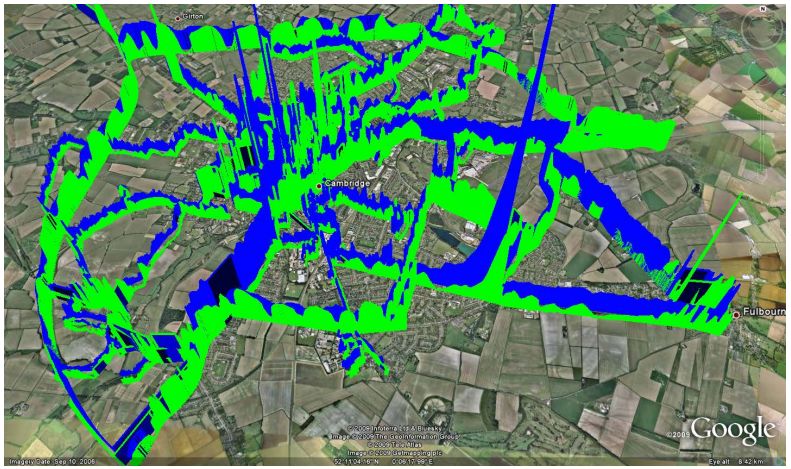
Combine technologies for low cost sensor network system

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

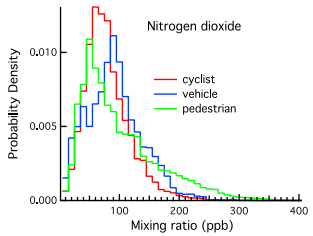
Real time data processing including analysis/interpretation and visualisation
(Imperial College)

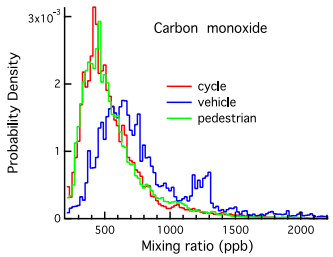


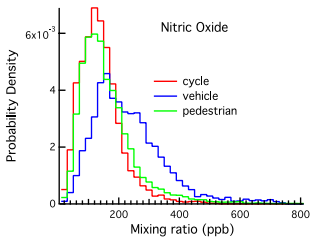
Cambridge deployment September 2009: NOx



Derive ensemble averaged statistics – distinguish between transport modes:

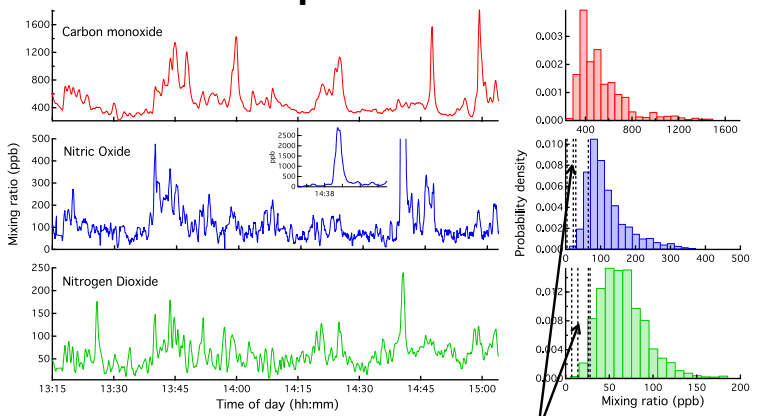






Snapshots…….

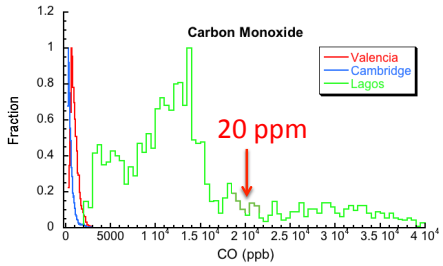
Individual exposure: are fixed site measurements representative?

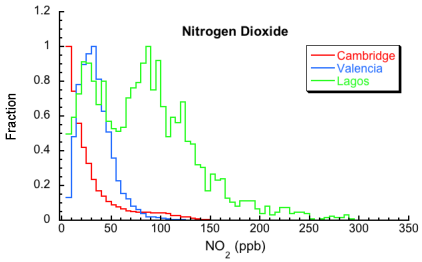


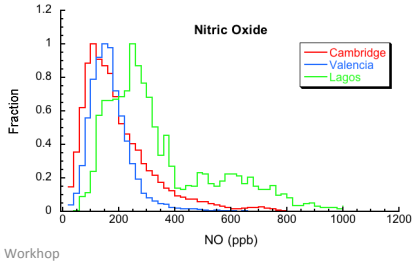
Fixed site hourly averages (dashed lines)

Answer: no……
Consequences?

Regional comparisons….



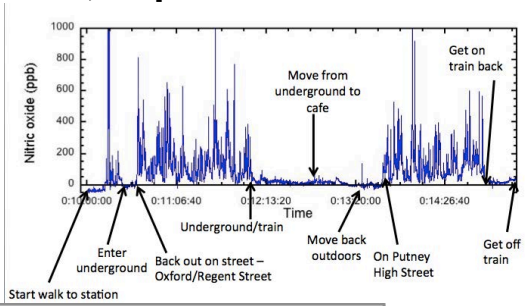


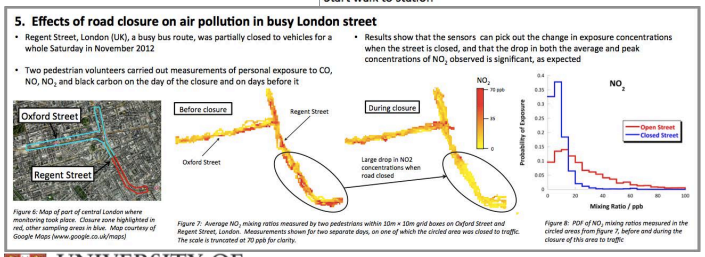


Dramatic differences…….

Flexible low cost way of characterising A/Q

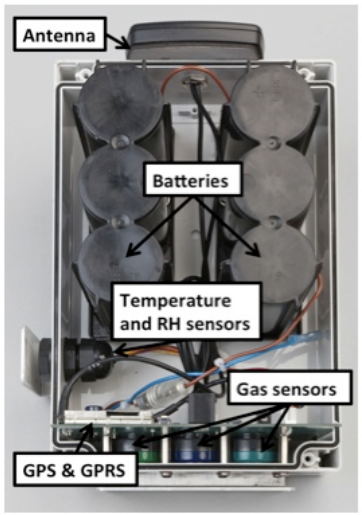
Personal exposure, impact studies

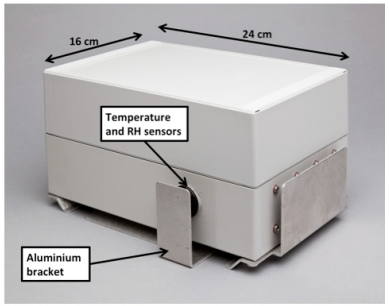




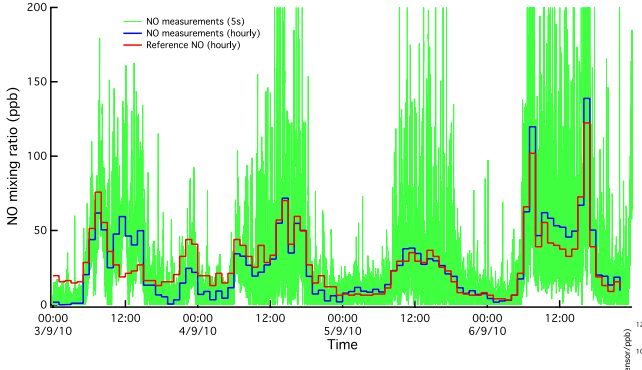
Gregor Stewart et al……

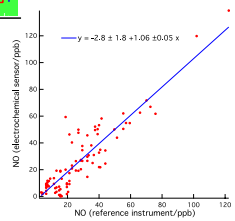
Three-species static sensor node





Hourly average *vs* fast response – near co-located instruments (nitric oxide)



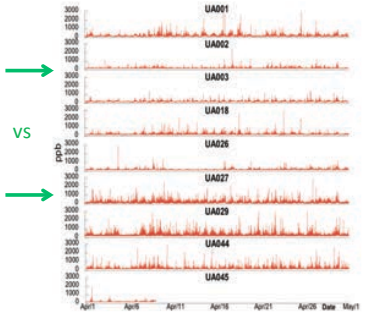


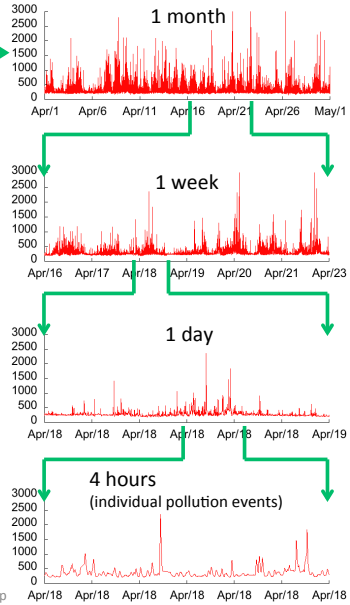
Structure present on all measured scales

Static deployments (carbon monoxide)

Grid
(46 sites)

vs





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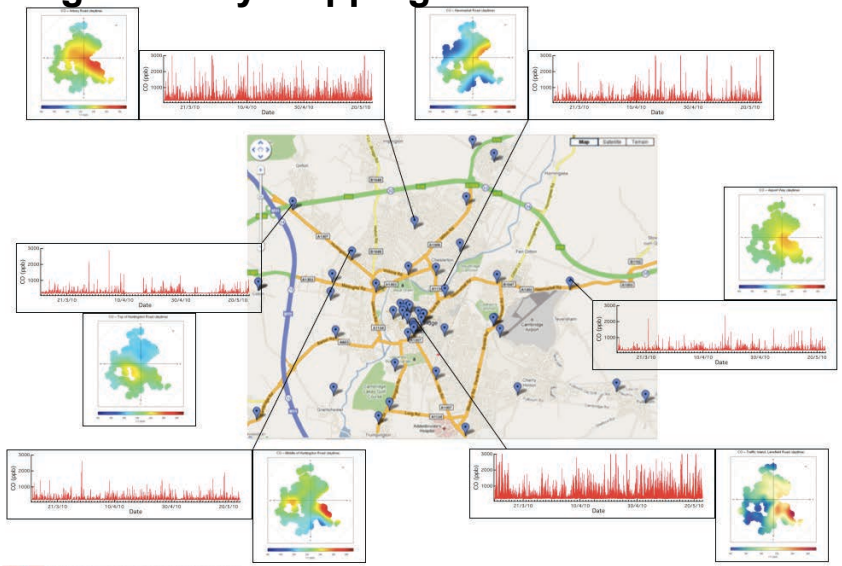
High-density mapping



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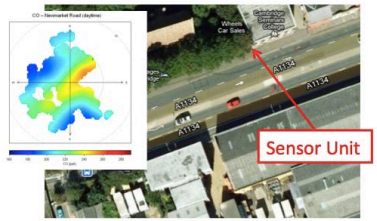
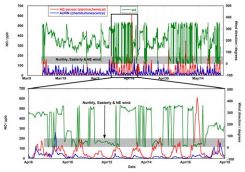
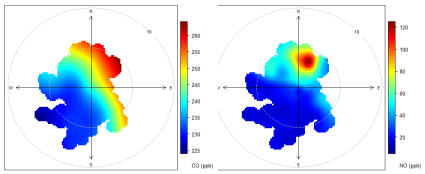
Street canyon effects: ventilation and re-circulation







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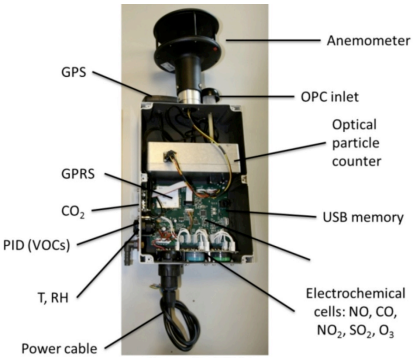
State of the art sensor network system at UK Heathrow airport

(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.
- Emissions inventory for LHR
- Network design optimisation.

Information content.....



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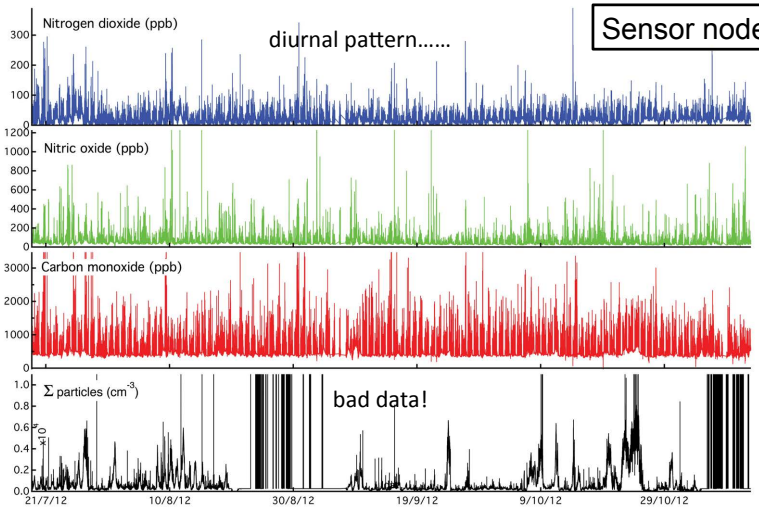
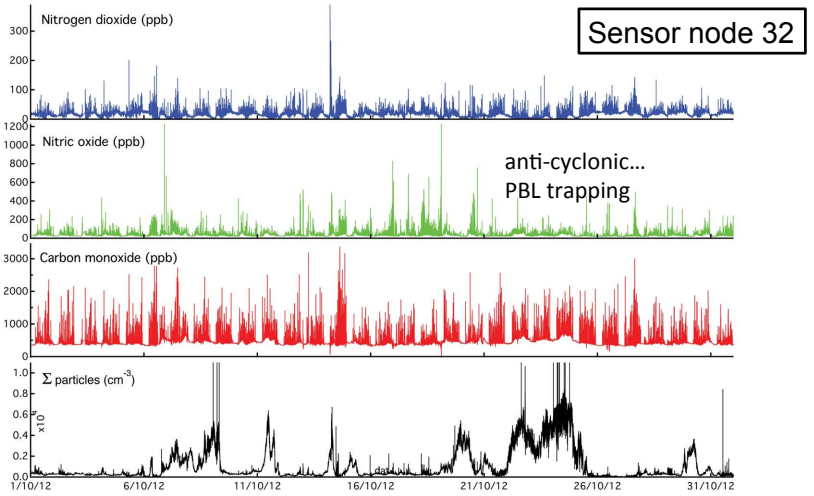
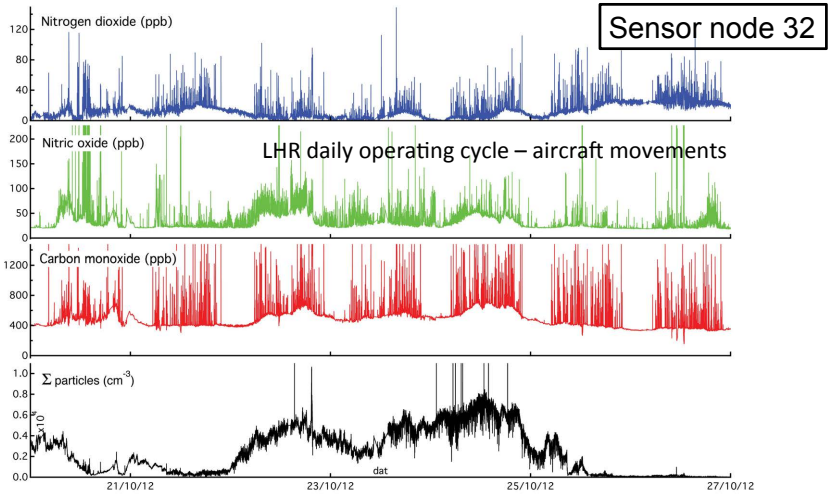
Preliminary LHR results .....3 months



Preliminary LHR results .....1 month

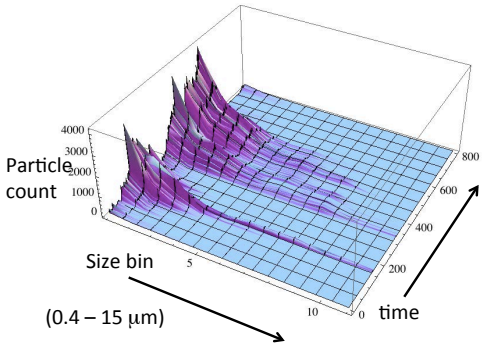


Preliminary LHR results .....1 week

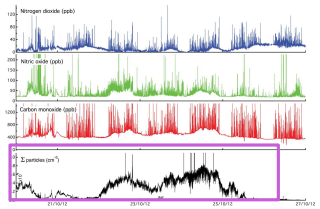


Clear evidence of airport operations (but)

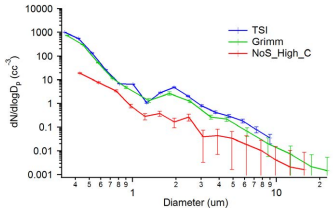
Other measurements: size speciated PM



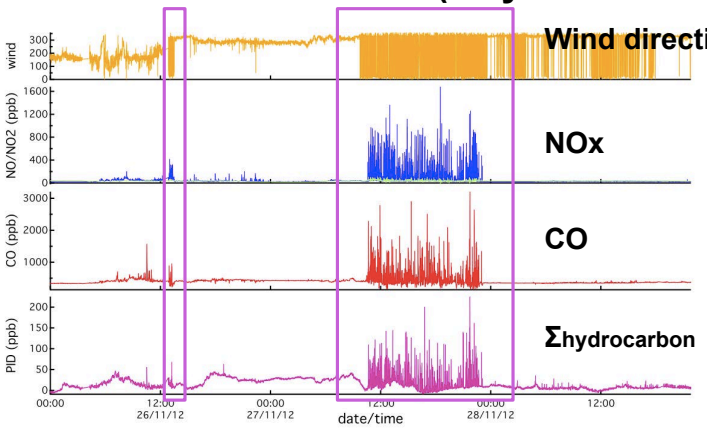
Sensor node 32



Successful comparison with reference instruments (Paul Kaye, Paul Williams)

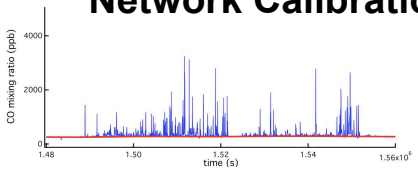


Other Measurements: PID (Σhydrocarbon)

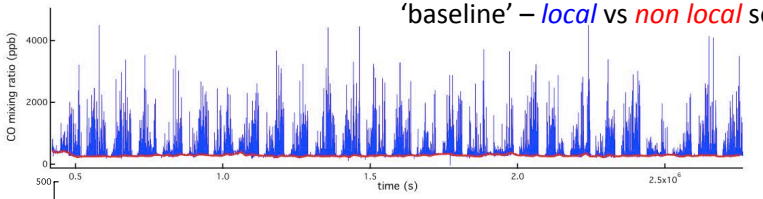


Correlation of hydrocarbon emissions with CO/NOx, and wind direction (value of multiple measurements)

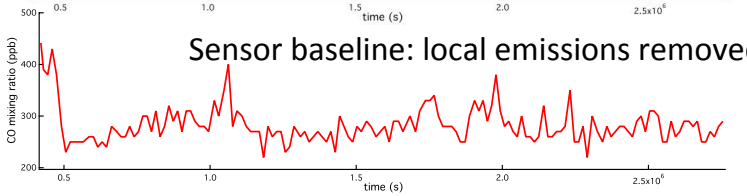
Network Calibration (I) (one sensor)



Intermittency of emissions, *if measured at high time resolution*, allows determination of sensor 'baseline' – *local* vs *non local* sources

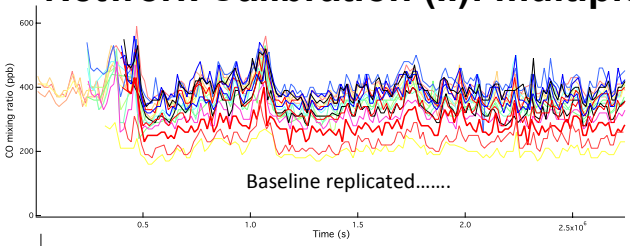


Sensor baseline: local emissions removed

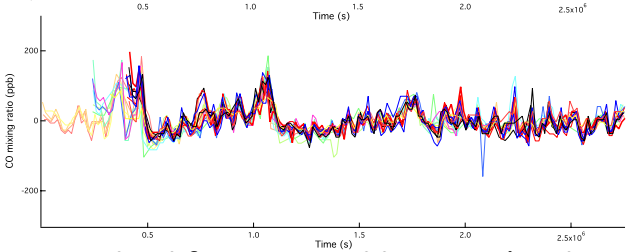


Information content in baseline?

Network Calibration (II): multiple sensors



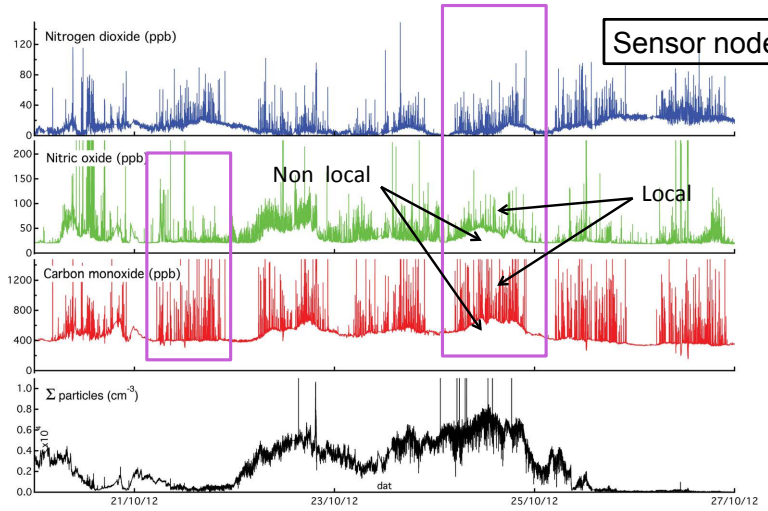
Unreferenced sensor baselines



Referenced sensor baselines

Method for intra-calibrating (and error checking) sensor networks: *a single referenced network*

Source attribution: local *vs* non-local



Network calibration *and* information

Small *is* beautiful

- Requires a change of philosophy
  - *Post processing vs instrument precision*
  - *Information content …. instrument location/network density?*
- Low cost sensors viable for a range of gas/PM measurements in the urban environment
  - *Static/mobile, integration with GPS/GPRS (and others)*
  - *Quantification*
  - *Exposure*
  - *Source attribution*
  - *Science!*
- Network calibration methodologies…..
  - *Cross network calibration/ quality control*
  - *Separation of scales – e.g. larger scales suitable for Kriging analyses*
- Finished article?
  - *Sensor development (e.g. cross interference)*
  - *'equivalence' – validation of methodology*

At/near the point to extend/complement current fixed site networks…..

Acknowledgements

Sensors and Sensor Networks
Iq Mead
Lekan Popoolan
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Mark Calleja
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Jeremy Cohen
Paul Kaye and UH team
Alastair Forbes/Martin Milton (NPL)
Paul Williams (UMAN)
David Carruthers (CERC)
…..
HAL (BAA), BA

Earlier work
MESSAGE
Imperial College (John Polak)
Peter Landshoff
…….