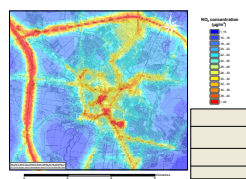
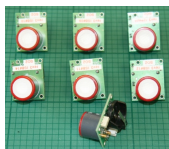
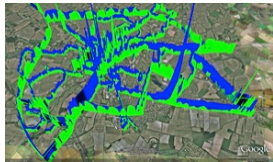
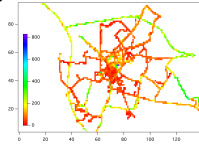


Monitoring air quality: small sensors start to show their capabilities



Rod Jones (and many others!)
Centre for Atmospheric Science
University of Cambridge
rlj1001@cam.ac.uk



Origins

Mobile Environmental Sensing
System Across Grid Environments



Engineering and Physical Sciences
Research Council



John Polak (IC), Peter Landshoff (Cambridge) and many others - incl. UCAM/RLJ!

High density Sensor Network
for monitoring Air Quality at
Heathrow Airport



SNAQ | Heathrow

details later.....

Philosophy of Approach:

information content vs instrument precision



VS

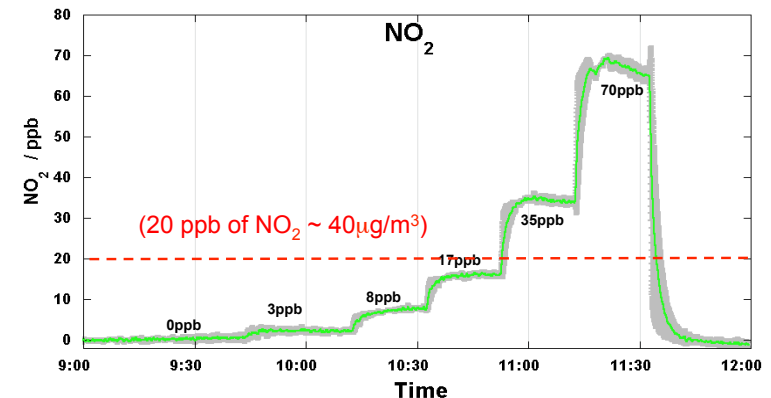


High precision measurement in the *wrong* place
has less value than a poor/indicative measurement
in the *correct* place.....

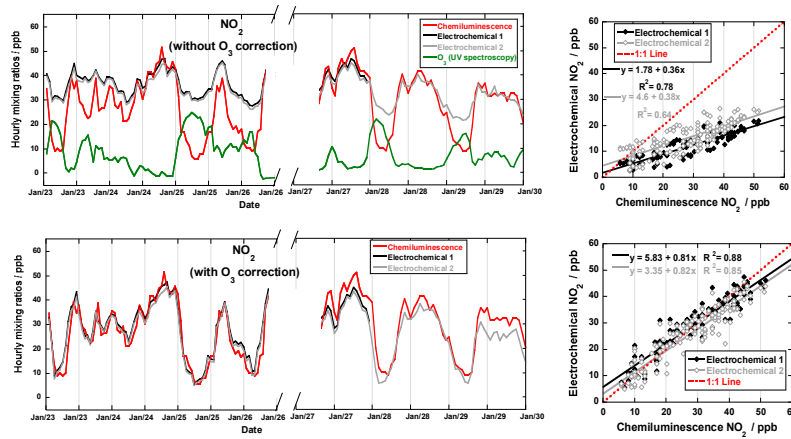
(But actually they're not that bad.....)

Challenges: enhance performance of e.g. electrochemical sensors (e.g. NO₂, laboratory)

ppm → ppb level response



Example of issues: characterisation of NO₂ cross sensitivity to O₃



Still not fully resolved at low NOx



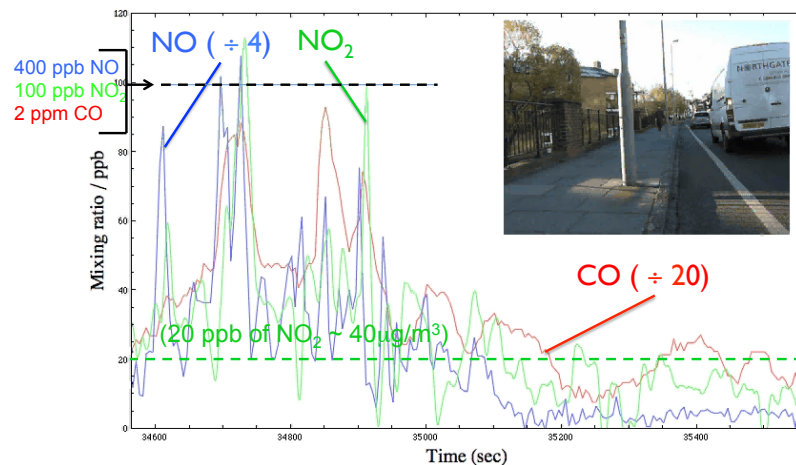
UKEOF, Edinburgh, Sept 24th, 2013

Three-species mobile sensor node



UKEOF, Edinburgh, Sept 24th, 2013

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

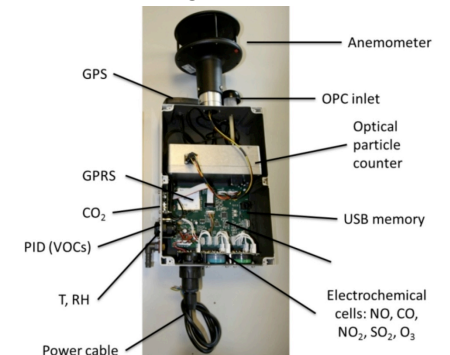


UKEOF, Edinburgh, Sept 24th, 2013

State of the art sensor network system at UK Heathrow airport

- 50 sensor nodes, real time data transfer (Electrochemical, NDIR, PID, Optical)
- NO, NO₂, CO, CO₂, SO₂, O₃, VOCs and size-specified 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....



UKEOF, Edinburgh, Sept 24th, 2013

49x22x16 cm, 2.8 kg

High density sensor network system for air quality studies at Heathrow airport

Participants:

Institution

University of Cambridge (PI)
 Imperial College London
 University of Hertfordshire
 University of Manchester
 CERC Ltd
 National Physical Lab.



Imperial College
 London

Input

sensors, a/q models
 traffic models, data visualisation
 aerosol measurements
 aerosol measurements
 a/q modelling – ADMS
 metrology, calibration



Cambridge Environmental Research Consultants
 Environmental Software and Services

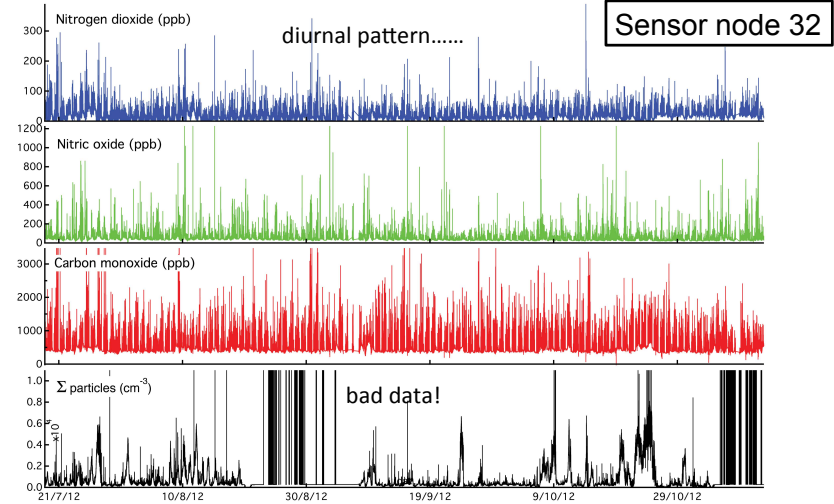


Heathrow Airport Ltd
 British Airways
 Alphasense Ltd

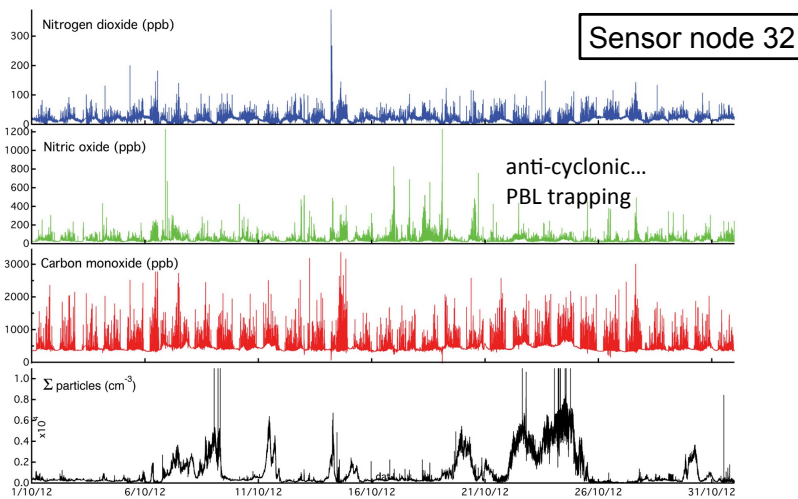
logistic, flight movements
 flight movements, throttle settings
 sensors, support



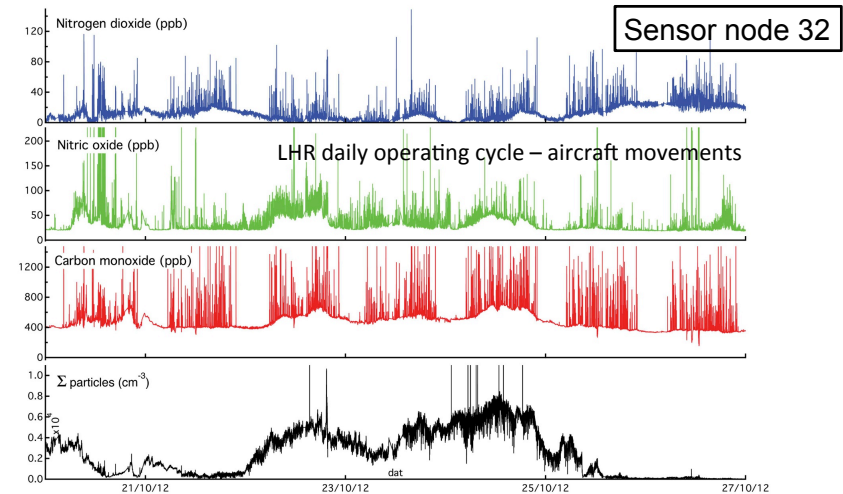
Preliminary LHR results3 months



Preliminary LHR results1 month

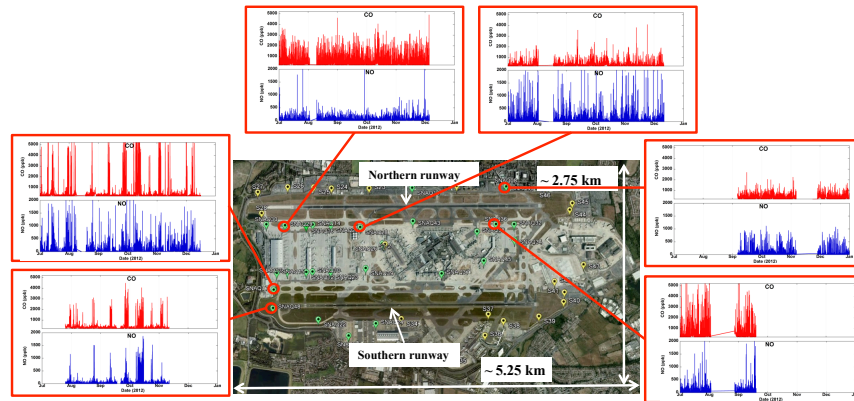


Preliminary LHR results1 week



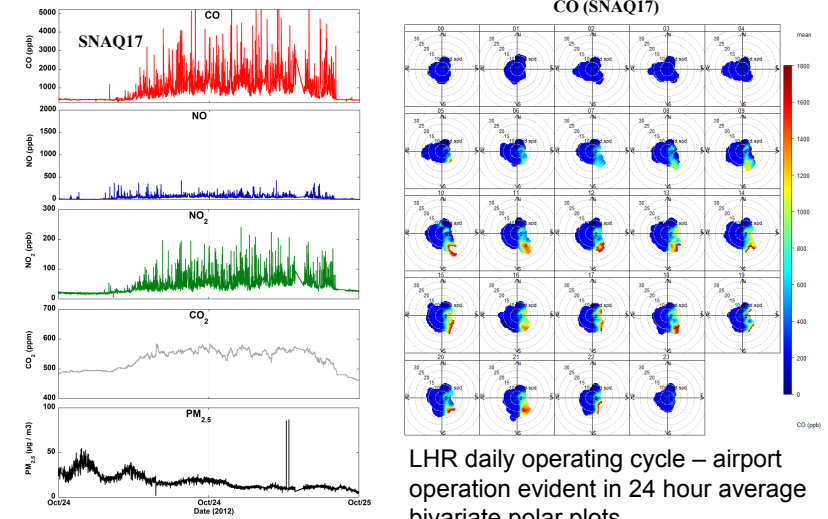
Clear evidence of airport operations (expected)

Preliminary Results SNAQ Heathrow Deployment



Snapshot of CO and NO measurements across the network

Preliminary LHR results24 hours



LHR daily operating cycle – airport operation evident in 24 hour average bivariate polar plots

Sensor Network Calibration?

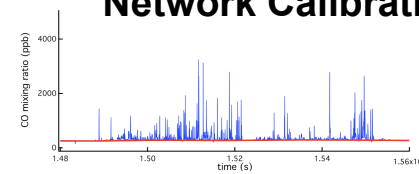
Fixed (AURN) sites: gas standards, intensive calibration methods.

Not feasible for low cost sensor networks....

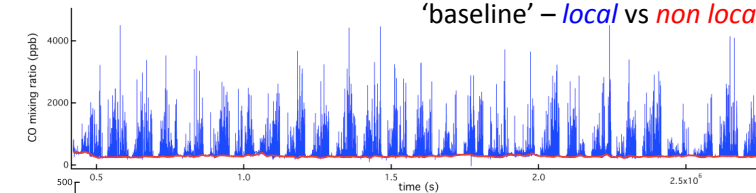
Alternative methodologies.....?

Network Calibration (I) (one sensor)

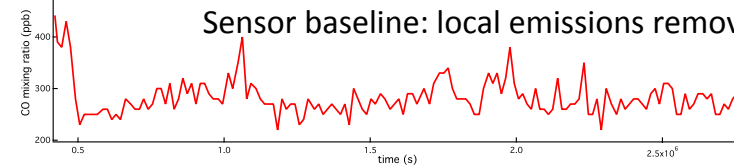
Intermittency of emissions, if measured at high time resolution, allows determination of sensor



'baseline' – local vs non local sources

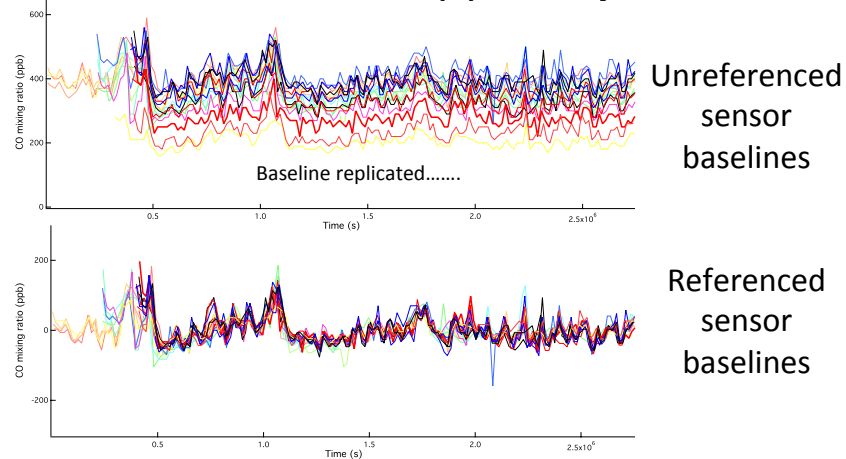


Sensor baseline: local emissions removed



Information content in baseline?

Network Calibration (II): multiple sensors

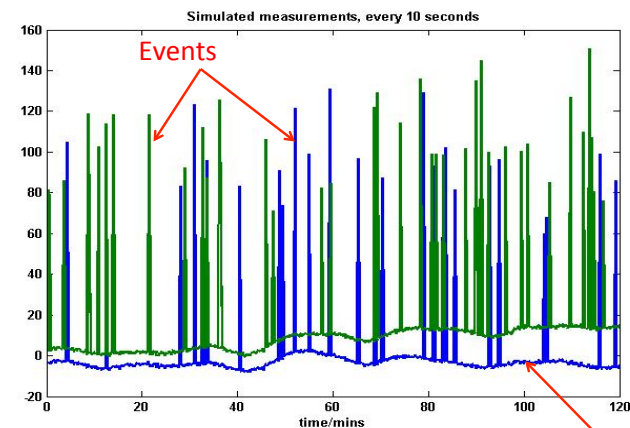


Method for intra-calibrating (and error checking) sensor networks: a single referenced network



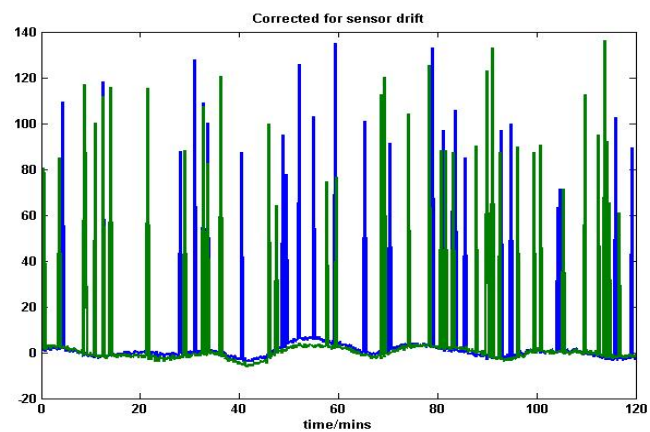
UNIVERSITY OF CAMBRIDGE

Simulated data, sensor drift



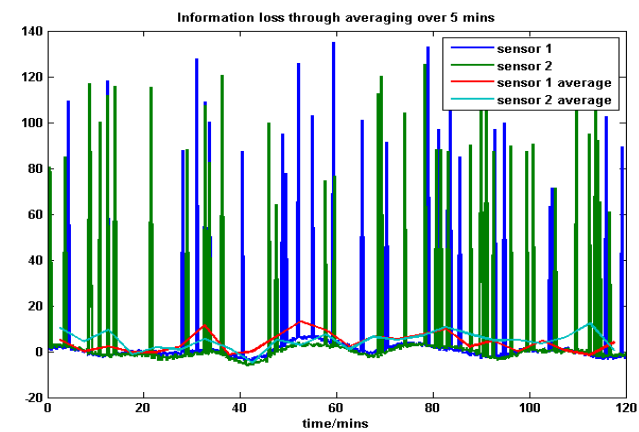
UKEOF, Edinburgh, Sept 24th, 2013

Corrected for sensor drift



UKEOF, Edinburgh, Sept 24th, 2013

Information loss through averaging



UKEOF, Edinburgh, Sept 24th, 2013

Information loss through time averaging

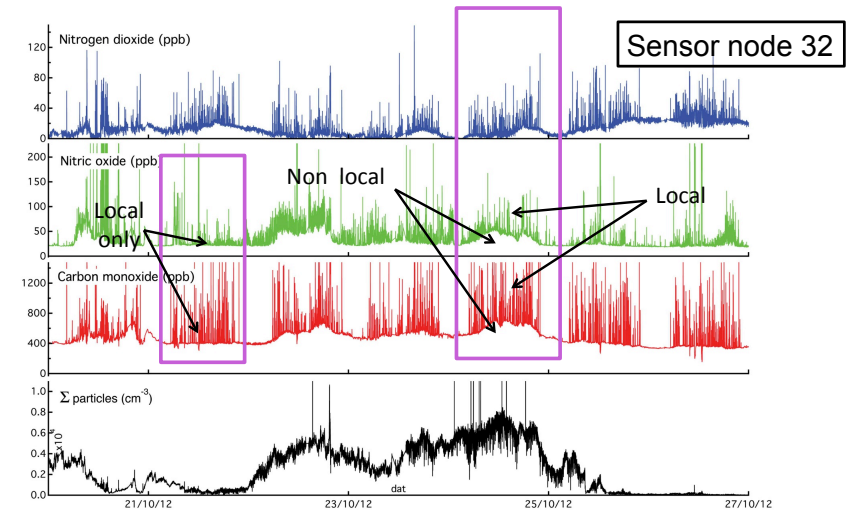
- Kriging interpolation/calibration methods *can* work well, but require appropriate spatial scales...
- High frequency sampling/filtering allows method to be extended to near source environments....

Statistical + Kriging based algorithms for network calibration (i.e. not requiring invasive methods) achievable for cross-network calibration/quality control.....



UKEOF, Edinburgh, Sept 24th, 2013

Source attribution: local vs non-local



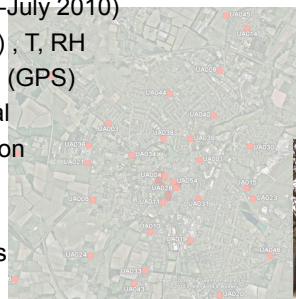
Network calibration *and* extra information

UKEOF, Edinburgh, Sept 24th, 2013

Static Sensor Deployment, Cambridge (UK)

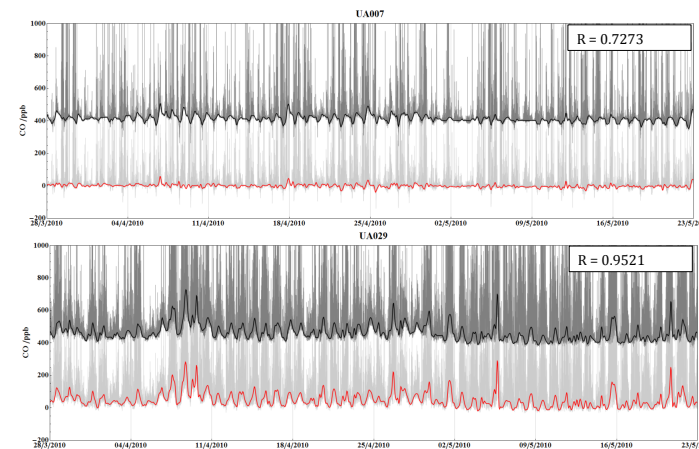
- >2 month deployment (May-July 2010)
- >40 sensors (CO , NO , NO_2), T, RH
- Lamp post mounted, GPRS (GPS)
- Inner city, mixed urban, rural
- Real time GPRS transmission

>25,000,000 measurements



UKEOF, Edinburgh, Sept 24th, 2013

Source attribution: regional and local signals:

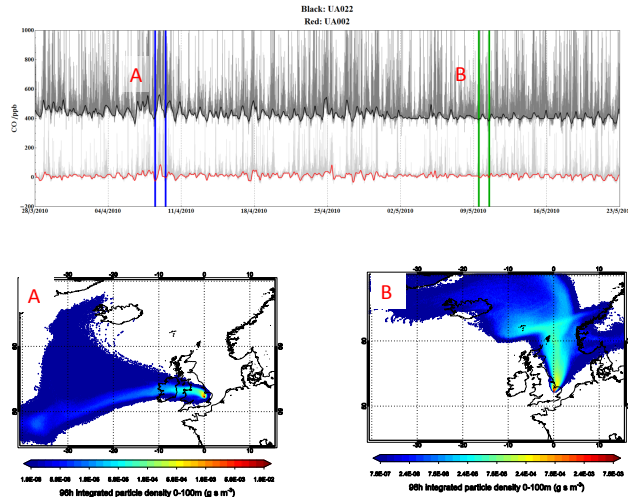


Data based source attribution – exploiting time resolution!



UKEOF, Edinburgh, Sept 24th, 2013

Source attribution: back trajectories



A:
Emission 8/04/2010 12:00 – 9/04/2010 12:00
(blue lines)
Most of the particles coming over Ireland and Birmingham

B:
Emission 9/05/2010 12:00 – 10/05/2010 12:00
(green lines)
Clean air coming over the North Sea, no pollutants transported

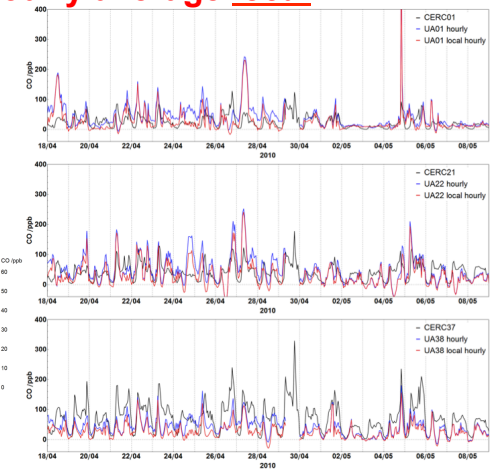
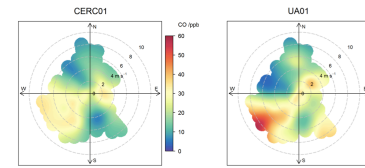
Data based source attribution contd.



UKEOF, Edinburgh, Sept 24th, 2013

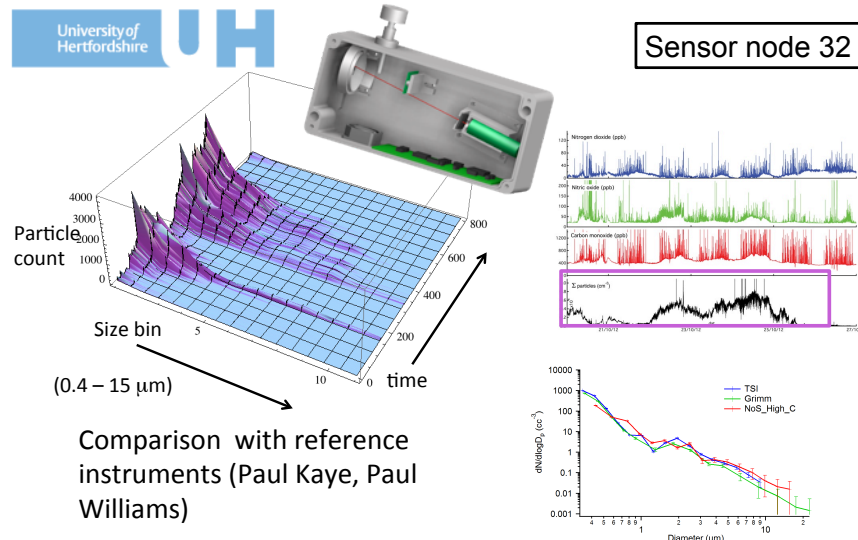
Local emissions comparison: ADMS (local dispersion model) calculations with hourly average and hourly average *local* measurements

Quantification of *local* emissions



UKEOF, Edinburgh, Sept 24th, 2013

Other measurements: size speciated PM



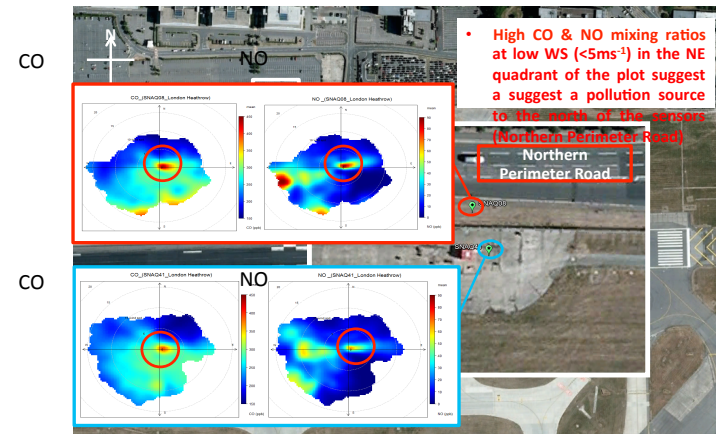
Comparison with reference instruments (Paul Kaye, Paul Williams)



UKEOF, Edinburgh, Sept 24th, 2013

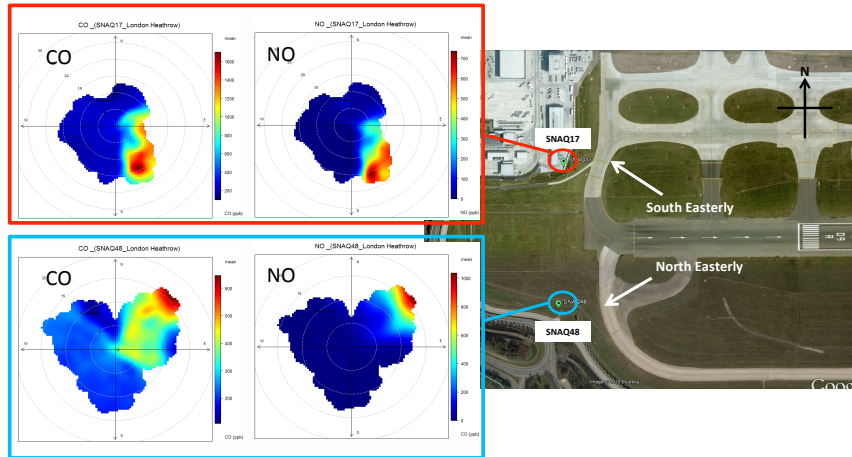
Data-based disaggregation methods

LHR: airside/roadside discrimination



UKEOF, Edinburgh, Sept 24th, 2013

Detection of jet exhaust plume (lofting)

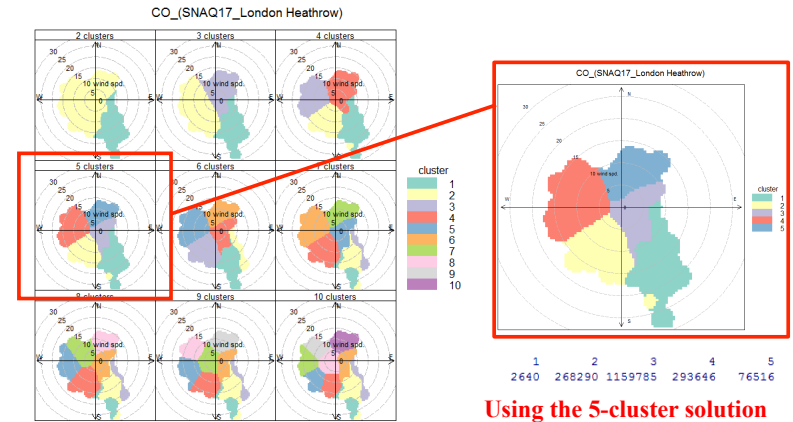


- Mirror image pollution mixing ratios observed in the two sensor nodes
- High CO & NO mixing ratios at higher wind speeds suggests aircraft plume lofting



UKEOF, Edinburgh, Sept 24th, 2013

Source attribution: Sensors at the west-end of southern runway (09R)



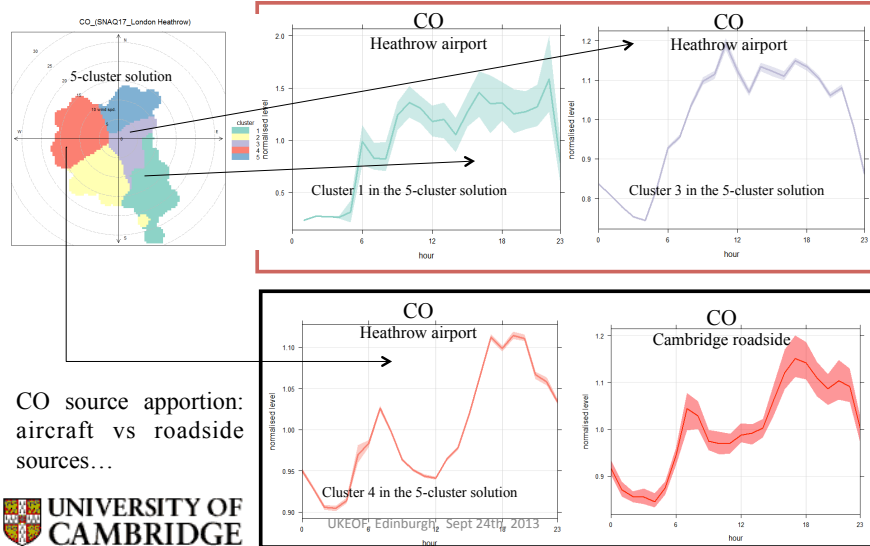
Using the 5-cluster solution

David Carslaw and Karl Ropkins (2012). openair: Open-source tools for the analysis of air pollution data. R package version 0.7-0.



UKEOF, Edinburgh, Sept 24th, 2013

Source attribution: Sensors at the west-end of southern runway (09R)



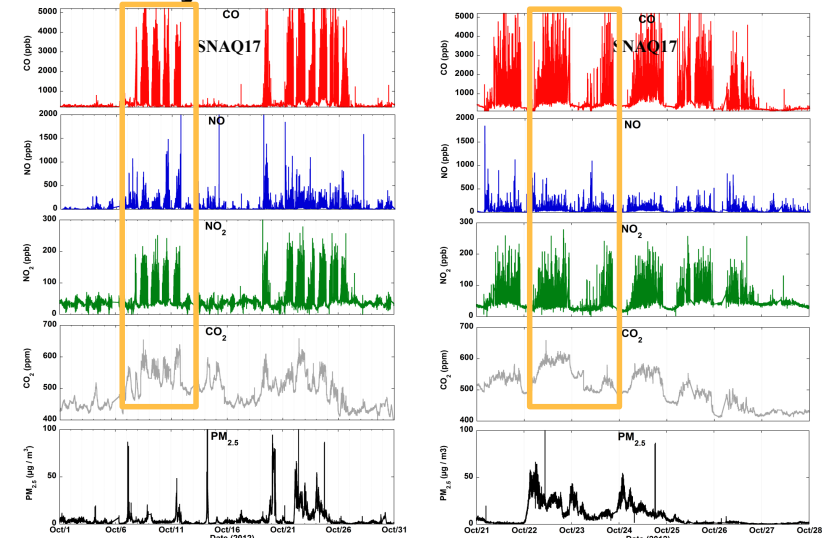
CO source apportion: aircraft vs roadside sources...



UKEOF, Edinburgh, Sept 24th, 2013

Preliminary LHR results

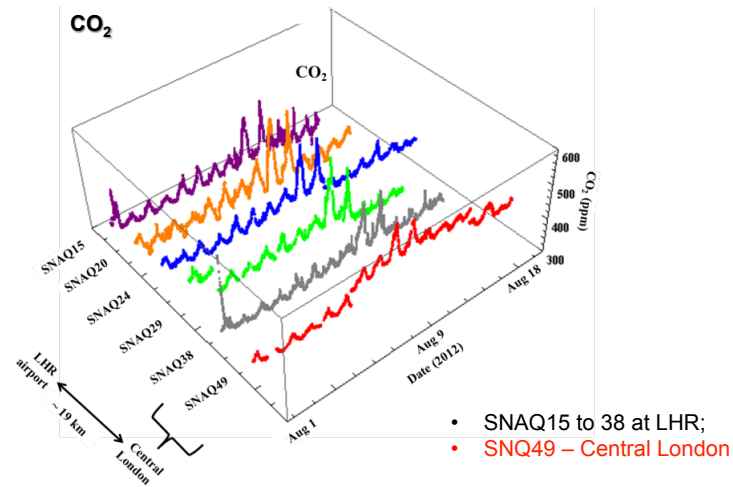
.....1 month vs 1 week



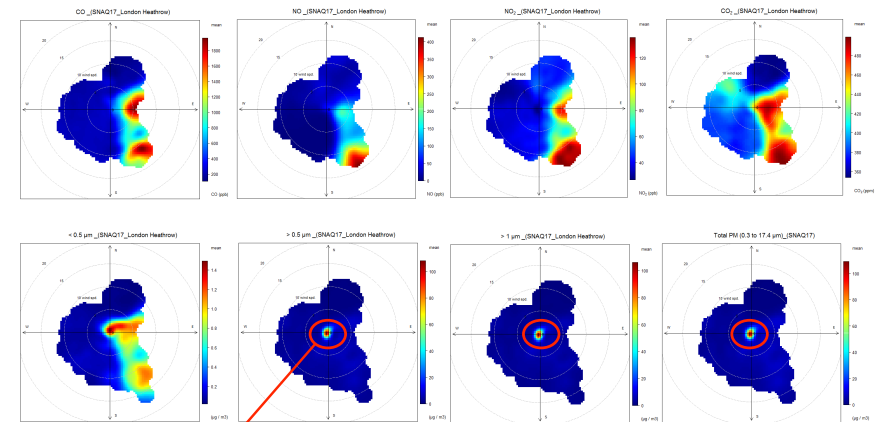
UKEOF, Edinburgh, Sept 24th, 2013

Emissions indices...

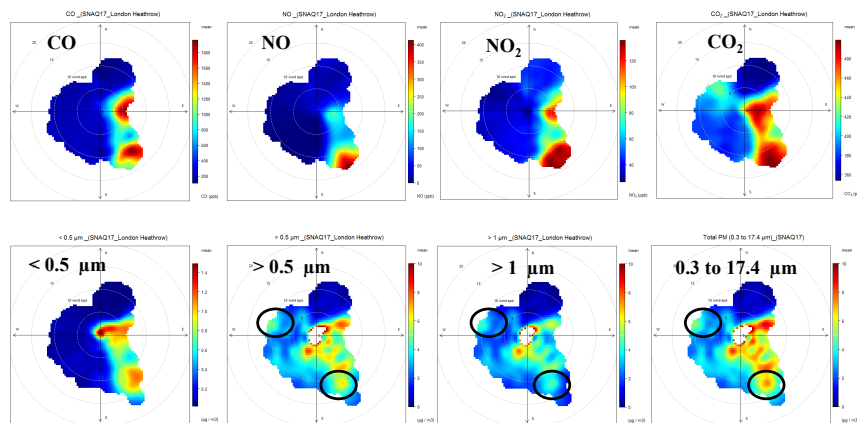
Regional pollution events observed across SNAQ network



Source attribution: SNAQ17 at the west-end of southern runway (09R) , 1 month data

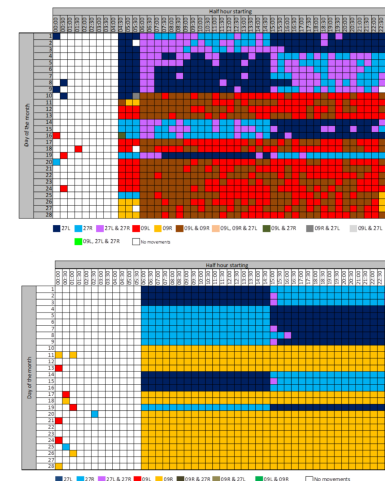


Source attribution: SNAQ17 at the west-end of southern runway (09R) , 1 month data



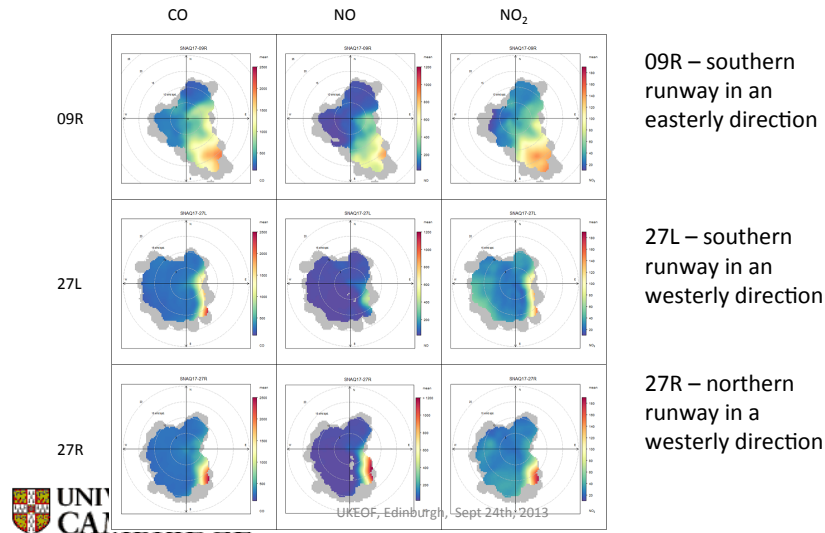
OPC ($\mu\text{g} / \text{m}^3$) Excluding anticyclone, other sources identified

Heathrow Operational Modes

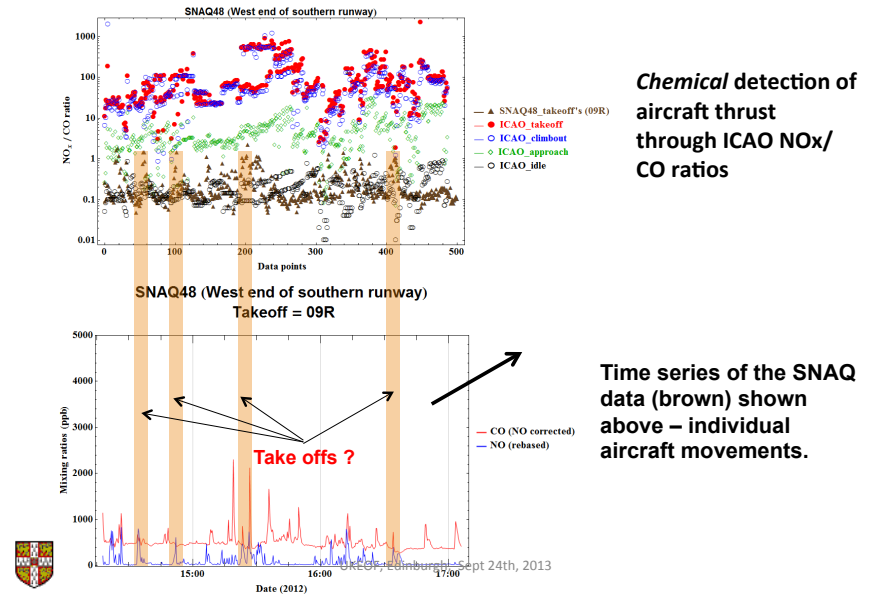


- A trial which ran between July 2012 and February 2013.
- "It explored whether new procedures could be used to bring benefits to passengers, by providing a more punctual service; the local community through less late-running flights; and to the environment, by reducing aircraft stacking times and reducing emissions."
- As part of the trial data was made available online as to which runways were active at any one time.
- Data is given for every half hour period.

Allows division of data according to airport activity... (here done by take-off)



NO_x / CO ratios: ICAO vs. SNAQ data



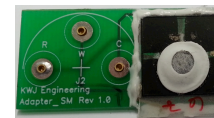
Low cost sensors/sensor networks?

- + Performance at the ppb level
- + Stability/reproducibility (not really discussed here)
- + Low cost gas *and* PM
- + Network calibration methodologies
- + Intrinsic value of high time resolution data...
- + Source attribution/data disaggregation
- + First major deployment of true low cost high density sensor network – still early days!

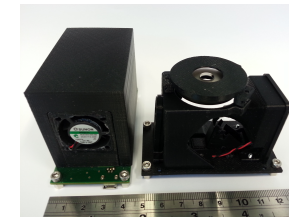
Caveats:

- PM only above 400nm, no chemical speciation (!)
- Cross interferences still an issue in some cases (e.g. NO₂/O₃ at low NO_x)

Future directions? indoor air quality, personal monitoring....



Screen (miniaturised) printed amperometric cells



Miniaturised size speciated PM

Acknowledgements

Iq Mead

Lekan Popoolan, Shaun Hurst, Gregor Stewart,
Vivien Bright, Ines Heimann (All UCAM)

John Saffell (Alphasense)

.....

Spencer Thomas, David Vowles (HAL/BAA, BA)

Jo Dicks, Anita Harris (Cambridge City Council)

Mark Hayes, Mark Calleja

Robin North/John Polak

Jeremy Cohen

Paul Kaye and UH team

Alastair Forbes/Martin Milton (NPL)

Paul Williams (UMAN)

David Carruthers (CERC)

.....

Funding Agencies: NERC, EPSRC



UKEOF, Edinburgh, Sept 24th, 2013