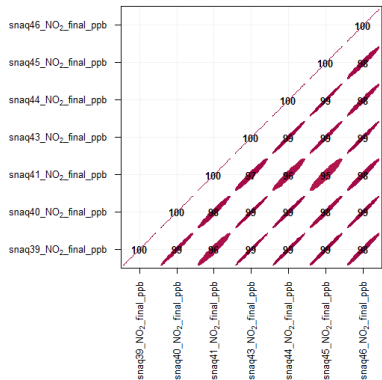
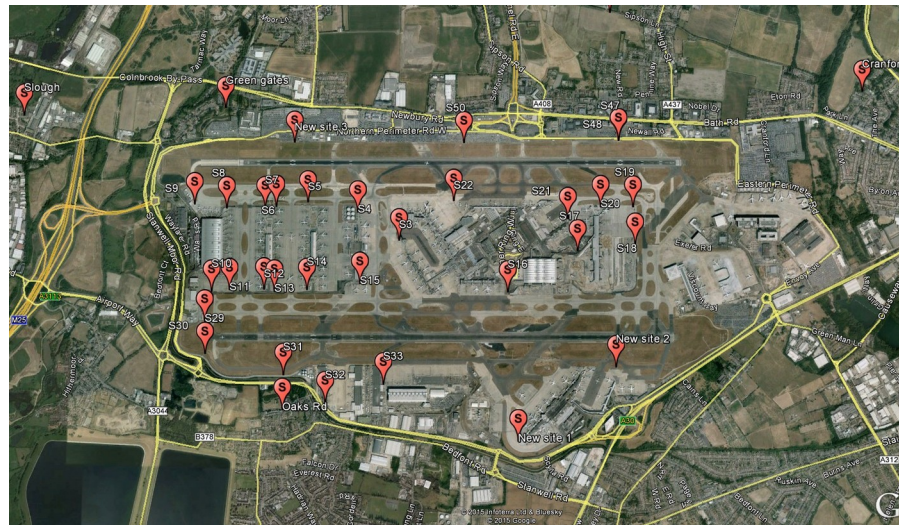
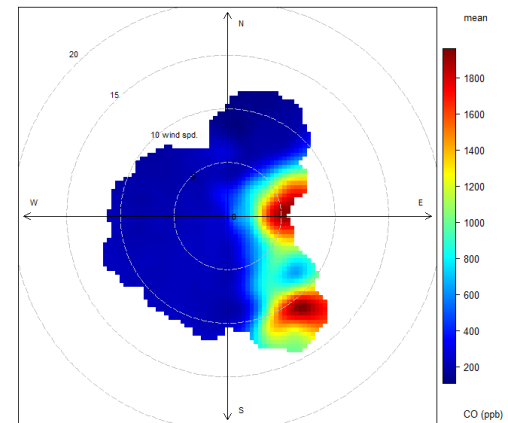
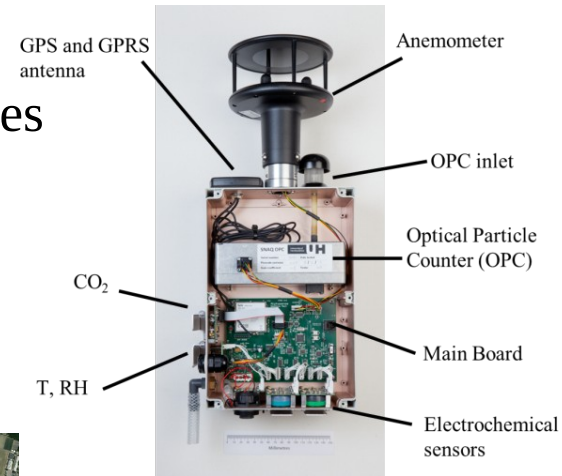


Low-cost portable sensors: revolutionising the studies of air quality

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University of Cambridge

oamp2@cam.ac.uk



Outline of Presentation

- **Low-cost sensors**
 - Method and applications
 - Sensor performance
- **SNAQ London Heathrow airport**
 - Scale separation
 - Emission indices estimation
- **Ambient PM measurements using low-cost sensors**
 - Cambridge
 - London
- **Conclusions**

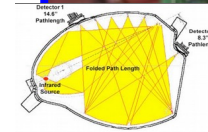
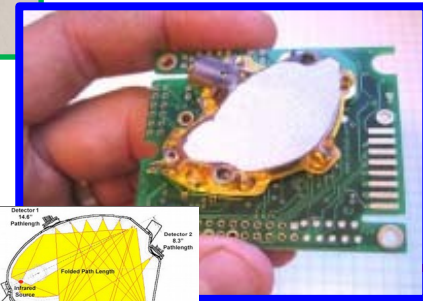
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Basis for portable sensor and sensor network approach

Low cost miniature gas sensor technologies

- Electrochemical
- Non Dispersive IR
- Photo Ionisation Detection
- Metal Oxide
- *Optical Particle Counter (OPC)*



Adaptation required from alarm/warning configuration
< £100s per sensor c.f. 10s £k for traditional methods

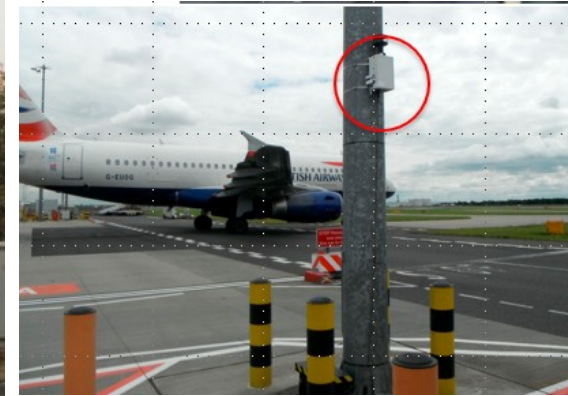
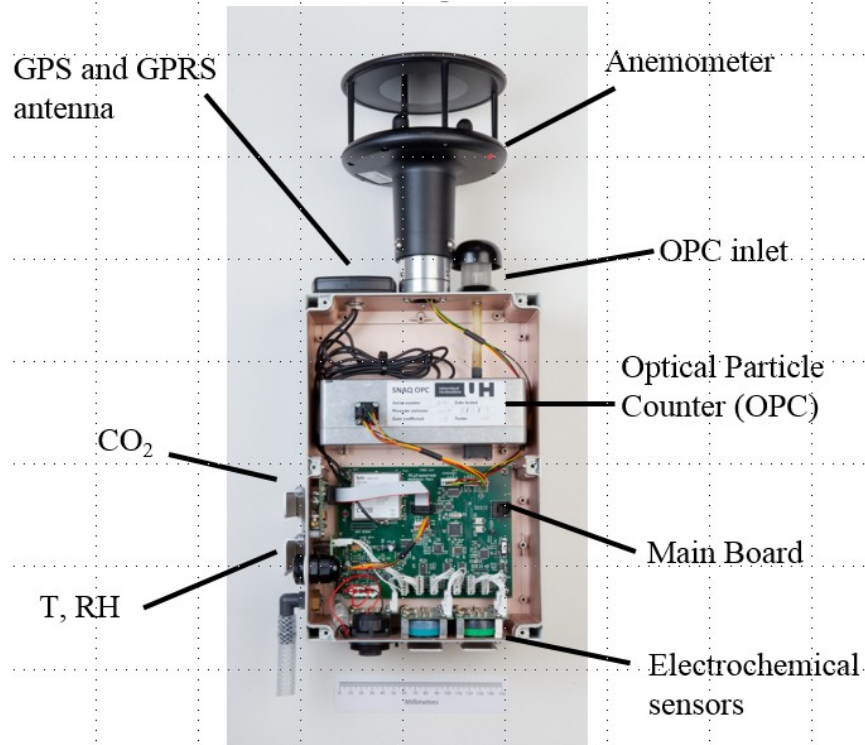
Philosophy of Approach (outdoor air quality): information content vs instrument precision



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

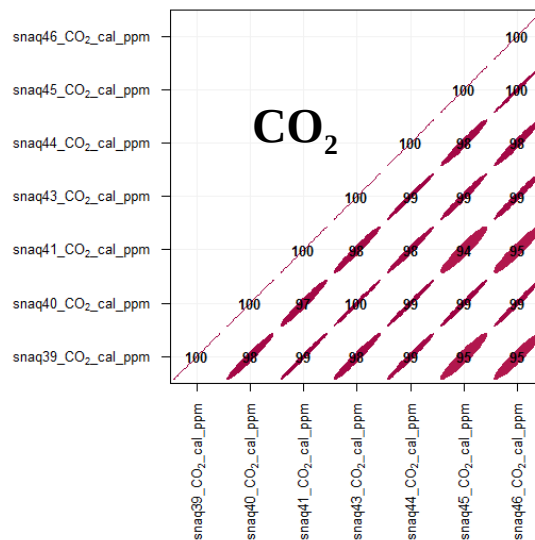
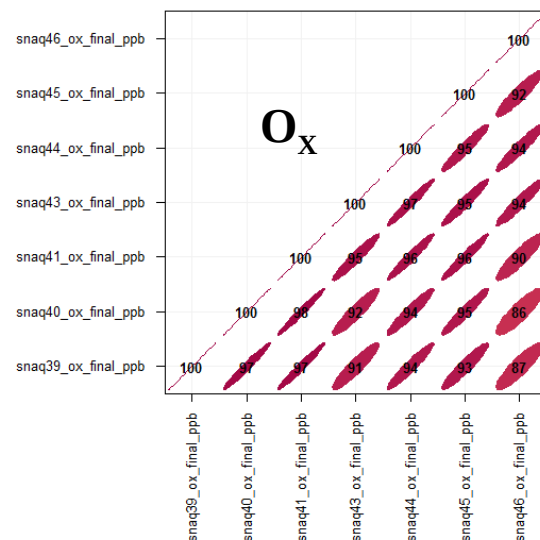
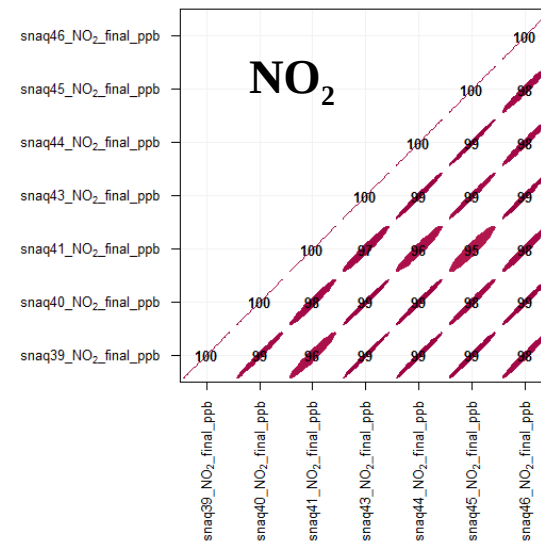
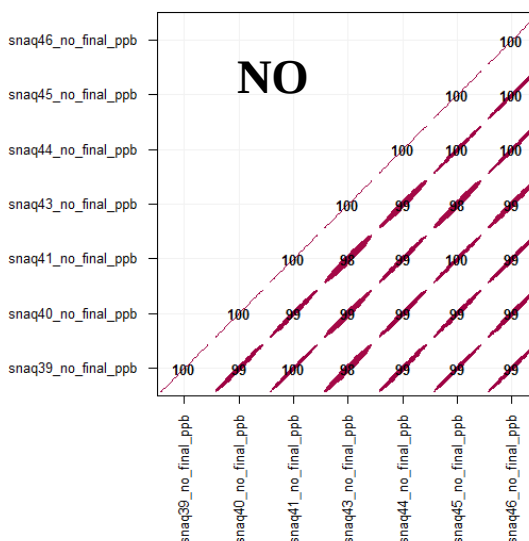
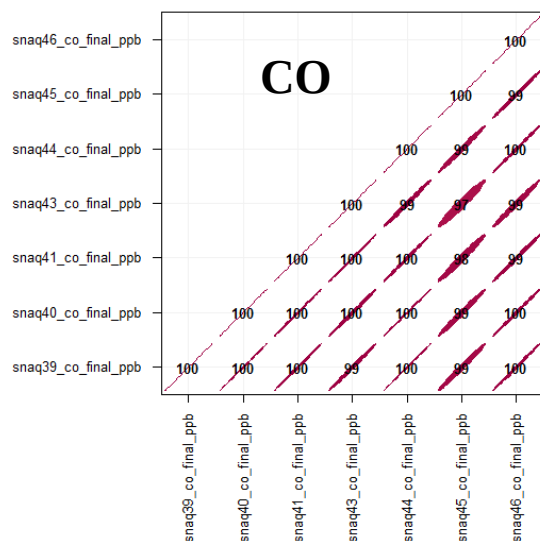
Low cost sensor networks

static nodes: outdoor air quality

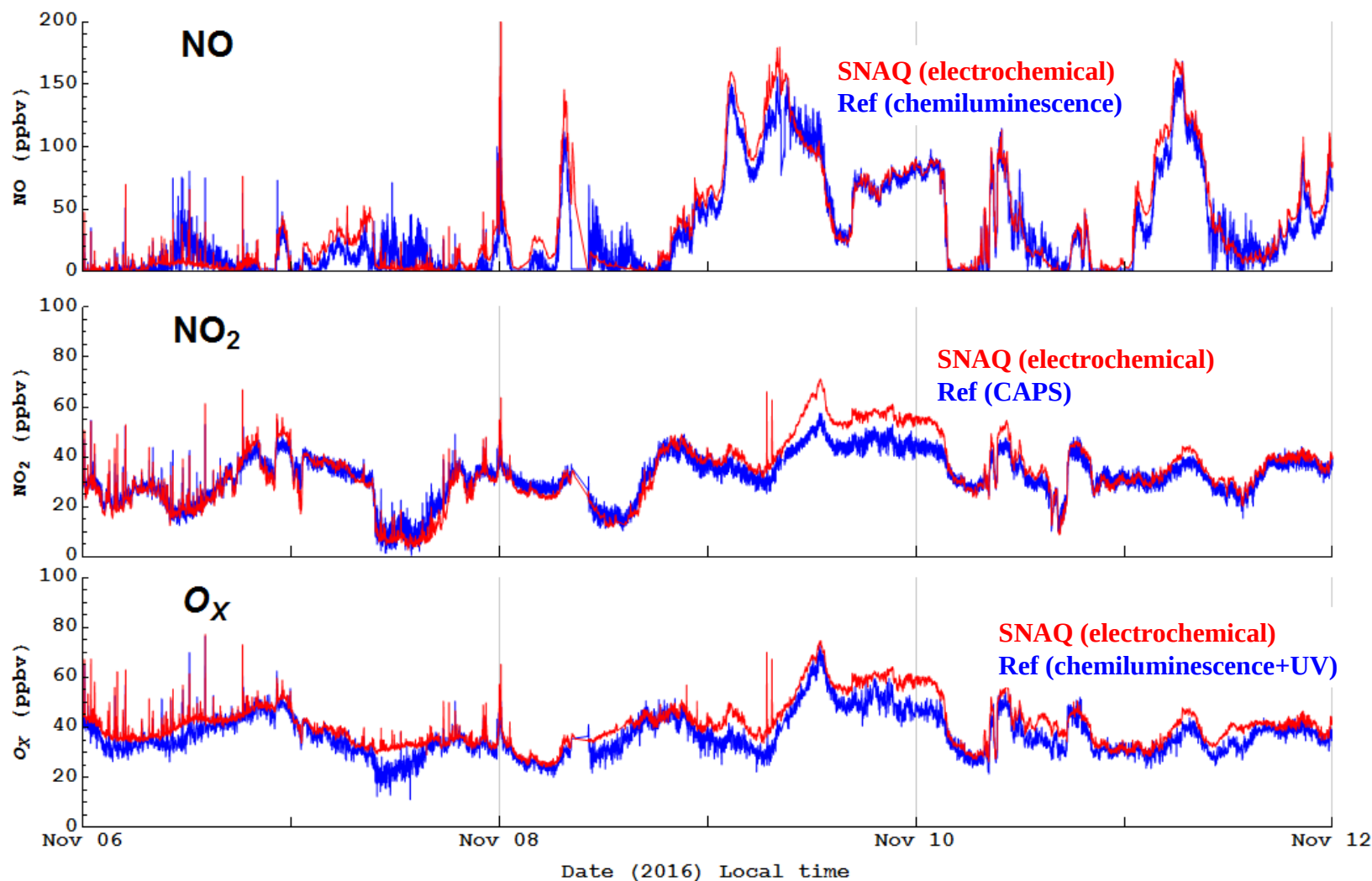


- Gas species (CO, NO, NO₂, O_x, SO₂, TVOCs & CO₂)
- Size speciated PM (0.38 – 17.4μ)
- Temperature, RH, wind speed and direction
- All 20s data

Reproducibility of SNAQ units: Pearson correlation



Comparison with reference techniques: Beijing



Sensors have very good agreement with conventional instrument

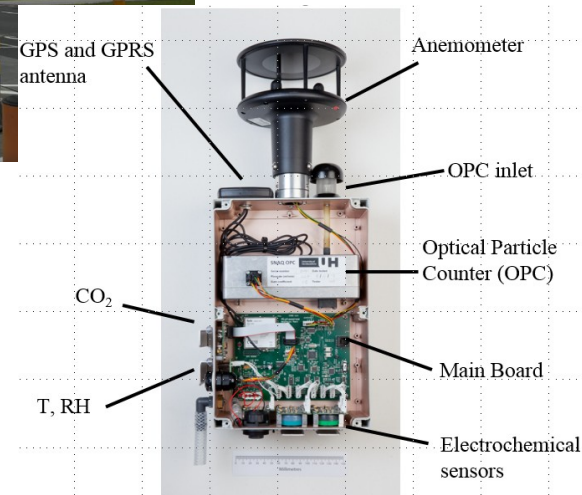
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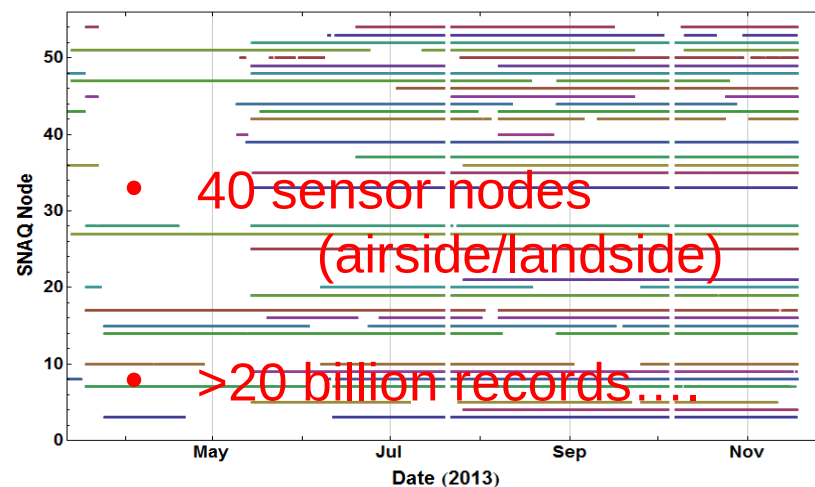
Sensor network system at Heathrow airport

40 sensor nodes (Electrochemical, **NDIR**,
PID, **Optical**)

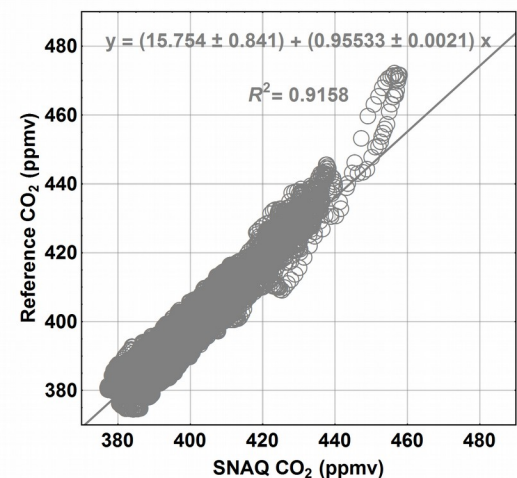
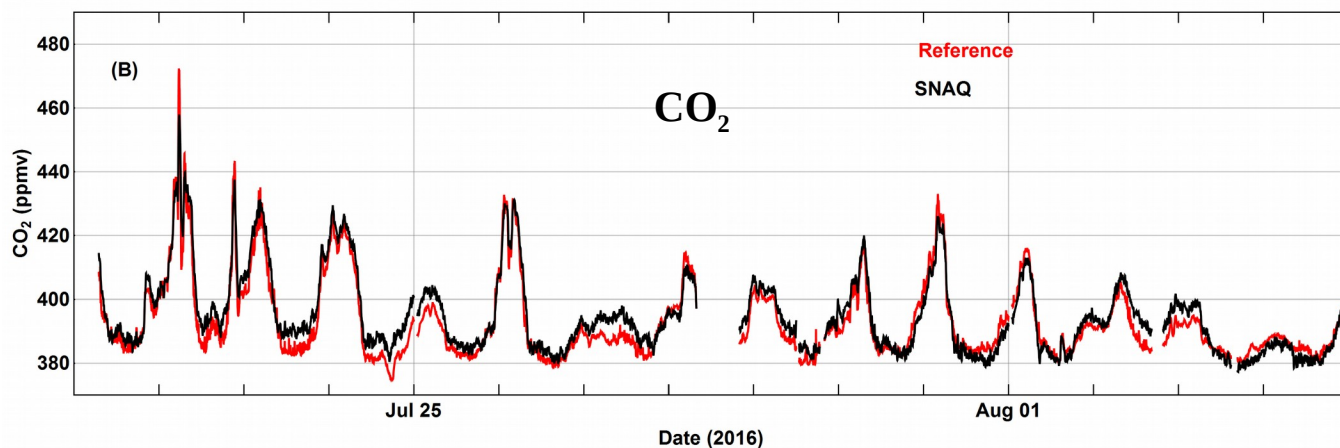
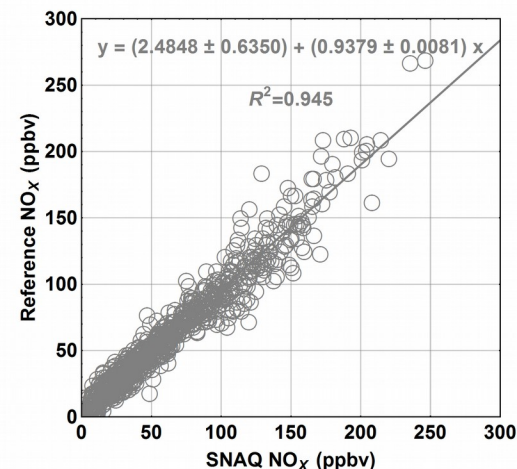
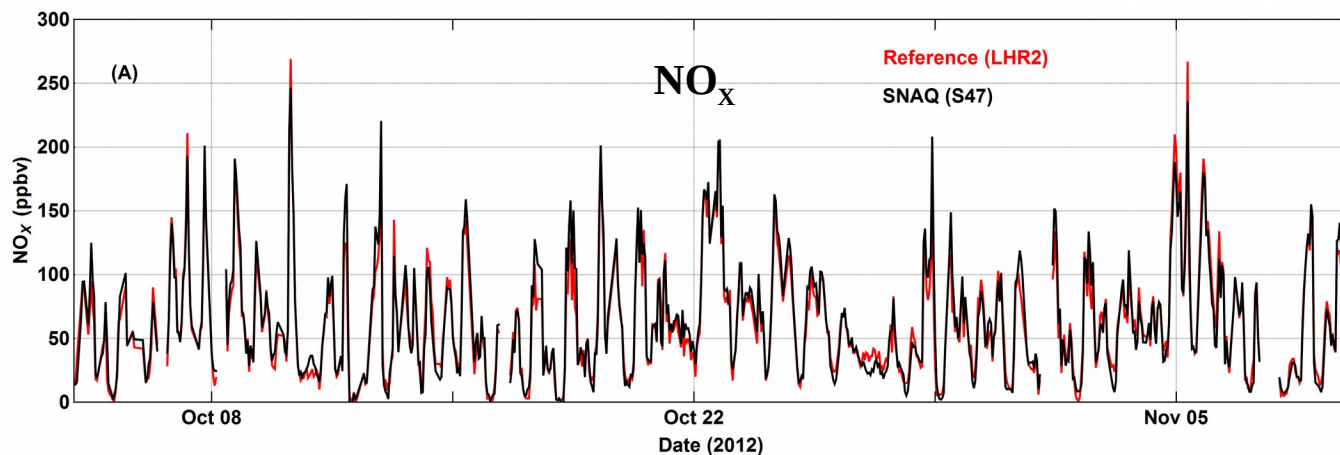
- Real time data transfer (GPRS)
- NO, NO₂, CO, **CO₂**, SO₂, O₃, **VOCs**,
PM 0.38 – 17.4μ)
- Software sensor network calibration



Data transmitted



Field validation of SNAQ performance

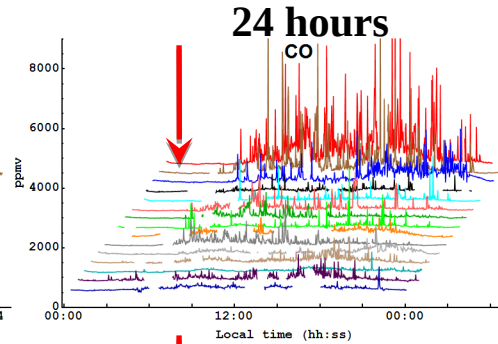
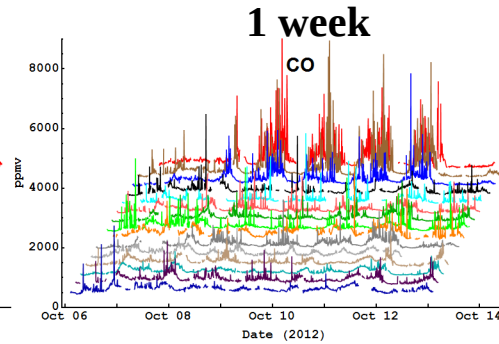
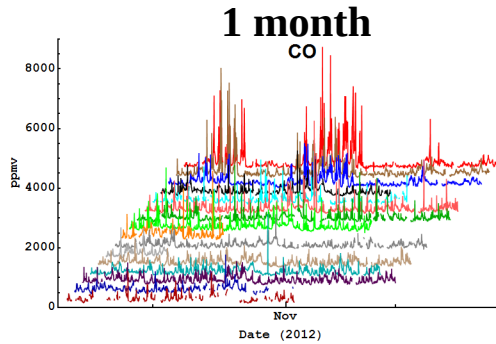


Sensors have very good agreement with conventional instrument

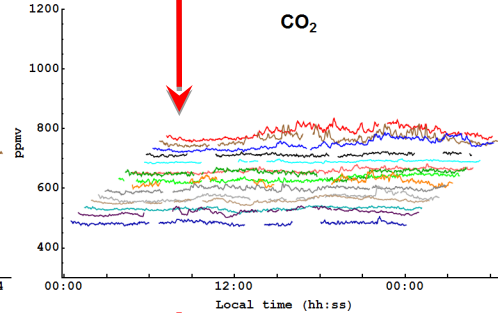
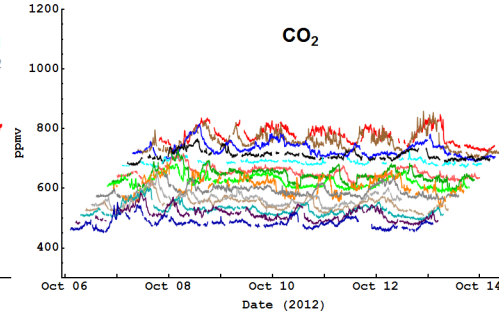
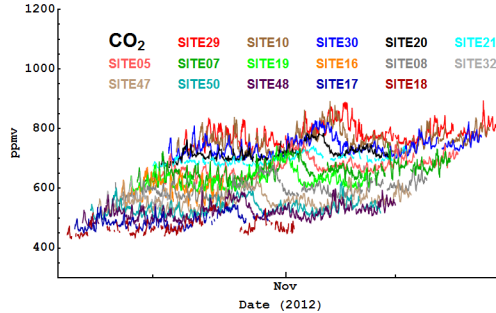
High temporal network data

Mixed emission signatures: *LHR* operations and large scale

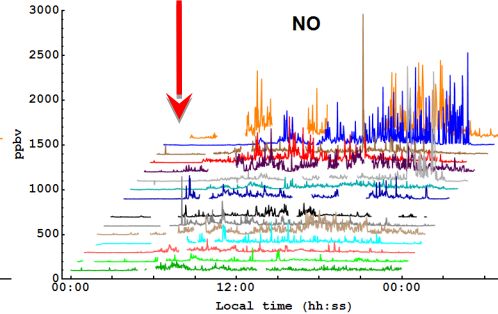
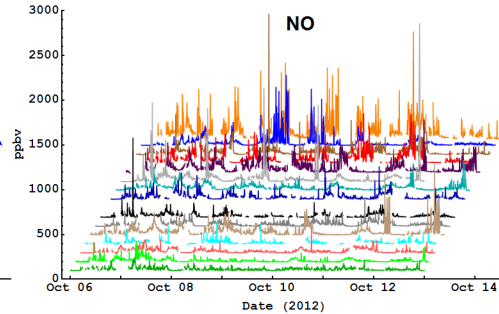
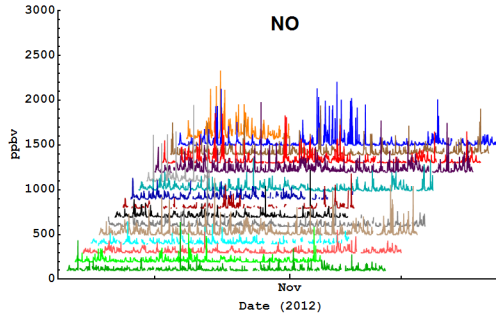
CO



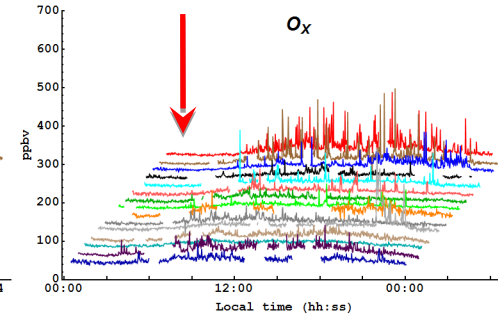
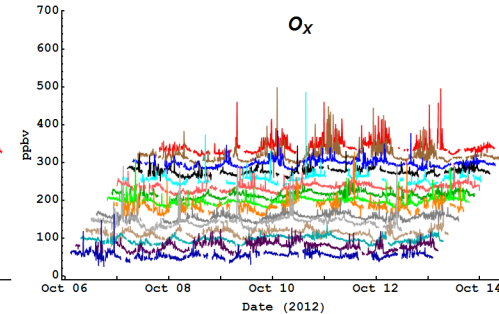
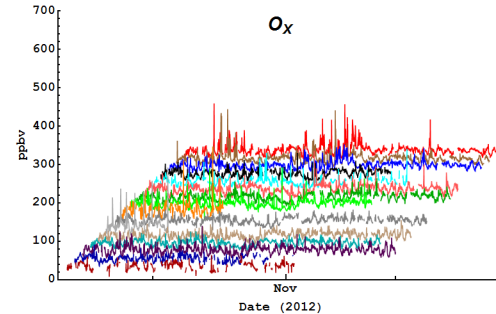
CO₂



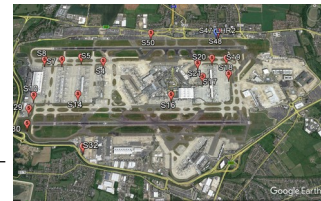
NO



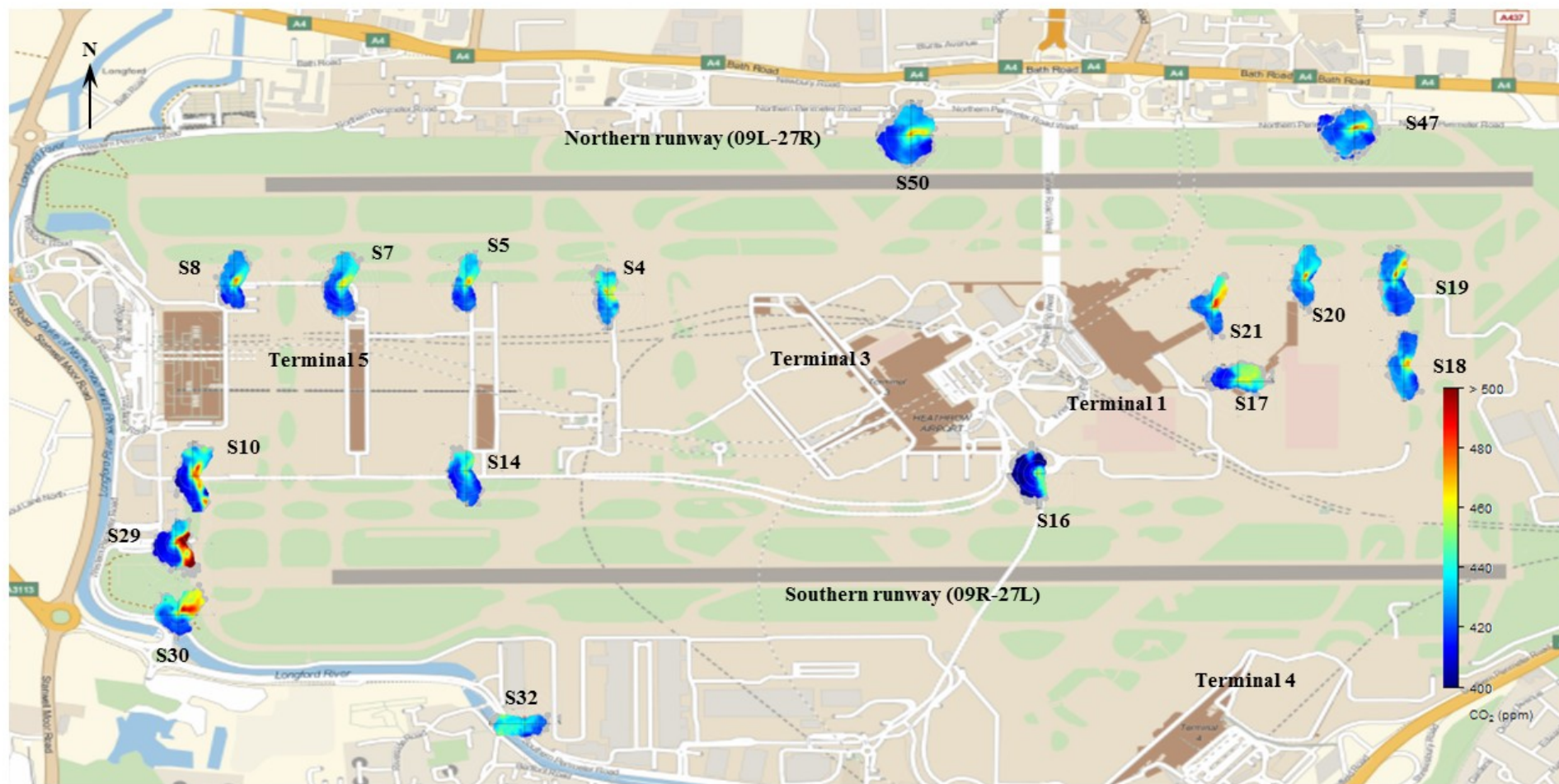
O_x



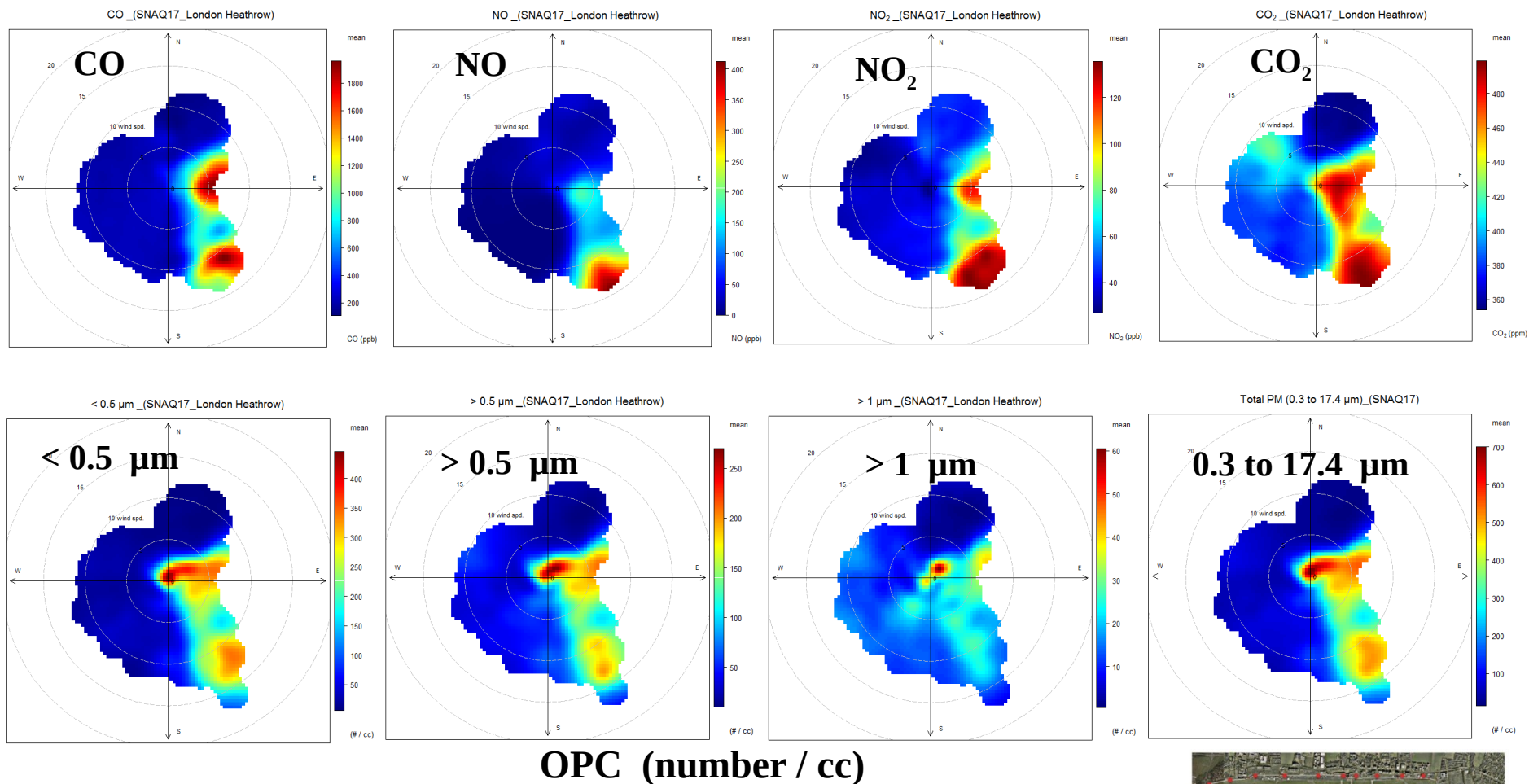
- Evidence of large scale emission.
- Individual aircraft emissions detected.
- Airport starts operations ~ 0600.



High spatial emission patterns at London Heathrow



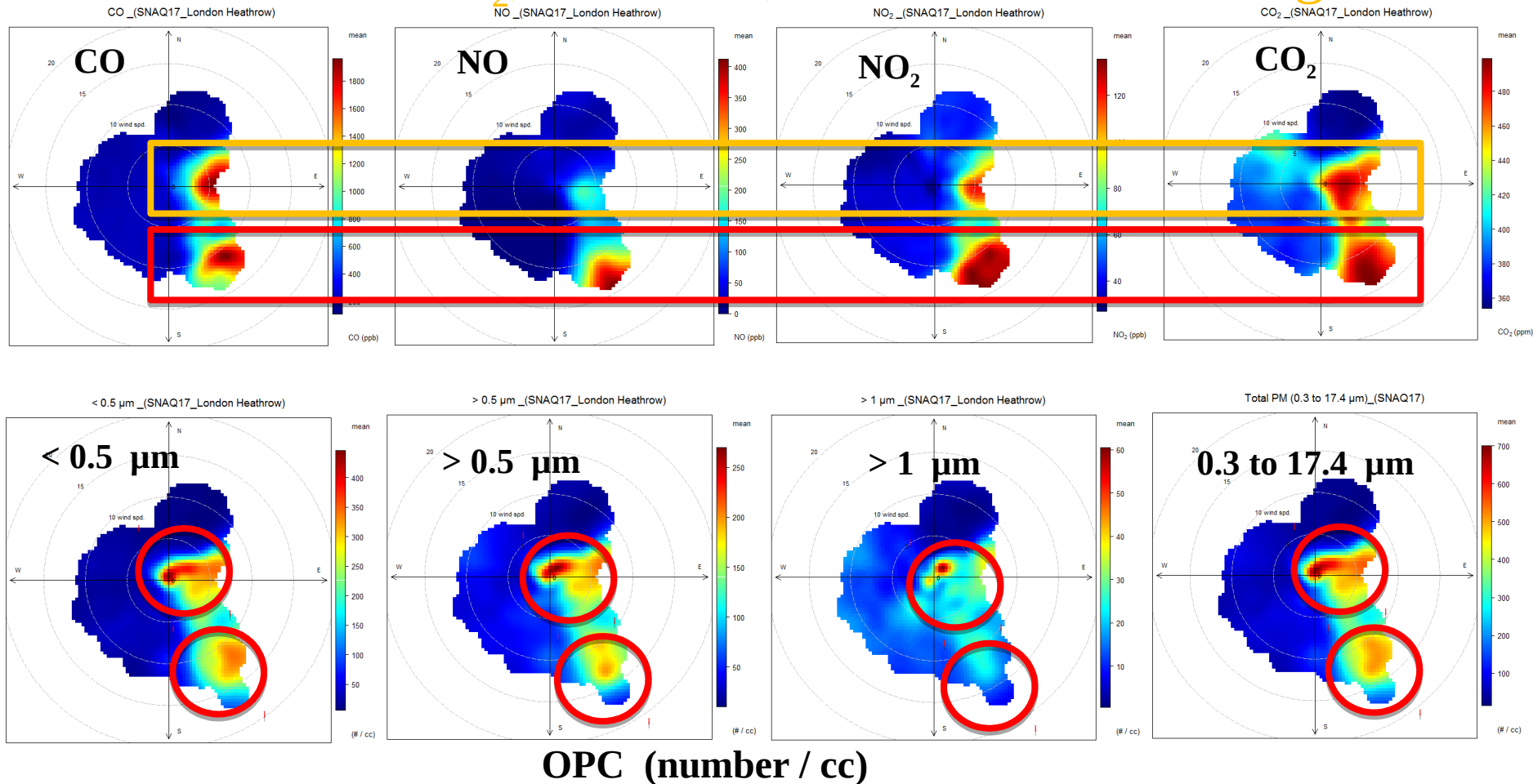
Source apportionment: **SNAQ17** at the west-end of southern runway (09R) , 1 month data



Direct determination of transport activities

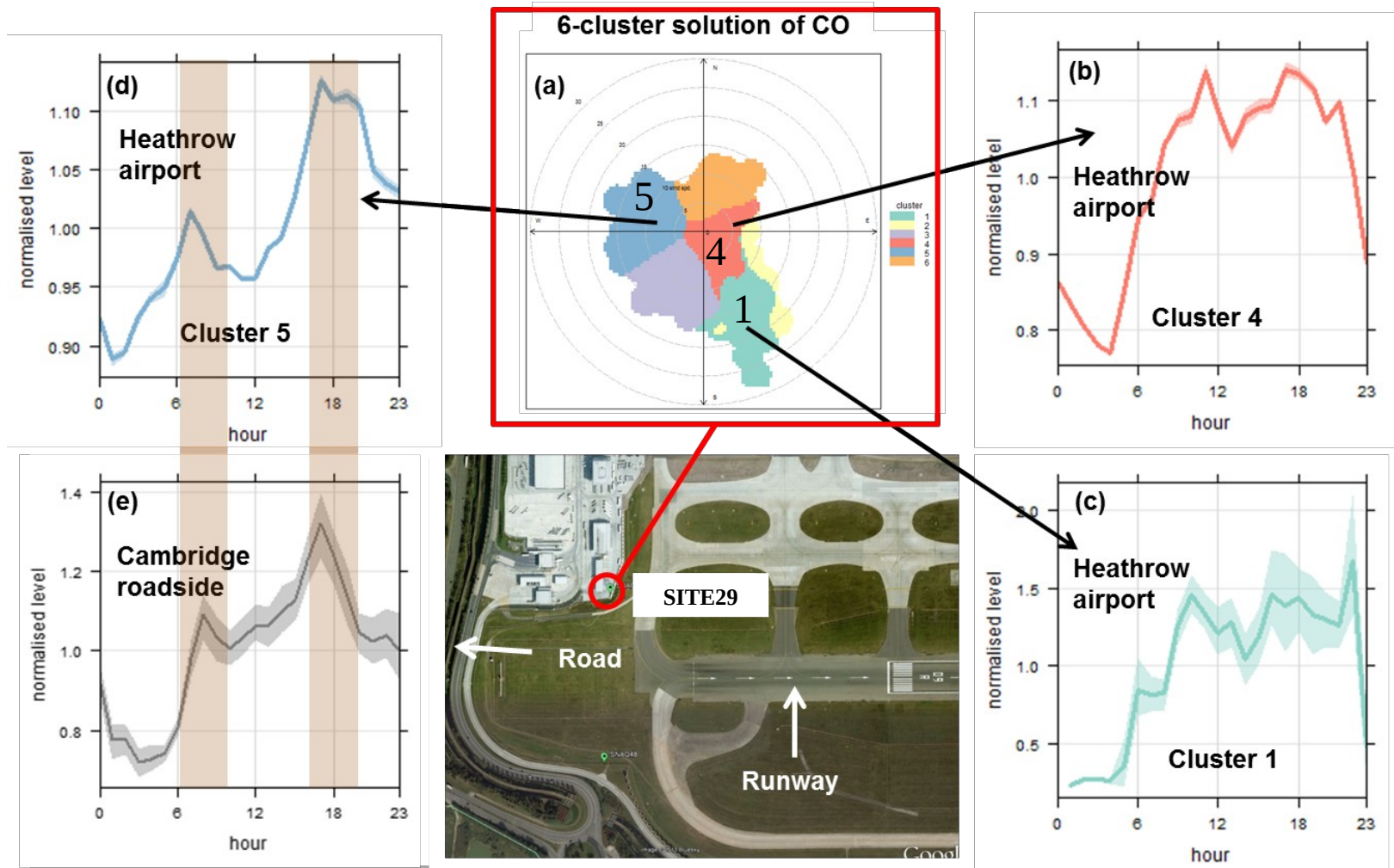
High CO₂, high NO_x, medium CO – take offs

Medium CO₂, low NO_x, medium CO – taxiing



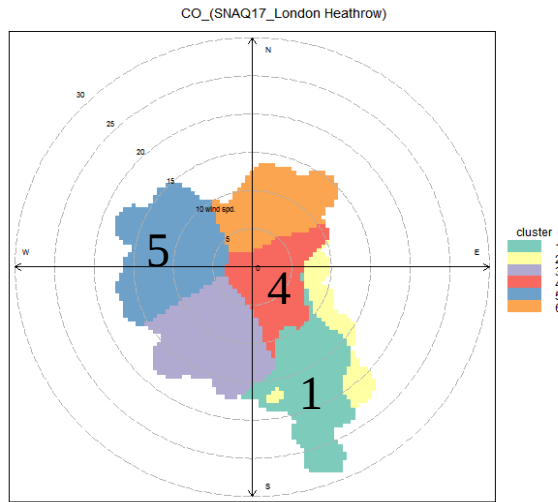
Also PM apportionment.....

Airside/roadside source apportionment: diurnal signatures



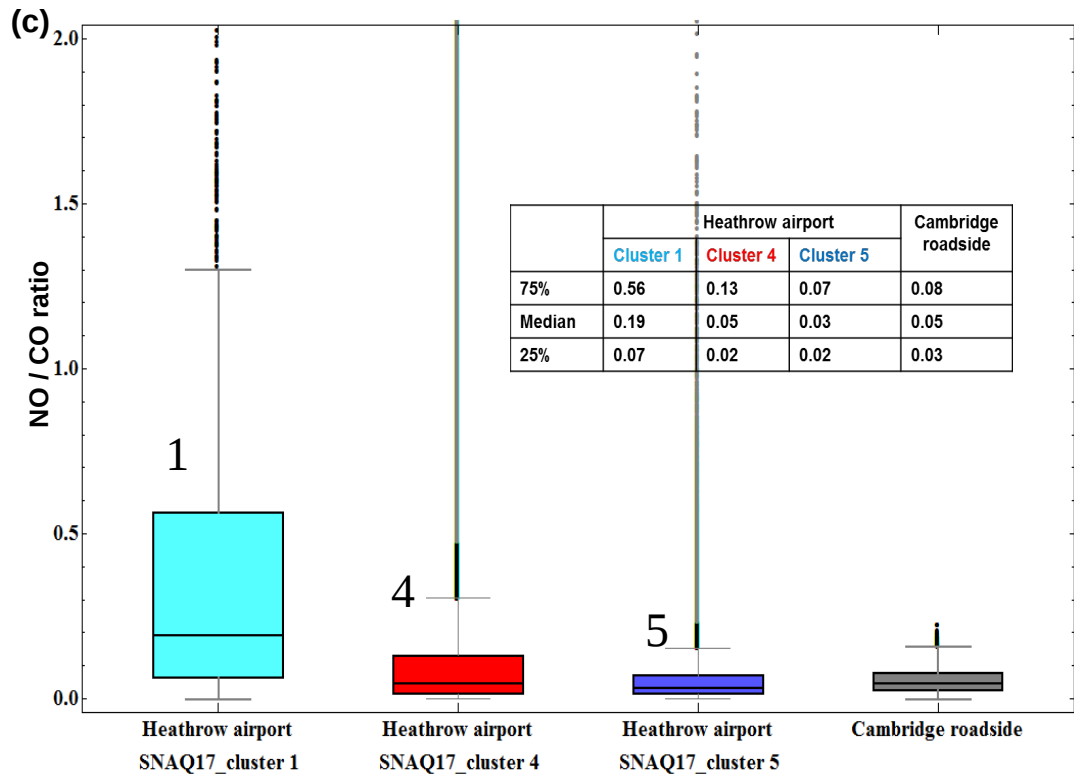
CO source apportion: aircraft
vs roadside sources...

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



Inferences from NO_x/CO ratios:

1. Take-off
4. Taxiway
5. Perimeter road traffic

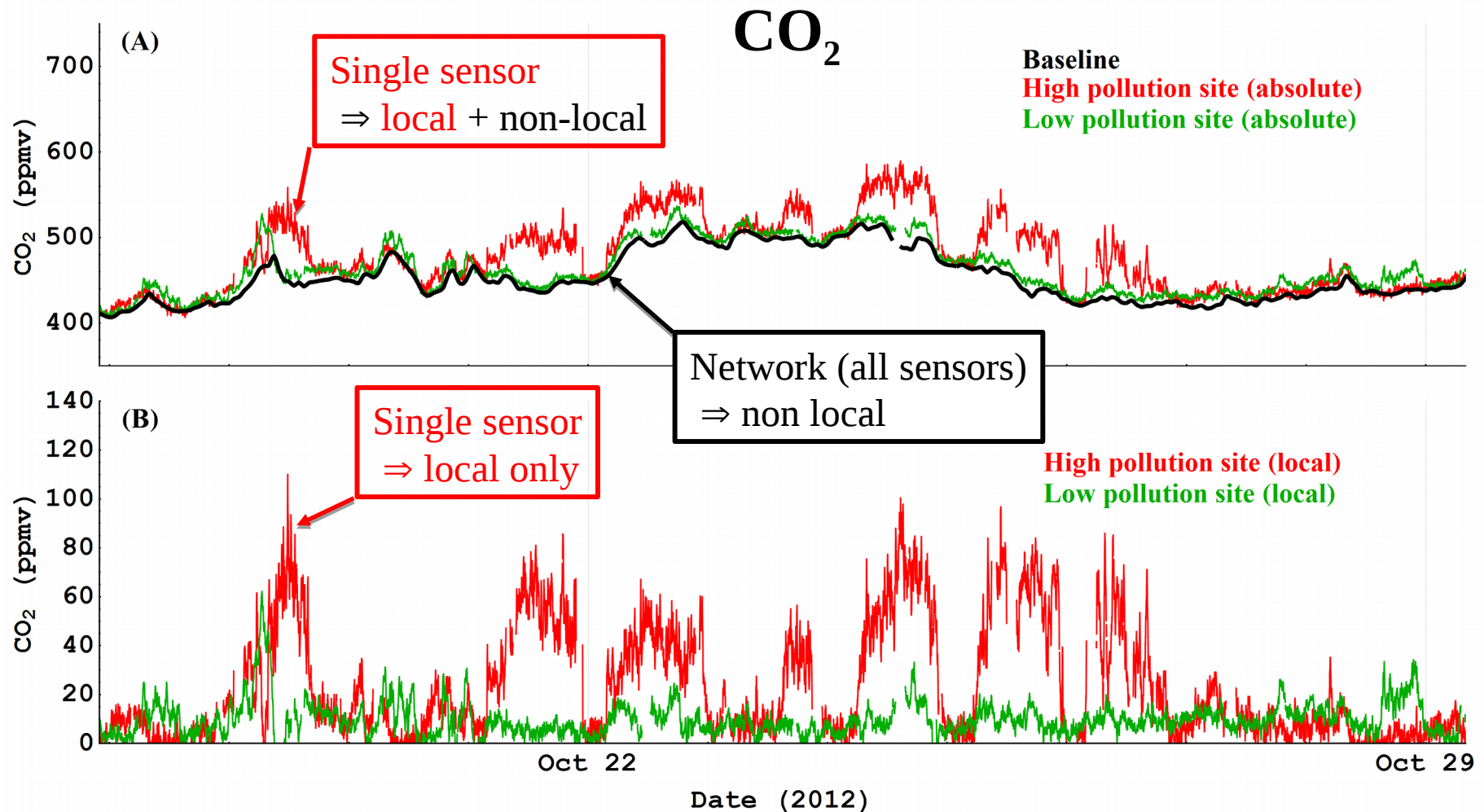


NO_x/CO ratios

Quantitative source attribution.....



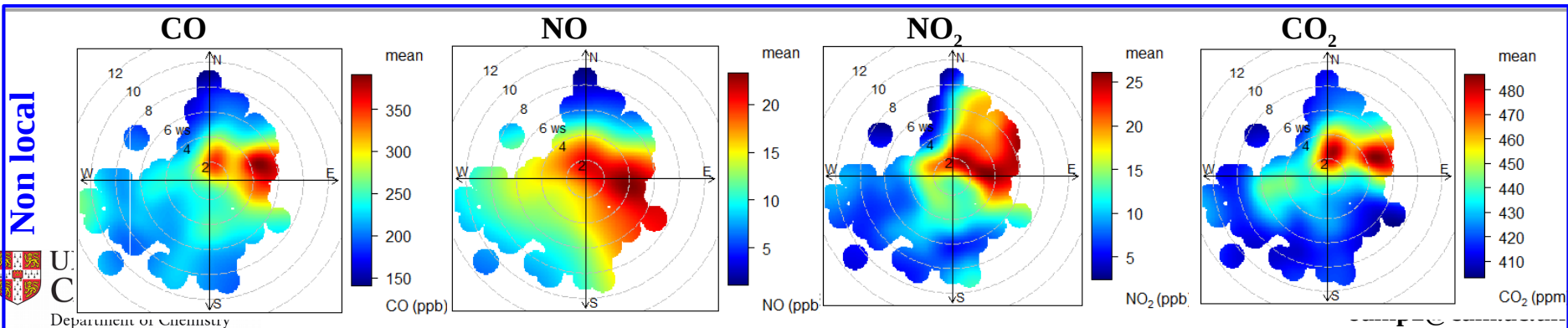
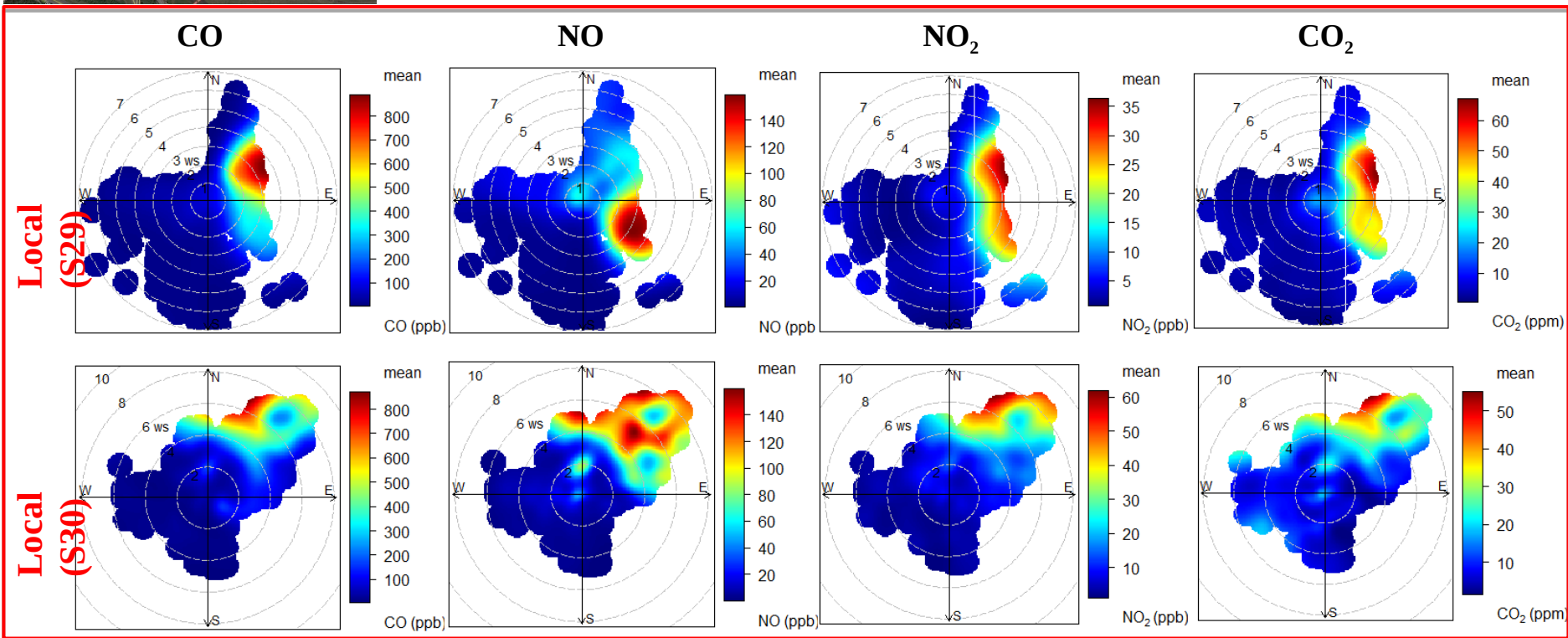
Use network to separate local and non-local sources ⇒ source location



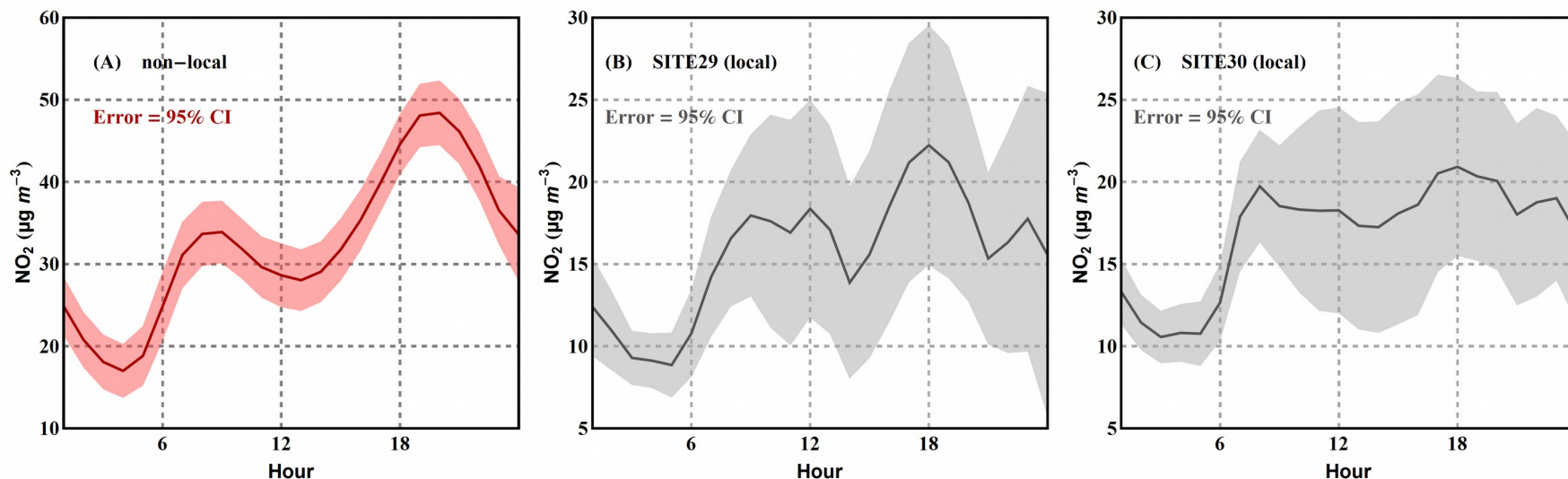
Now do it for other species.....



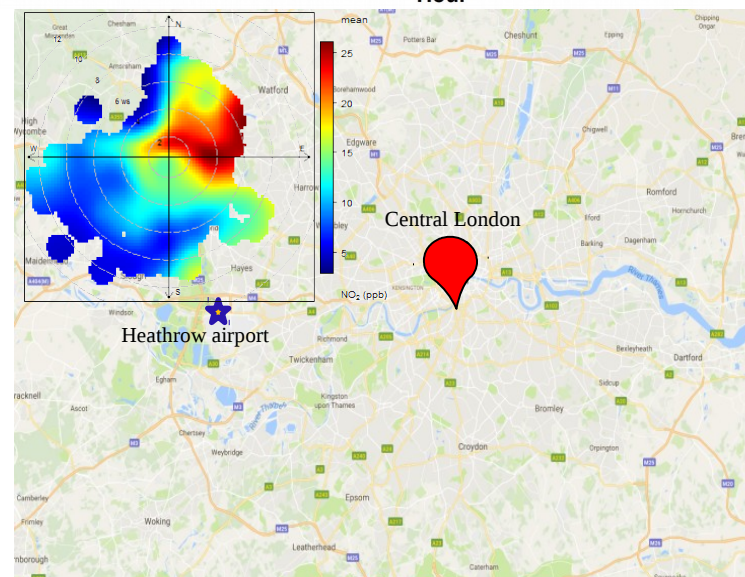
Source pattern (local vs non-local)



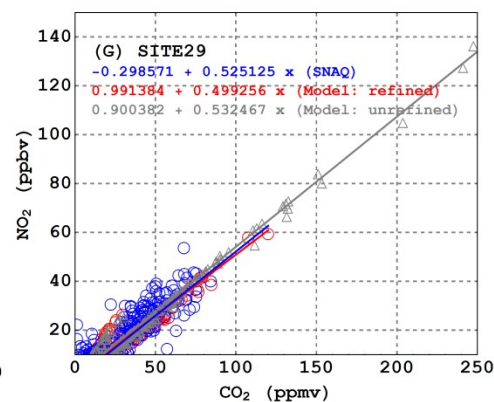
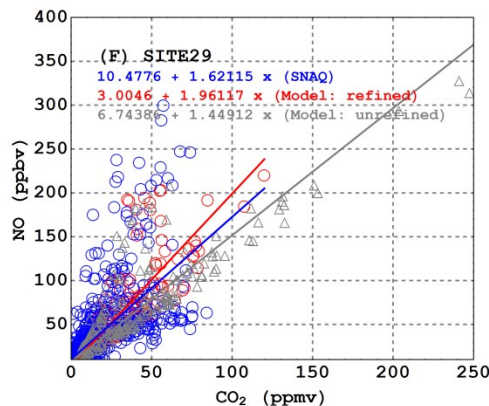
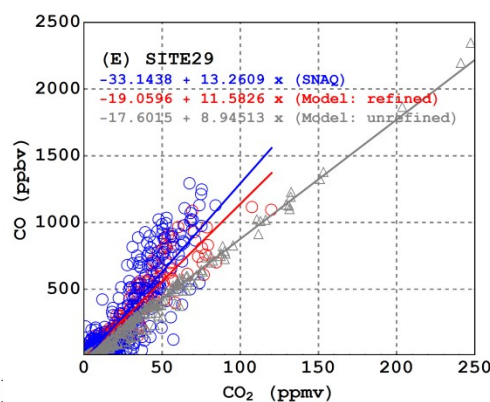
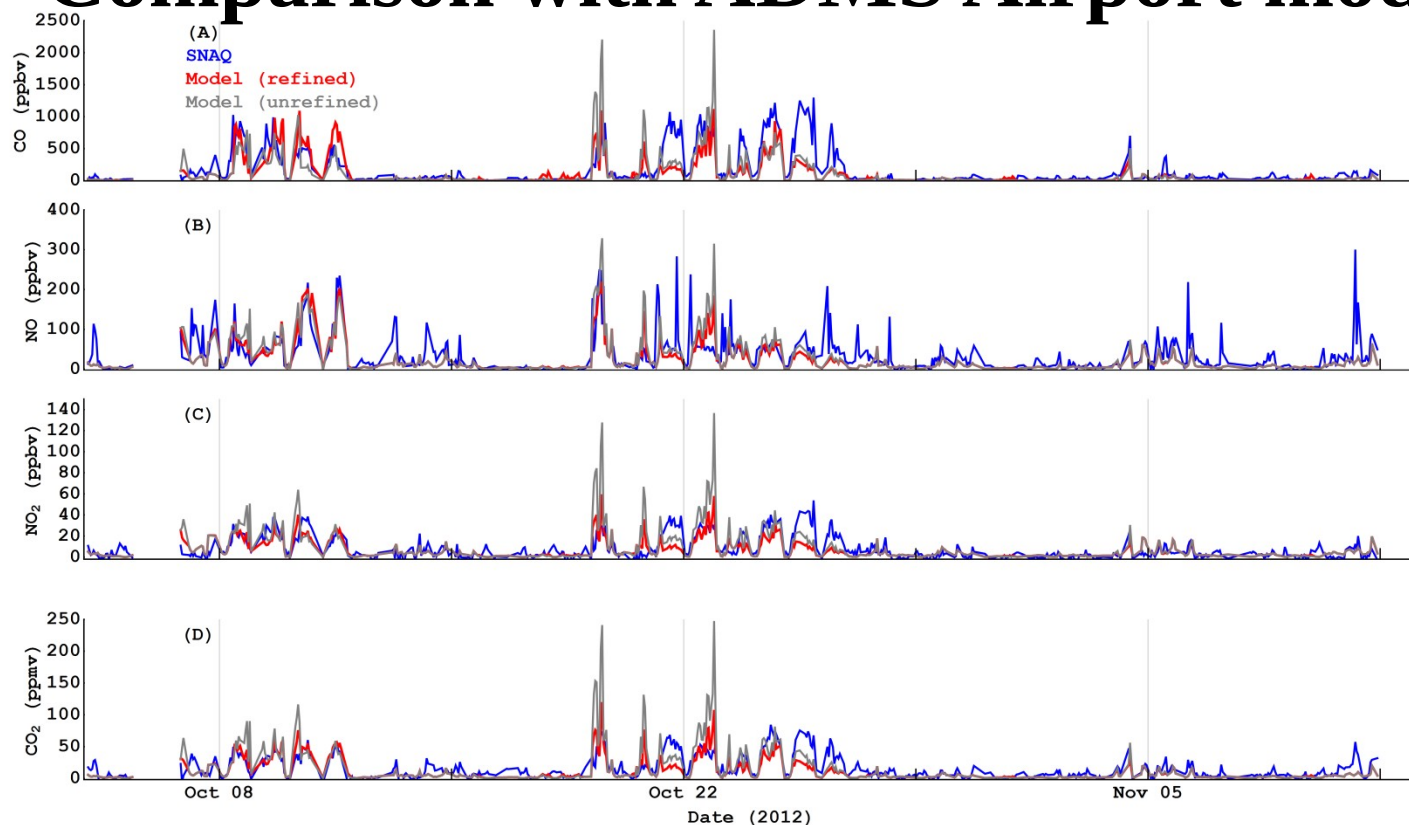
London Heathrow airport and London city emission (NO₂)



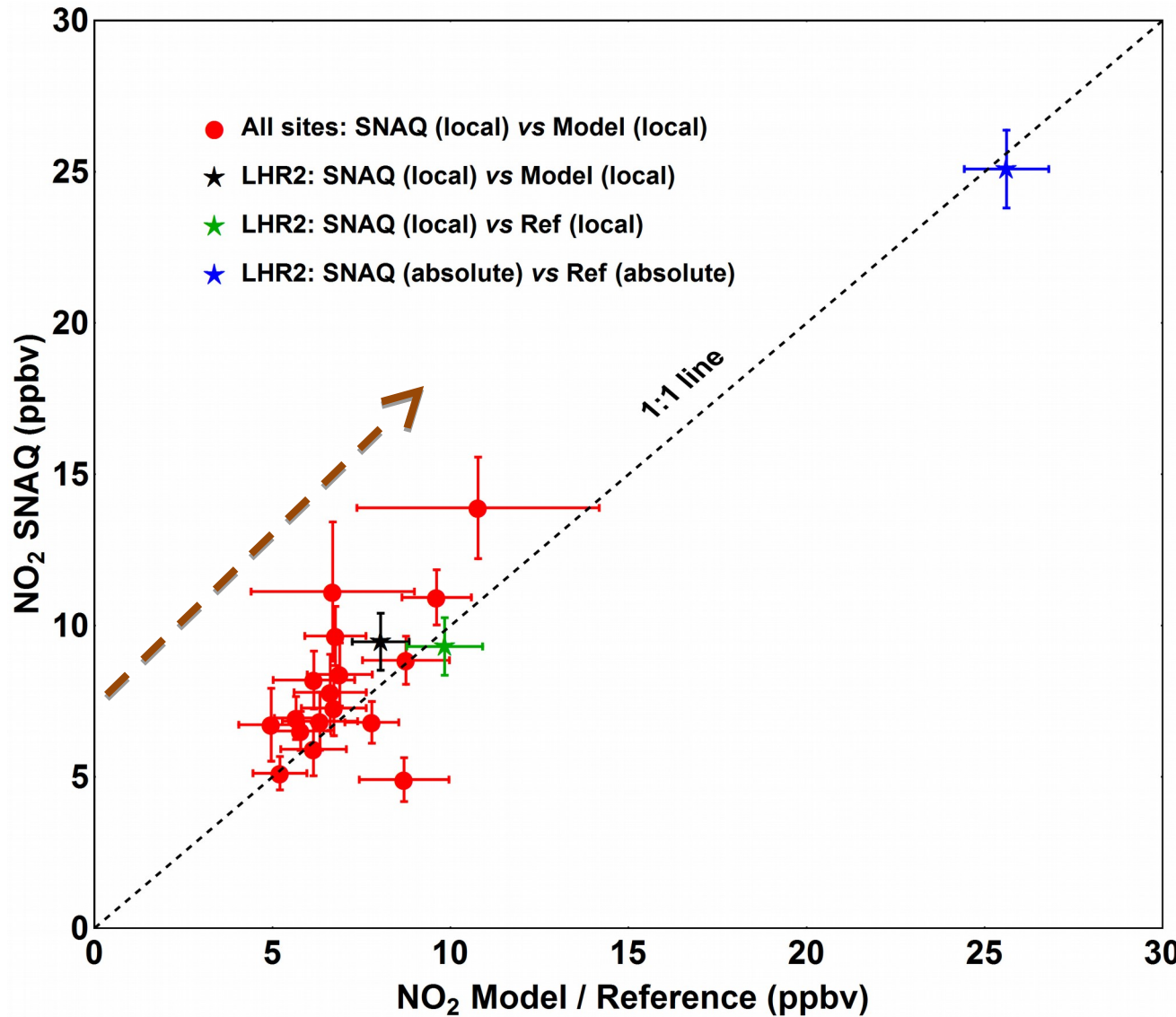
- Local diurnal pattern consistent with airport activities
- Non-local diurnal pattern indication of traffic emission (Central London)
~32 µg/m³ for the 5 week period shown



Comparison with ADMS Airport model



NO₂ network comparison: SNAQ, reference and ADMS model



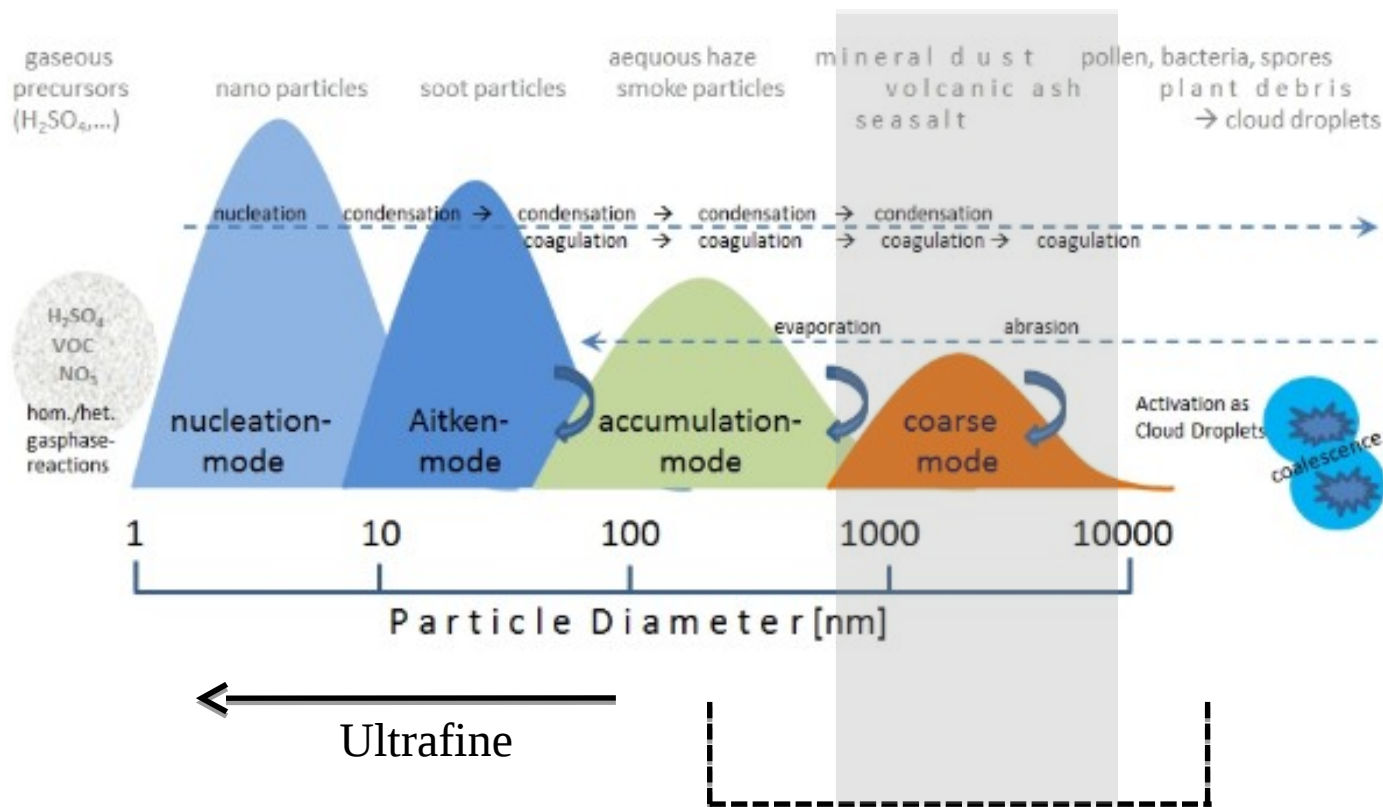
Model ~ captures observed spatial gradients
⇒ **local (spatially heterogeneous) sources**

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Low-cost particle sensors measurement range

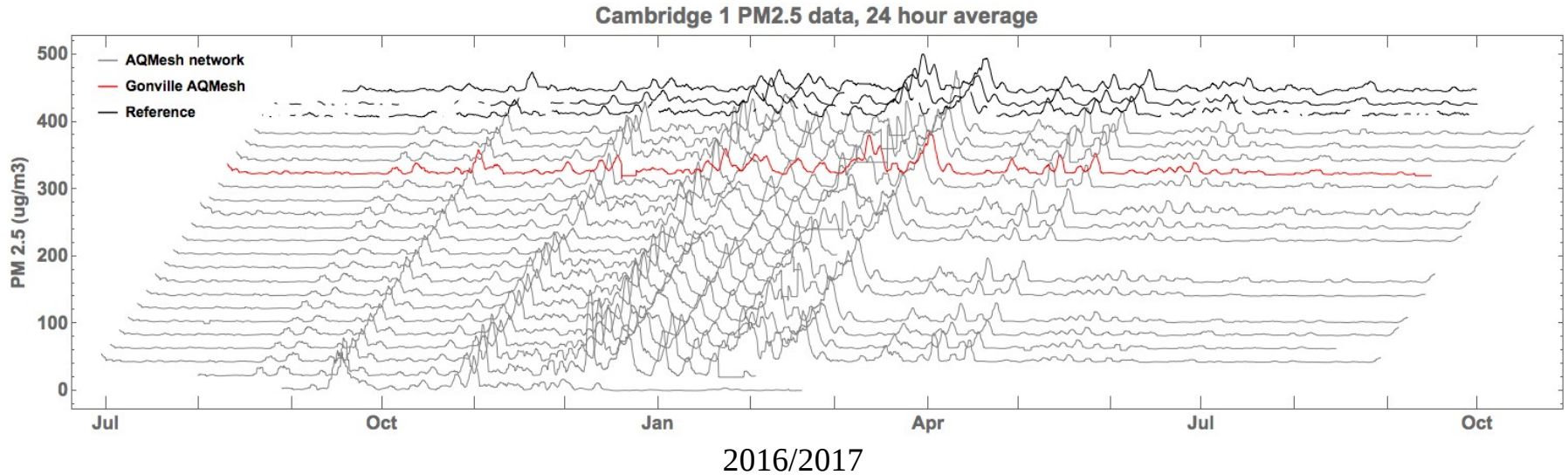
Ideal for dust measurements



Low cost OPC (0.38 – 17.4μ)

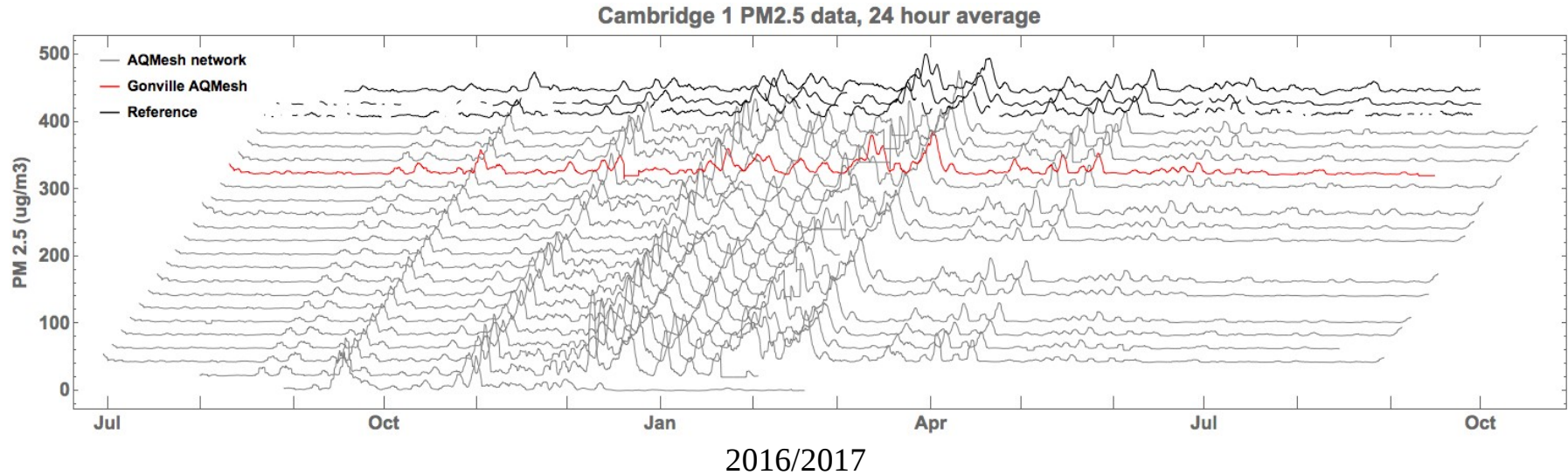
https://www.dwd.de/EN/research/observing_atmosphere/composition_atmosphere/aerosol/cont_nav/particle_size_distribution.html

Cambridge: PM_{2.5} – all sites: variability explained



- Variability **replicated at all sites** (reference, AQMesh)
- PM_{2.5} dominated by **non-local** sources
- (NO&NO₂ not shown dominated by **local** sources)

Cambridge: PM_{2.5} – all sites: variability explained



- Variability **replicated at all sites** (reference, AQMesh)
- PM_{2.5} dominated by **non-local** sources
- (NO&NO₂ not shown dominated by **local** sources)

⇒ NO_x: local intervention **will work**

⇒ PM: local intervention **will not work** ☹️

Mobile measurements Breathe London Project

(conventional methods)



Also note ~ constant $\text{PM}_{2.5}$ 'background'



Areas highlighted show ΔCO_2 , ΔNO_2 , ultrafine etc, but little $\Delta\text{PM}_{2.5}$



Conclusions

- Low cost sensors/sensor networks viable for A/Q monitoring – gases, PM.
- Current low cost PM sensors can't detect ultrafine particles
(technology needs to improve)
- Scale separation and source attribution (gas, PM).
implications for interventions?
- Surface network allows *direct measurement* of emission indices for different sources.
- Provide information on the physical and chemical processes driving the atmosphere.....
- The wider society (scientist, policy makers and citizens)

Thank you for your attention

Acknowledgements

CERC..... David Carruthers, Chetan Lad

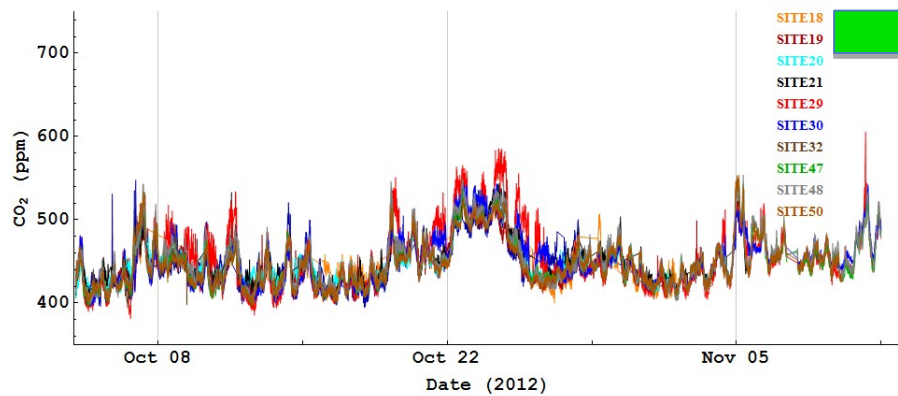
Alphasense..... John Saffell, Ronan Baron, Mark Giles

Small sensors group Iq Mead, Anika Krause,
Andrea Di Antonio, Geoff Ma, Lia Chatzidiakou, Ray Freshwater

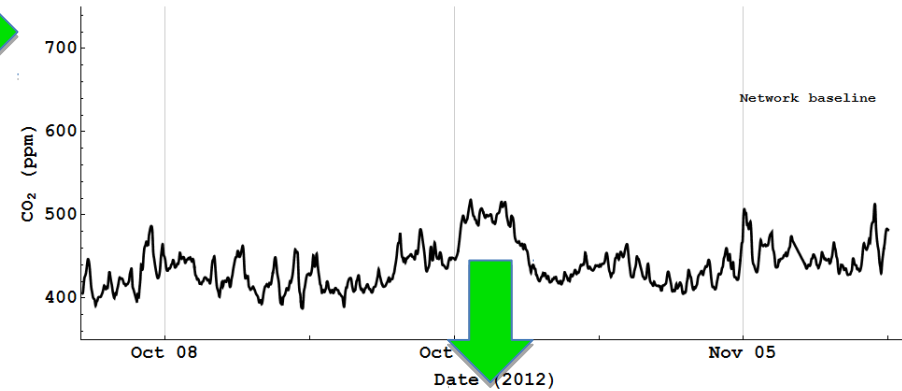
Supplementary slides

London Heathrow Airport Deployment exploiting sensor network: scale separation *local and non-local/baseline estimation*

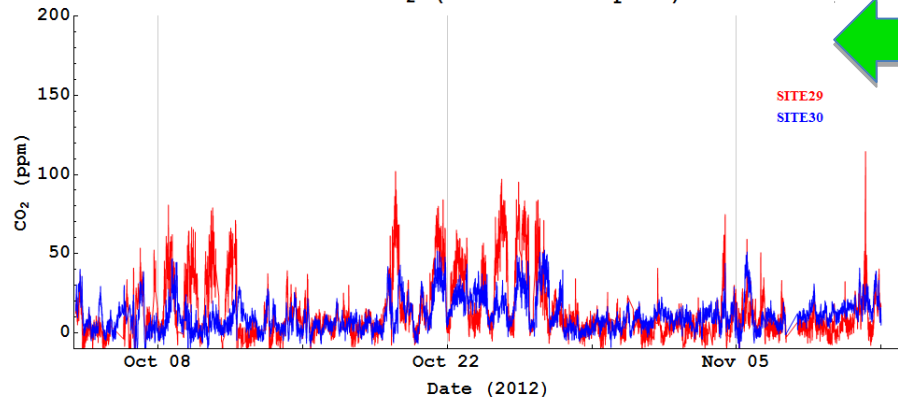
Absolute CO₂ ensemble (Heathrow airport)



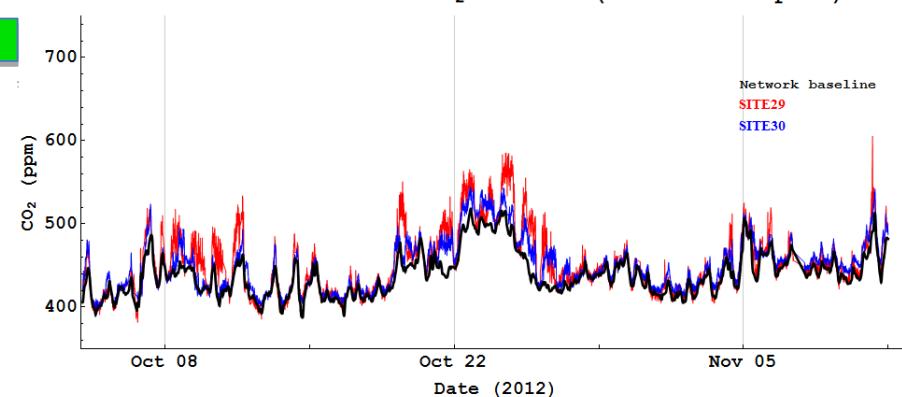
Baseline CO₂ (Heathrow airport)



Local CO₂ (Heathrow airport)



Baseline & absolute CO₂ ensemble (Heathrow airport)



RH correction of PM data for low-cost sensors

