Using a commercial low cost sensor network (AQMesh) to quantify urban air quality: comparing measured and modelled (ADMS-urban) pollutant concentrations

D. Carruthers[1], D. Clarke[2], K. J. Dicks[3], R. A. Freshwater[4], M. Jackson[1], R. L. Jones[4], C. Lad[1], I. Leslie[5], A. J. Lewis[3], H. Lloyd[4], O. A. M. Popoola[4], A. Randle[6], S. Ulrich[4]

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Talk outline

- AQMesh

- Premise of inter-comparison

- Pre-deployment inter-comparison

- Comparison with reference instruments

- Comparison with ADMS model

- Snapshot (v. superficial)

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Premise of inter-comparison:

- Test of 'out of box' AQMesh performance

- No local calibration/re-scaling

- No pan-network analysis (individual sensors)

- NO, NO_2, $PM_{2.5}$, PM_{10} only (reference instruments)

Sensor Calibration

Gas sensors

Comparison between Alphasense electrochemical sensors and local (to AQMesh) reference instrumentation to determine sensor specific calibration parameters.
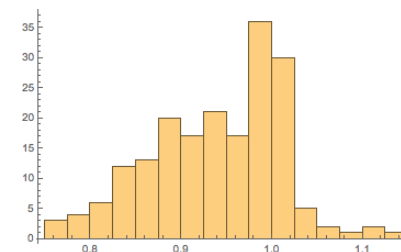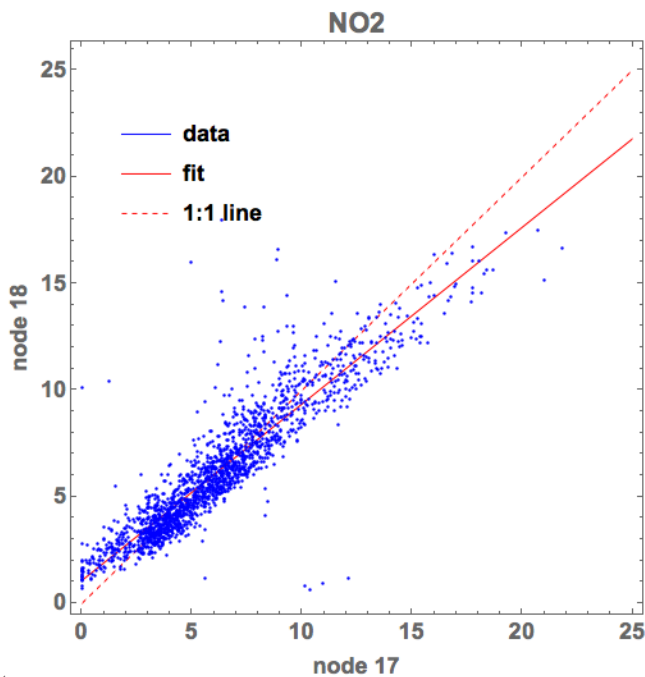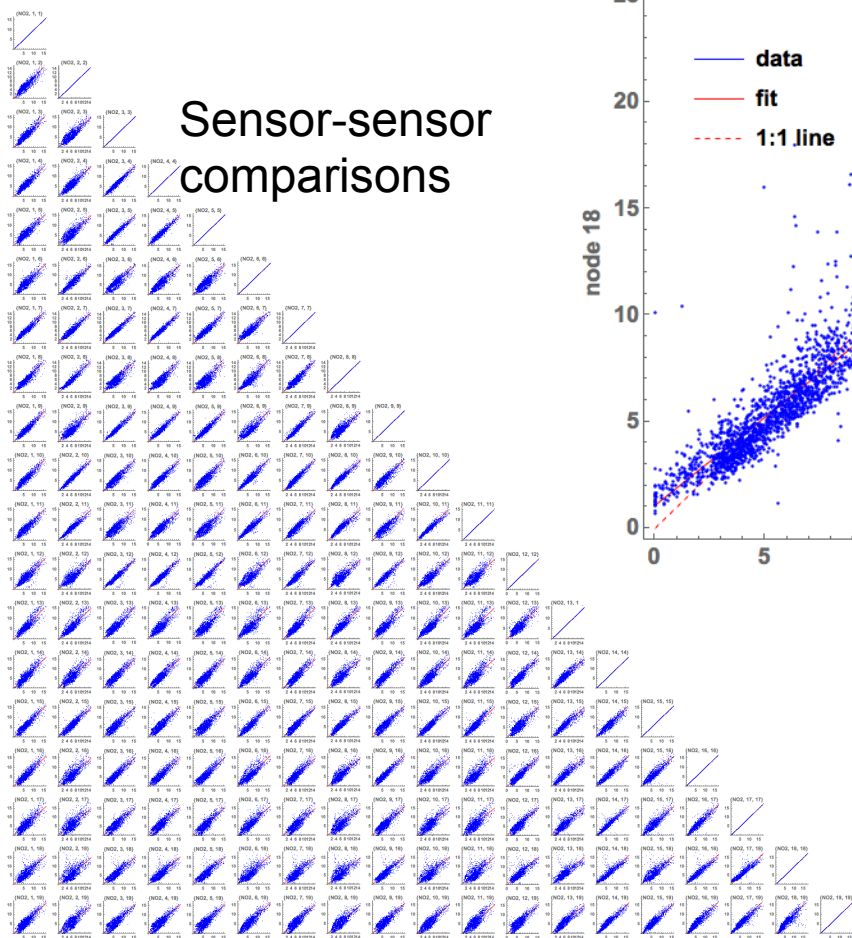
Particle sensor

OPCs co-located with a "gold standard pod" at the AQMesh outdoor test facility to provide consistent calibration parameters.

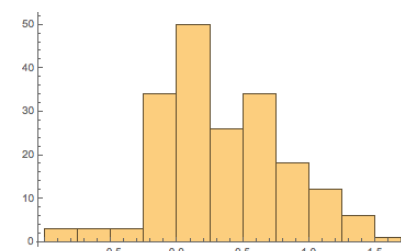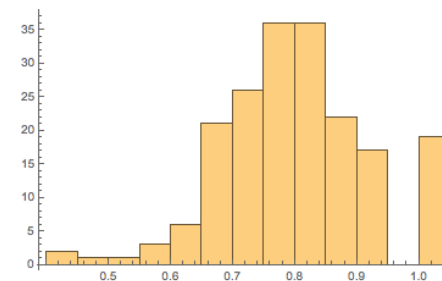CO, NO, NO_2, O_3, SO_2, PM_1, $PM_{2.5}$ and PM_{10}

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Cross network NO₂ performance (pre-deployment)

Sensor-sensor comparisons

Gradients = 0.94 ± 0.07

Intercepts = 0.34 ± 0.47ppb

R^2 = 0.8 ± 0.11

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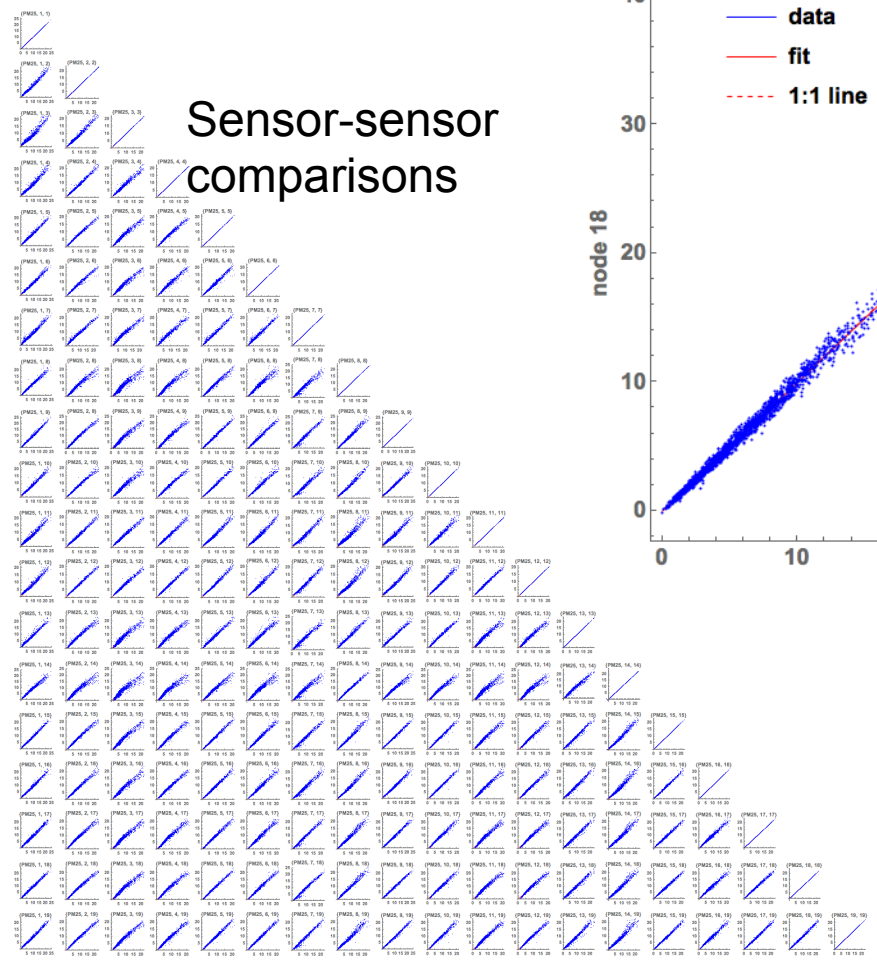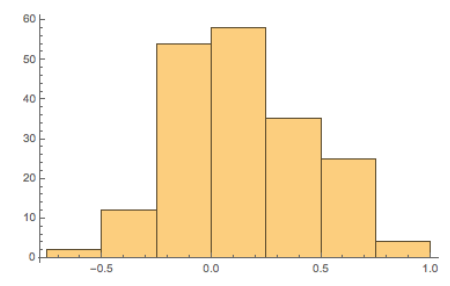
Cross network PM$_{2.5}$ performance (pre-deployment)

Sensor-sensor comparisons

PM25
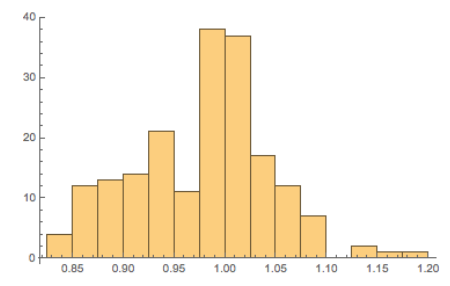
Gradients = 0.98 ± 0.07

Intercept=0.13 ± 0.3ug/m3

R^2 = 0.98 ± 0.17

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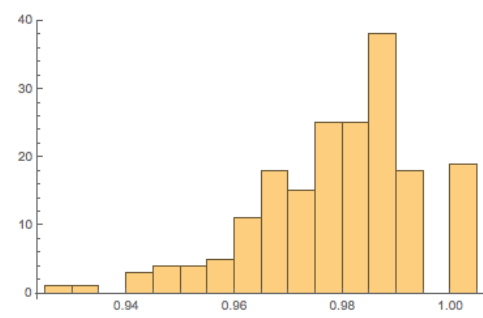
Pre-deployment co-location comparison statistics

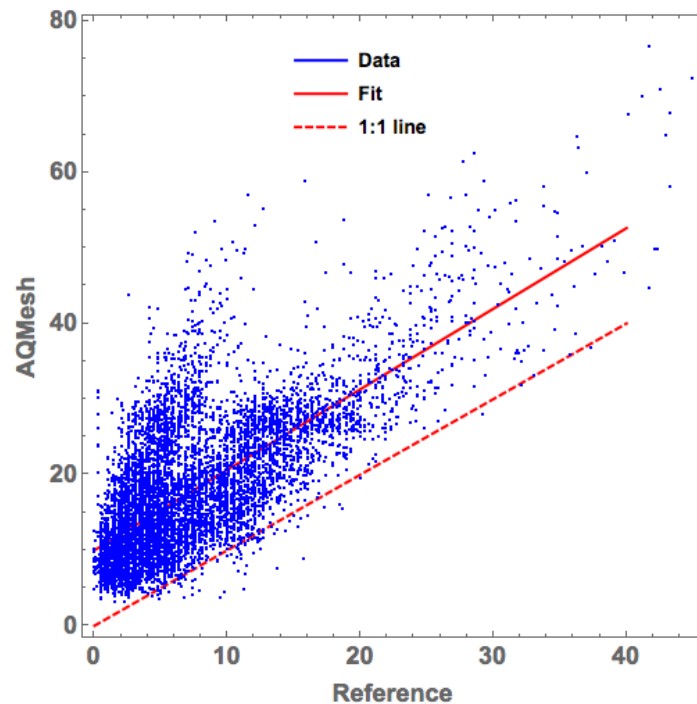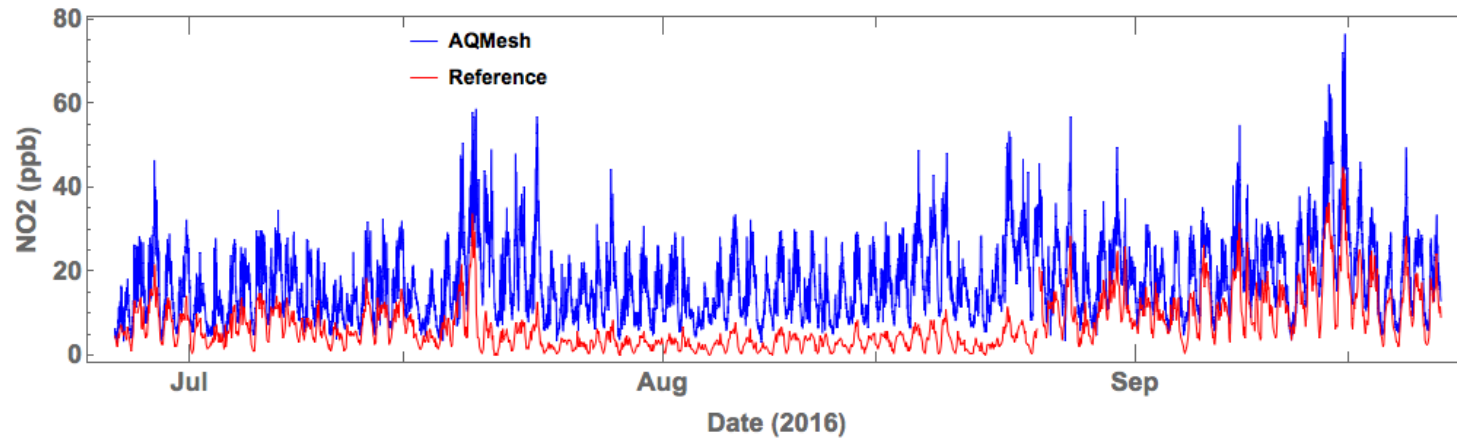|	Gradient	Intercept	R^2	Average (min-max)
NO_2	0.94±0.07	0.34±0.47	0.8±0.11	6.2 (0-22.3)
NO	-	*Comparable performance*		-
CO	0.91±0.12	54.7±76.7	0.89±0.13	606 (390-8300*)
O_3	0.88±0.16	4.16±6.2	0.74±0.18	32.9 (0.13 – 227**)
SO_2	0.88±0.37	0.13±0.37	0.93±0.08	0.48 (0 - 60*)
PM_1	0.98±0.46	0.03±0.046	0.97±0.03	1.64 (0 – 8.4)
$PM_{2.5}$	0.98±0.07	0.13±0.03	0.98±0.02	7.02 (0 – 52)
PM_{10}	0.96±0.03	0.50±082	0.95±0.03	12.6 (0 – 104)

** single event
* single measurement

Excellent sensor-sensor performance (only part of the issue)

Cambridge deployment (20 nodes)

Northwest Cambridge
(building development)

Reference site
(Gonville Place)

Central Cambridge
(high traffic density)

South Cambridge
(biomedical campus
development)

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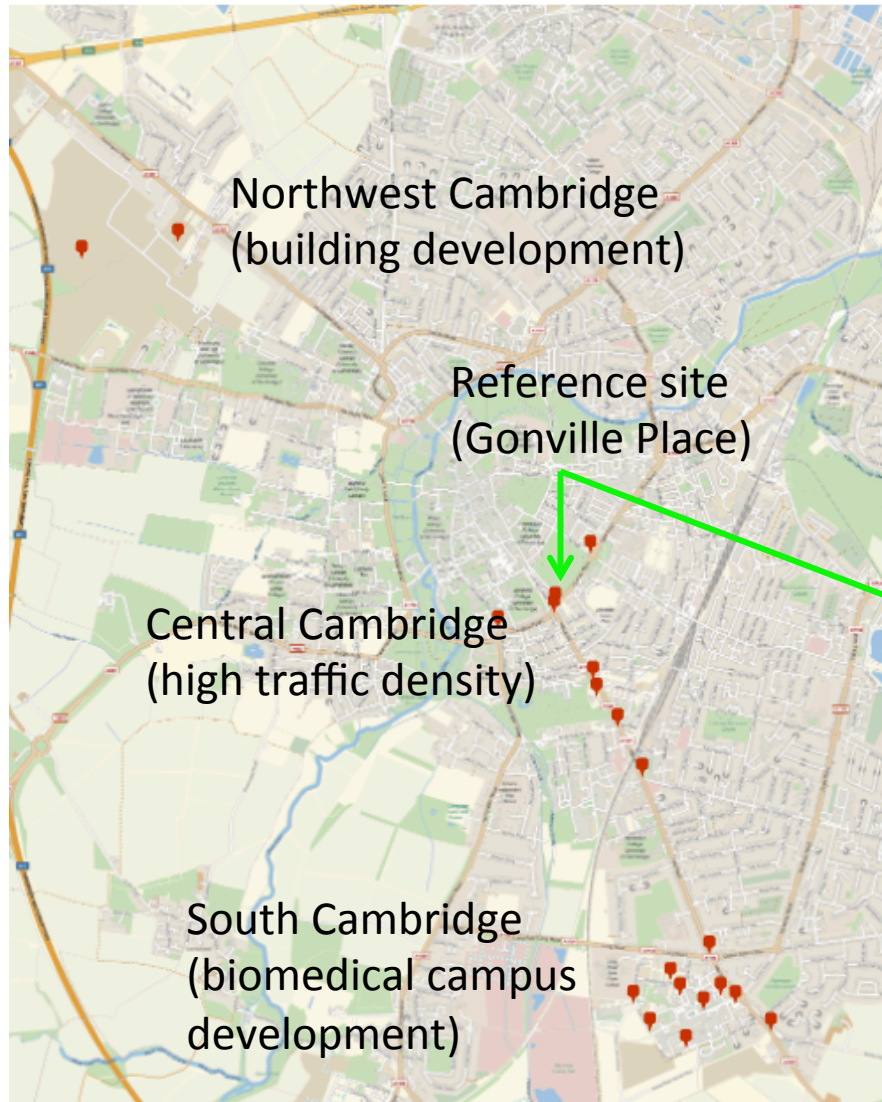
NO$_2$ Gonville Place comparison (pre-ratified)

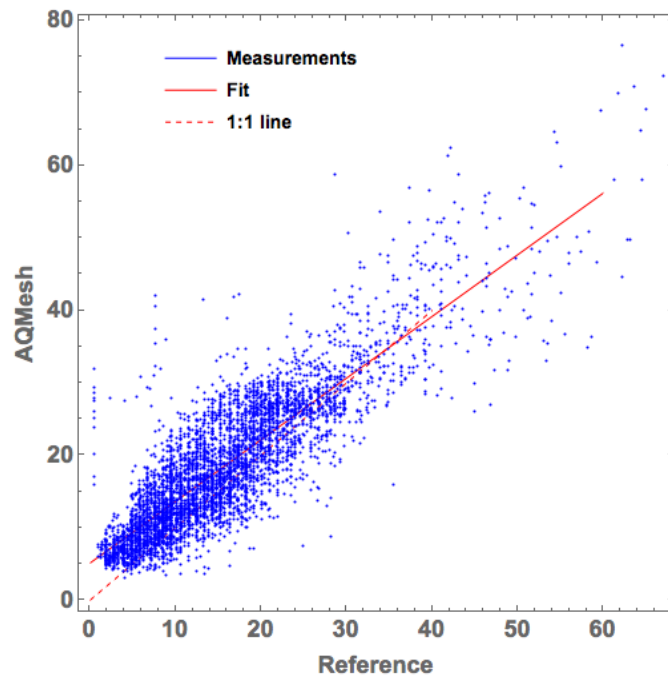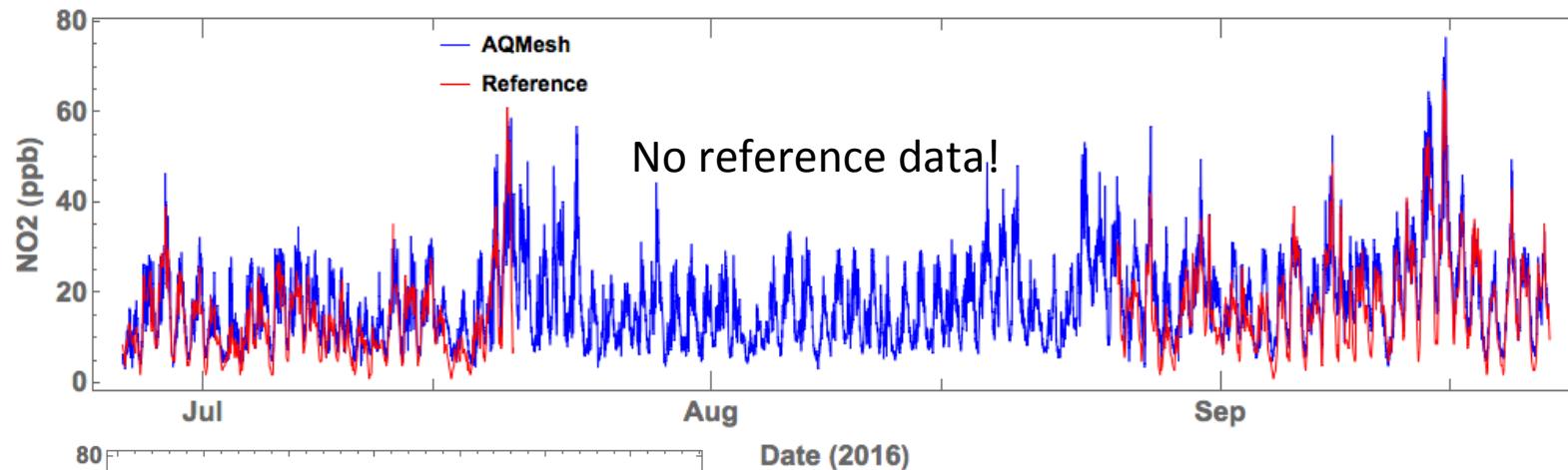| Gradient	Intercept	R^2
1.07 (0.01)	10.0 (0.1)	0.50

- Similar features (diurnal signatures) in both
- AQMesh significantly higher in absolute amounts than reference (not consistently)

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NO$_2$ Gonville Place comparison (pre-ratified)

Gradient	Intercept	R^2
1.45 (0.02)	4.5 (0.2)	0.64
3.23 (0.04)	6.1 (0.16)	0.64
1.29 (0.014)	4.9 (0.19)	0.78
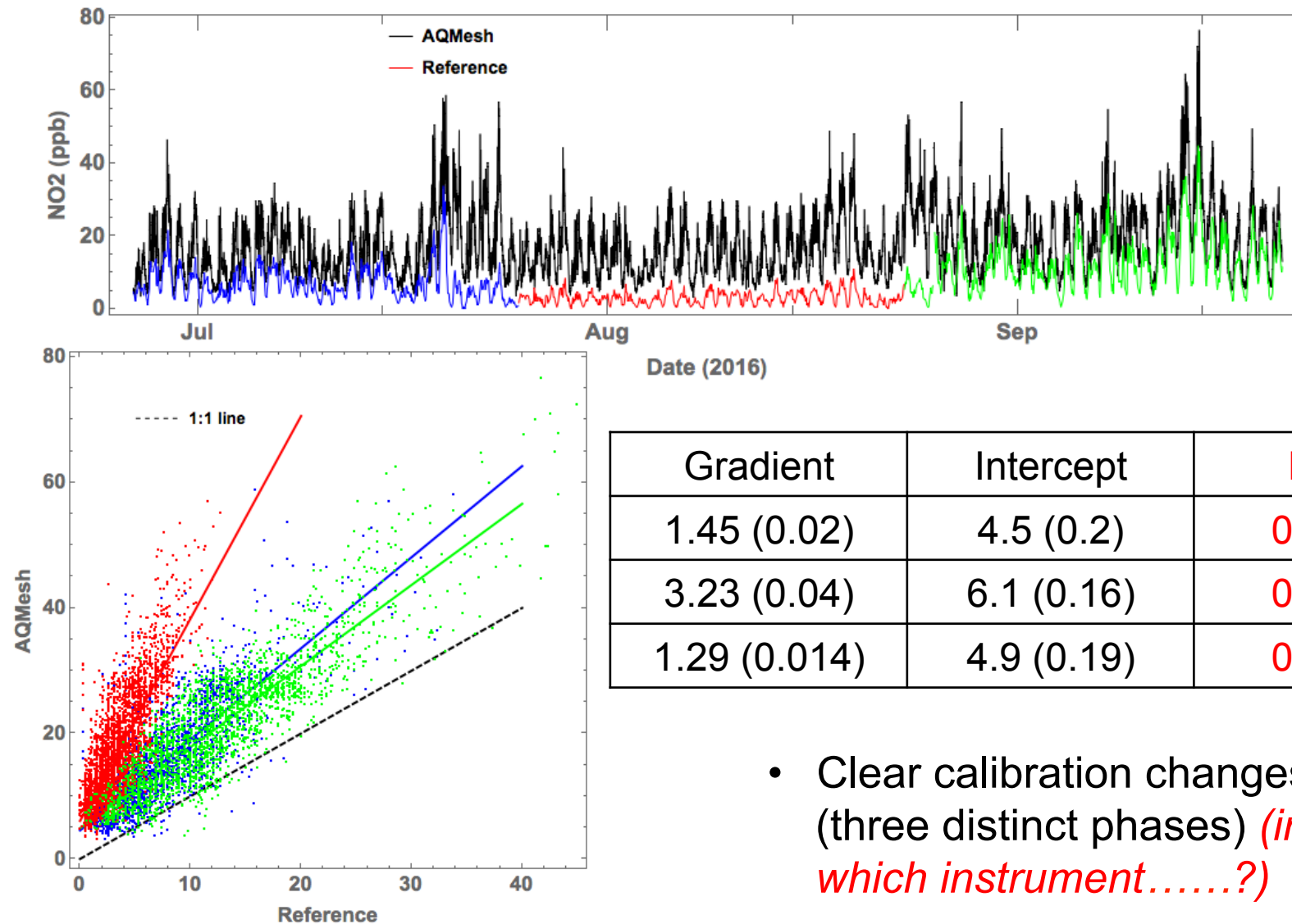
- Clear calibration changes (three distinct phases) *(in which instrument……?)*

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NO$_2$ Gonville Place comparison (ratified)

	Gradient	Intercept	R^2
pre	1.07 (0.01)	10.0 (0.1)	0.50
post	0.82 (0.01)	5.1 (0.13)	0.74

- Outliers removed (from reference)
- Significantly improved R^2
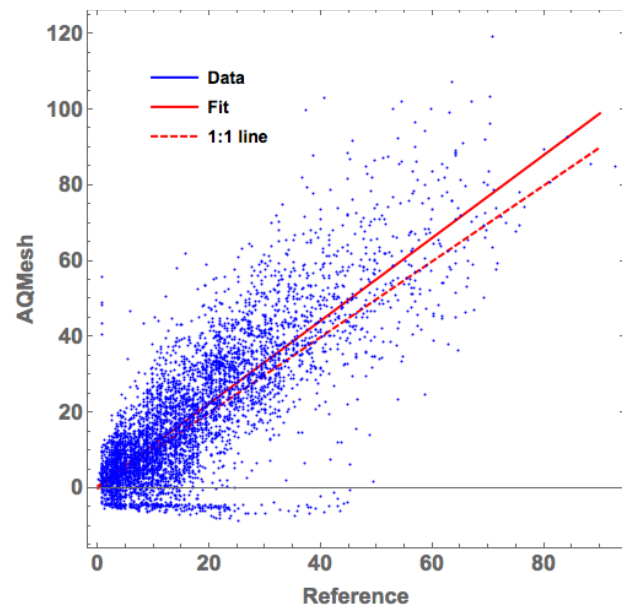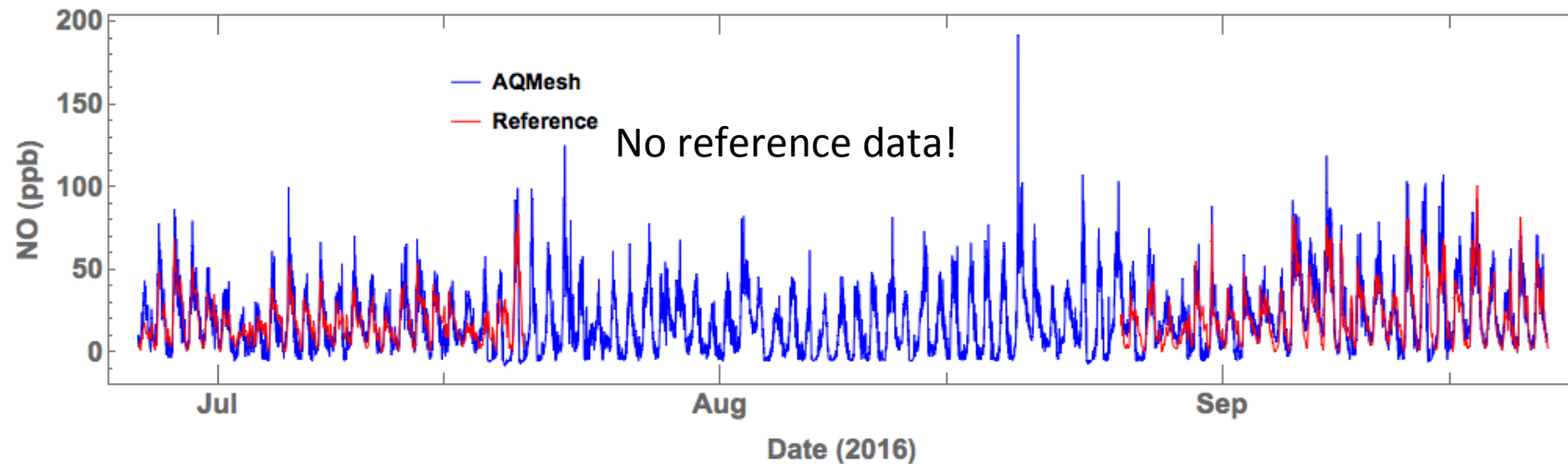- AQMesh ~ 0.82 of reference (unscaled)

NO Gonville Place comparison (pre-ratified)
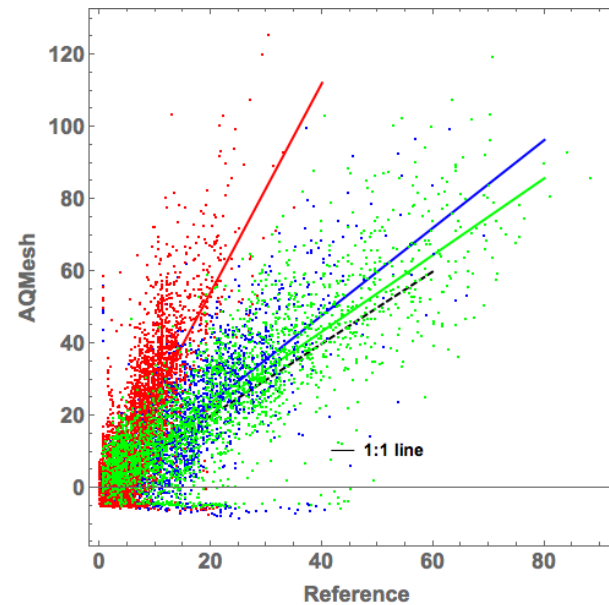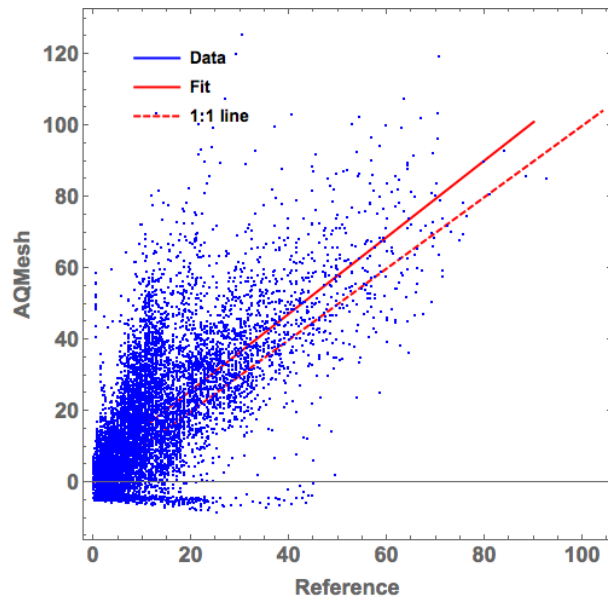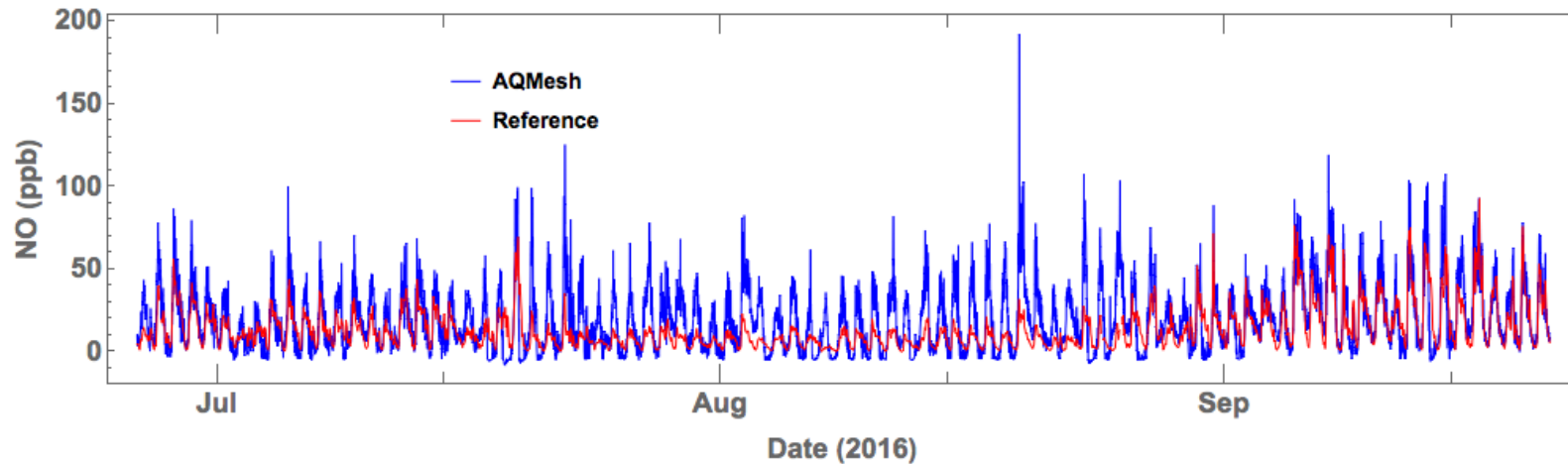
Same story…
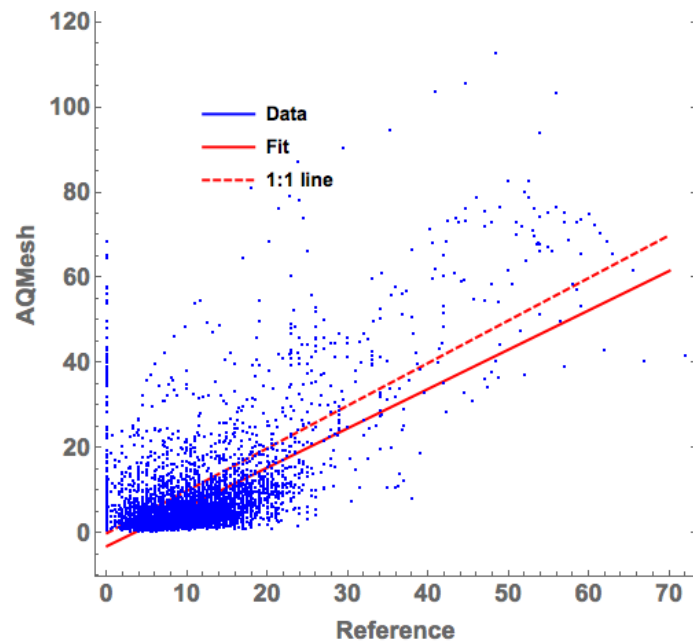- Diurnal pattern
- AQMesh high
- Not consistent

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NO Gonville Place comparison (ratified)

No reference data!

	Gradient	Intercept	R^2
pre	1.07 (0.01)	4.4 (0.21)	0.49
post	1.09 (0.01)	0.63 (0.27)	0.65

- Reference data removed
- Improved R^2
- Gradient ~ unchanged
- Some -ve AQMesh values
- Some AQMesh outliers

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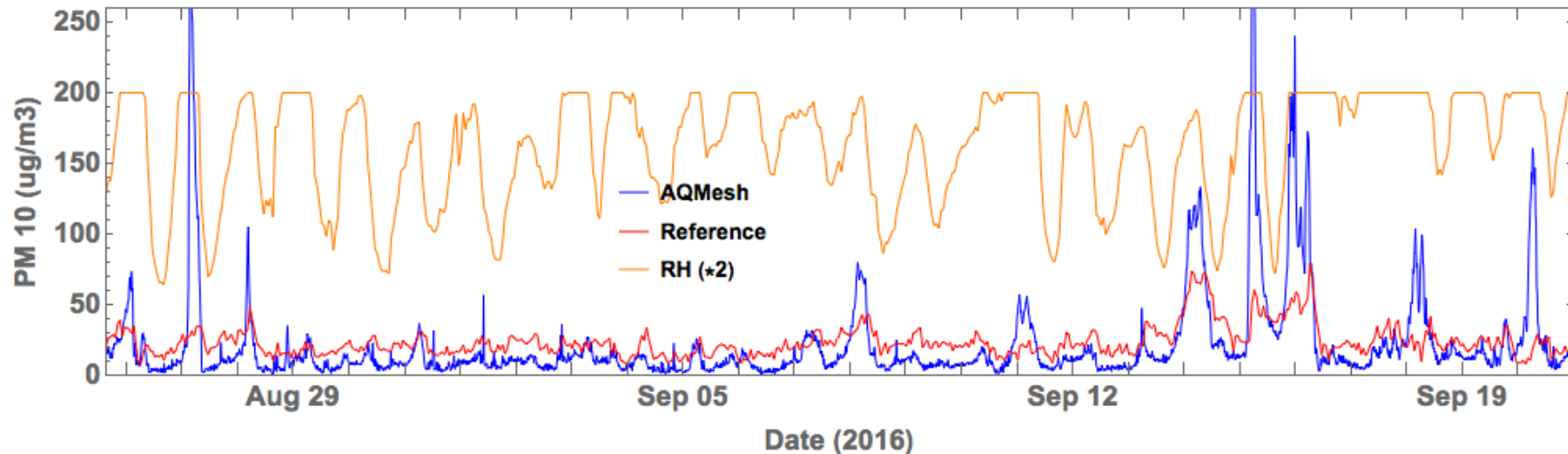# PM$_{2.5}$ Gonville Place comparison (ratified)
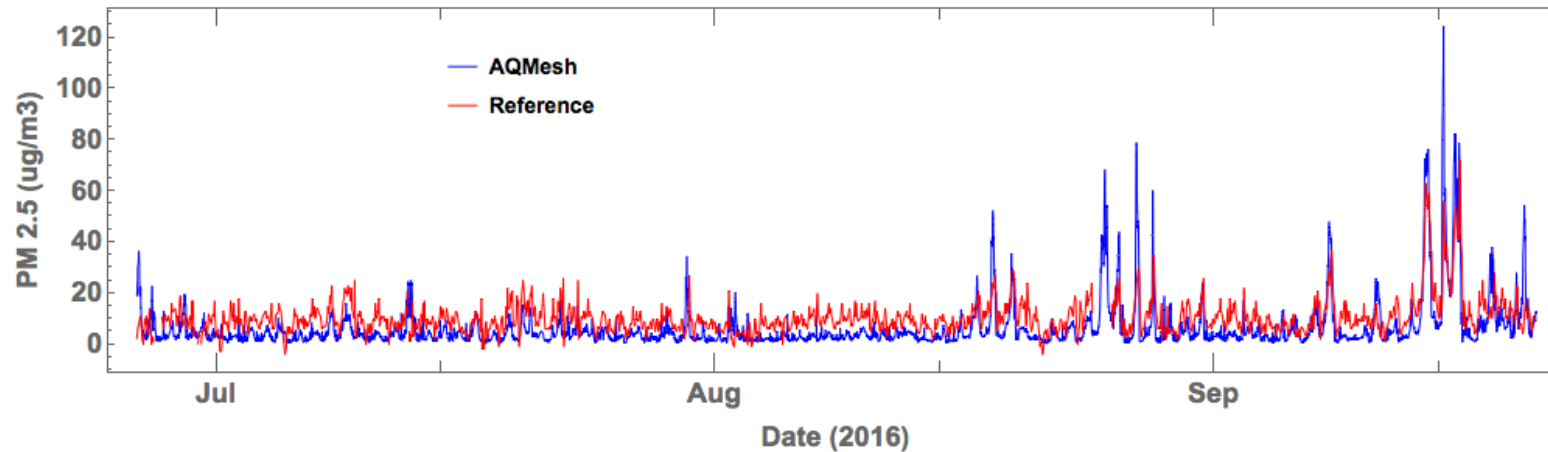
- Little difference on ratification
- PM events captured, magnitudes somewhat overestimated by AQMesh
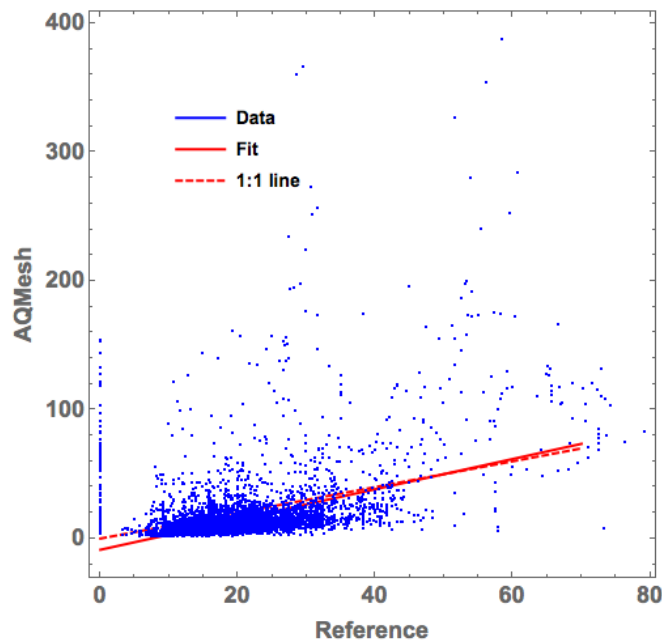
	Gradient	Intercept	R^2
pre	0.92 (0.01)	-3.0 (0.15)	0.41
post	0.92 (0.01)	-3.0 (0.15)	0.42

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PM$_{2.5}$ Gonville Place comparison (ratified)

- PM events captured, magnitudes overestimated

- OPC measures at ambient RH – deliquescence effects at high RH?

- Algorithm correction?

PM$_{10}$ Gonville Place comparison (ratified)
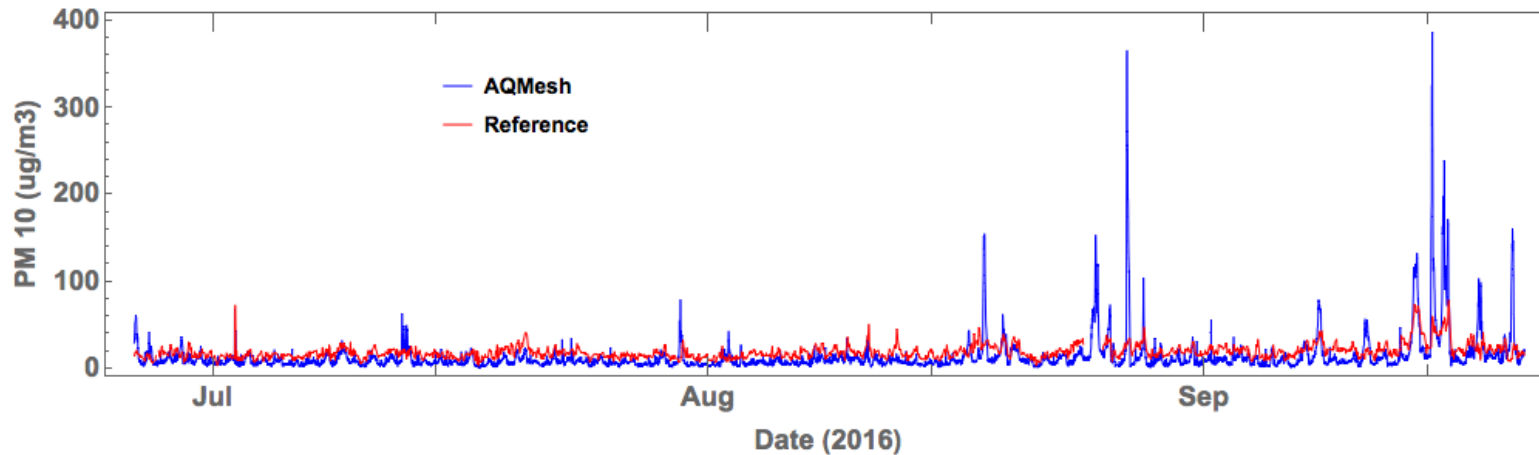
- Little difference on ratification
- PM events captured by AQMesh
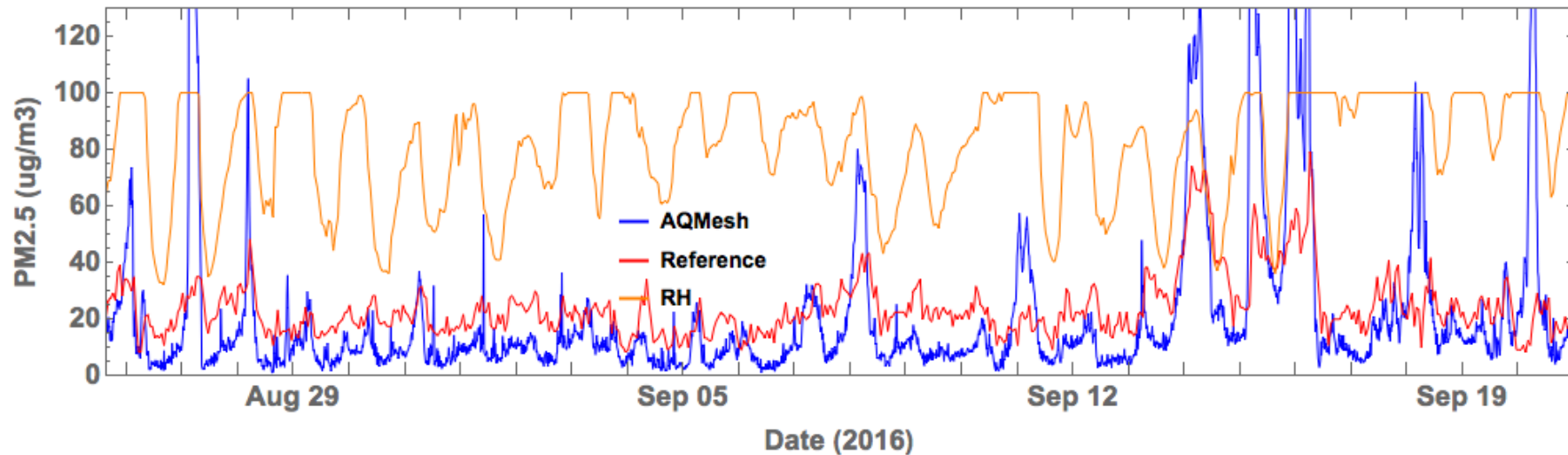- Magnitudes significantly overestimated in AQMesh

	Gradient	Intercept	R^2
pre	1.17 (0.02)	-8.7 (0.51)	0.21
post	1.17 (0.02)	-8.7 (0.51)	0.21

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PM$_{10}$ Gonville Place comparison (ratified)

- PM events captured, magnitudes <u>significantly</u> overestimated in AQMesh

- OPC measures at ambient RH – deliquescence effects at high RH?

- Algorithm correction?

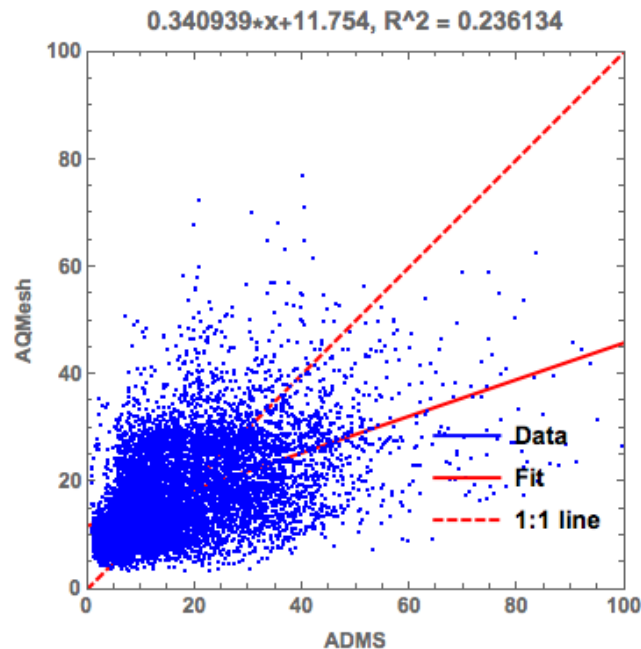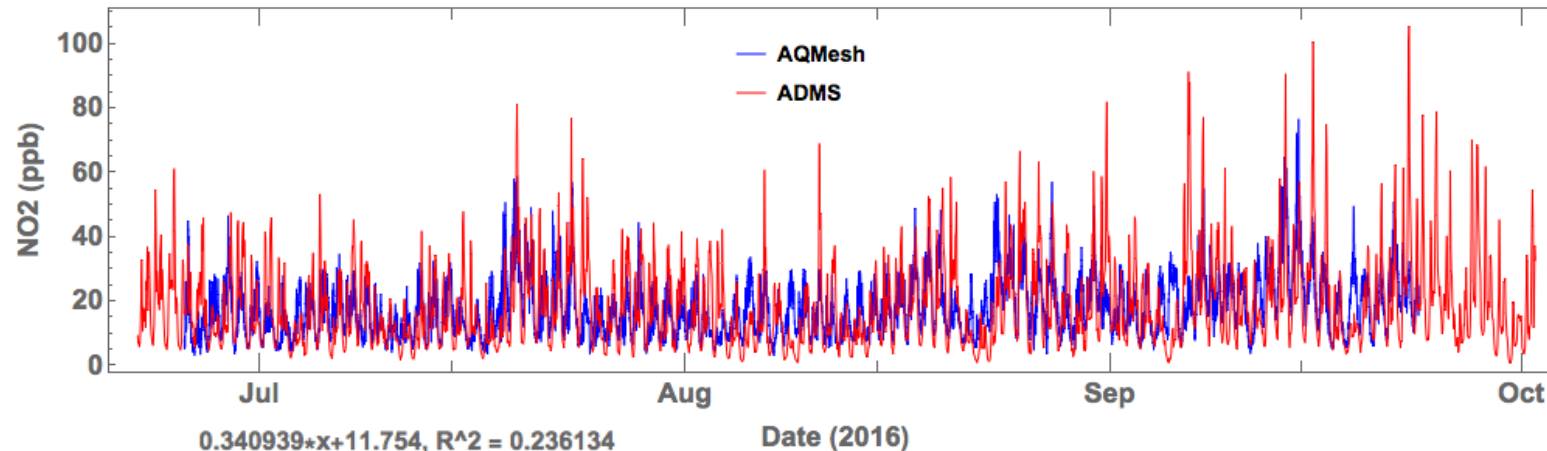# Gonville Place AQMesh reference comparison statistics

Pre- AURN ratification

	Gradient	Intercept	R^2
NO_2 pre	1.07 (0.01)	10.0 (0.1)	0.50
NO pre	1.07 (0.01)	4.4 (0.21)	0.49
$PM_{2.5}$ pre	0.92 (0.01)	-3.0 (0.15)	0.41
PM_{10} pre	1.17 (0.02)	-8.7 (0.51)	0.21

Post- AURN ratification

	Gradient	Intercept	R^2
NO_2 post	0.82 (0.01)	5.1 (0.13)	0.74
NO post	1.09 (0.01)	0.63 (0.27)	0.65
$PM_{2.5}$ post	0.92 (0.01)	-3.0 (0.15)	0.42
PM_{10} post	1.17 (0.02)	-8.7 (0.51)	0.21

Improvement is from *AURN ratification*

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NO$_2$ Gonville Place ADMS-AQMesh comparisons

$0.340939*x + 11.754$, $R^2 = 0.236134$

	Gradient	R^2
AQMesh - ADMS	0.34	0.24
AQMesh - reference	0.82	0.74

- Captures broad diurnal pattern
- Elevated outliers (traffic queueing)
- Poorer R^2 c.f. AQMesh-reference

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NO Gonville Place ADMS-AQMesh comparisons

0.272574*x+12.4464, R^2 = 0.120395
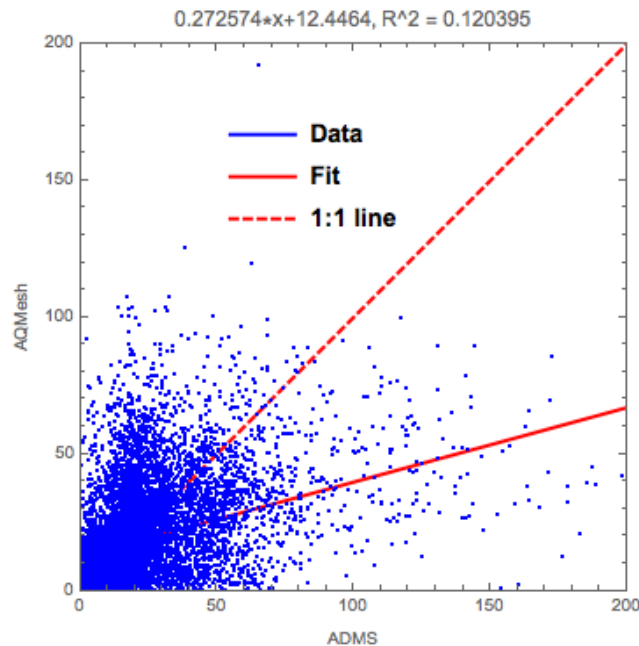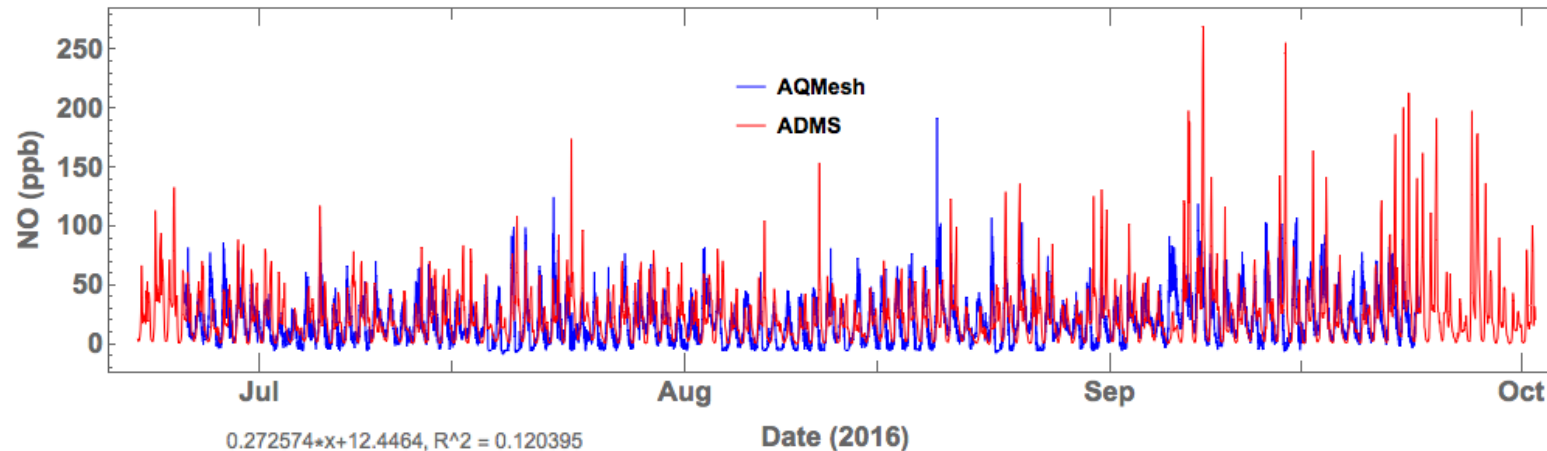
	Gradient	R^2
AQMesh - ADMS	0.27	0.12
AQMesh - reference	1.09	0.65

- Captures broad diurnal pattern
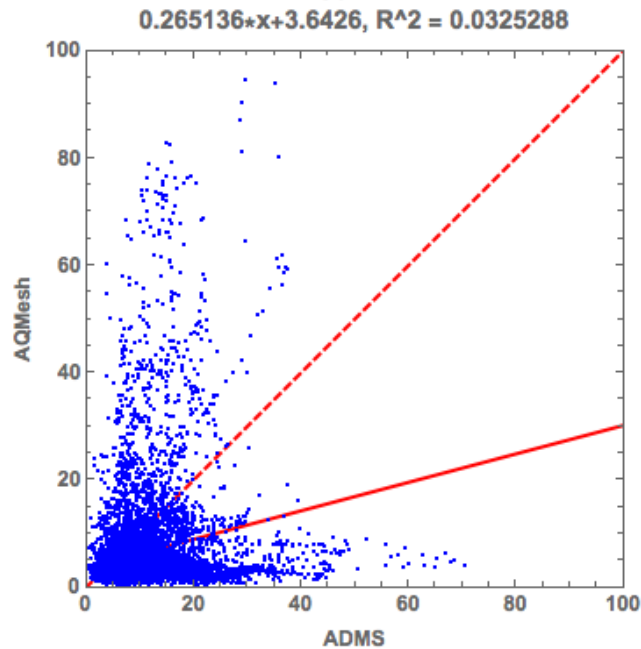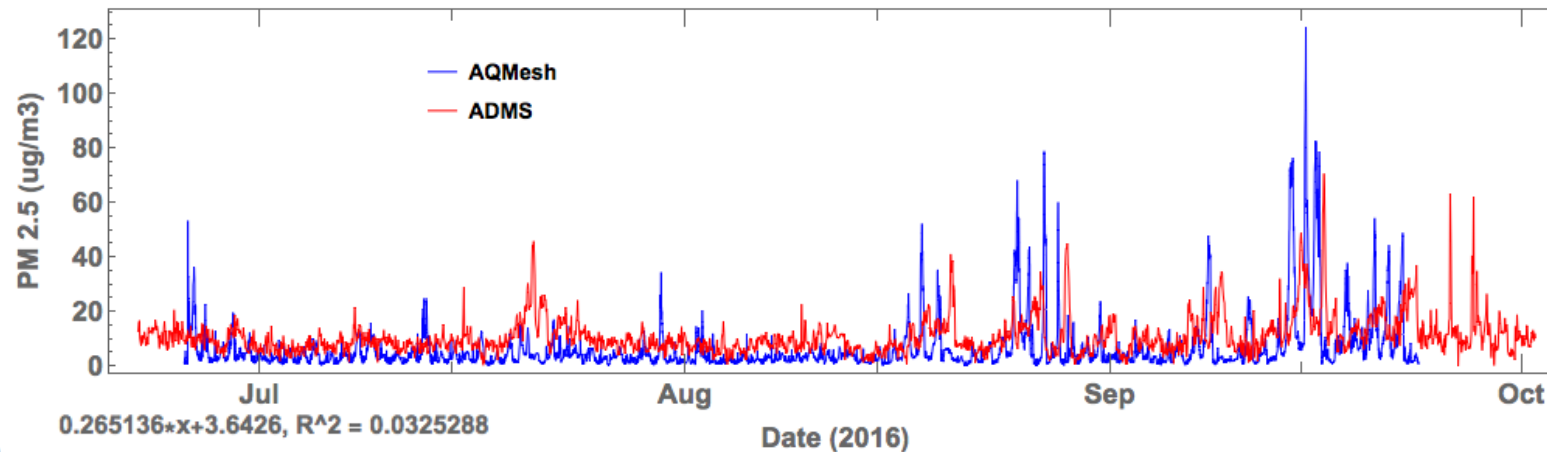- Elevated outliers (traffic queueing)
- Poorer R^2 c.f. AQMesh-reference

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PM$_{2.5}$ Gonville Place ADMS-AQMesh comparisons

0.265136*x+3.6426, R^2 = 0.0325288

	Gradient	R^2
AQMesh - ADMS	0.265	0.03
AQMesh - reference	0.92	0.42

- Captures magnitudes of events *but not timing…..*
- Significantly poorer R^2 c.f. AQMesh - reference

PM$_{10}$ Gonville Place ADMS-AQMesh comparisons

$0.109899 \cdot x + 12.3733, R^2 = 0.00454824$
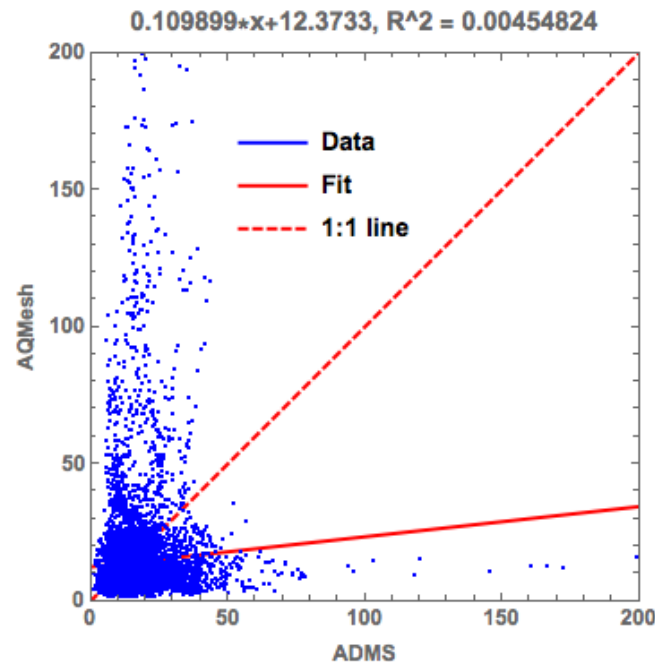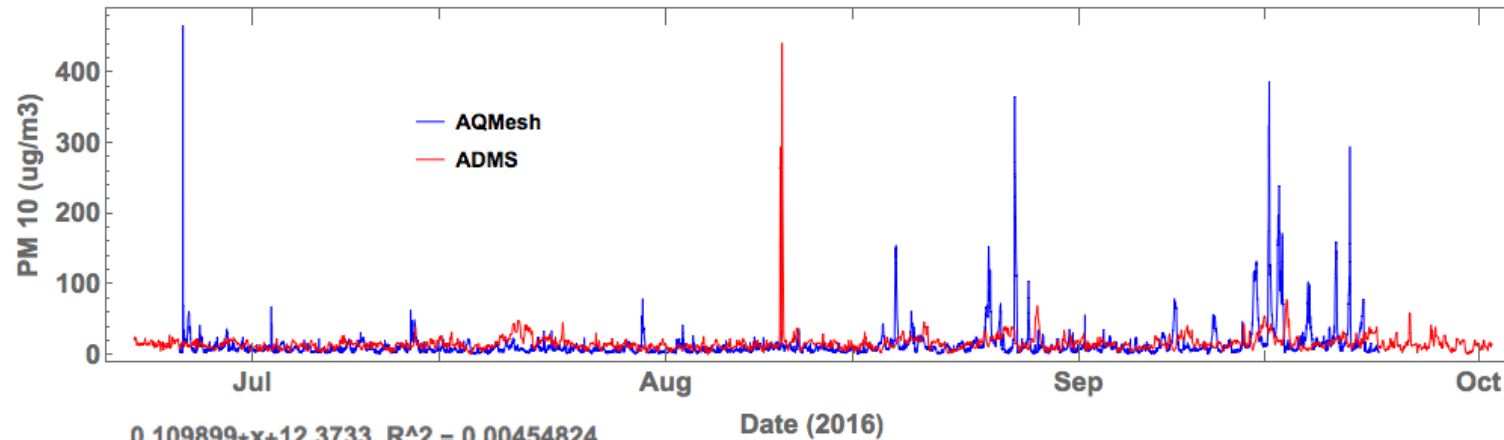
	Gradient	R^2
AQMesh - ADMS	0.109	0.005
AQMesh - reference	1.17	0.21

- Captures magnitudes of events *but not timing……*
- Significantly poorer R^2 c.f. AQMesh - reference

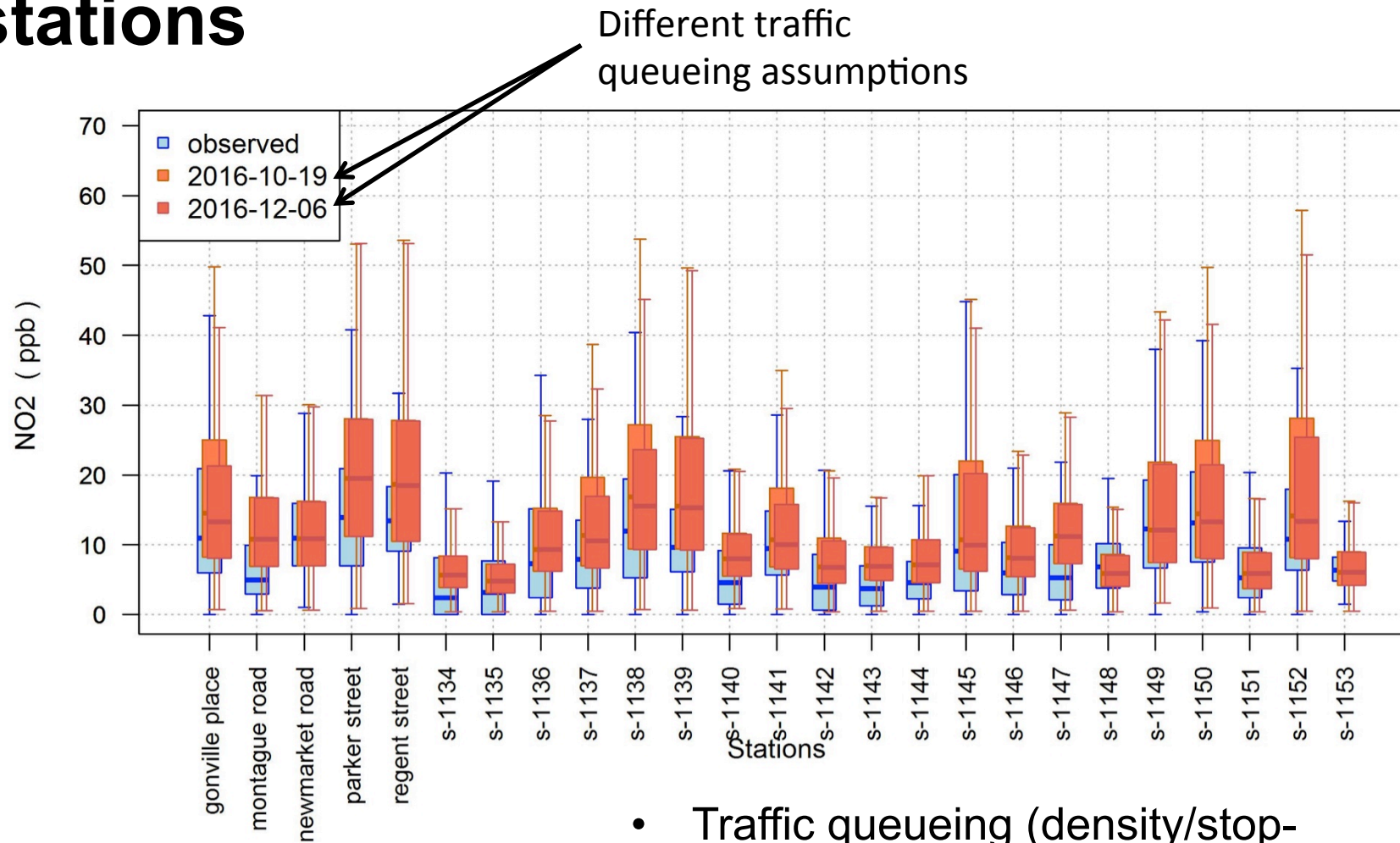Air Quality Monitoring: Evolving Issues and New Technologies, December 13th 2016

NO$_2$ ADMS-AQMesh comparisons – all stations

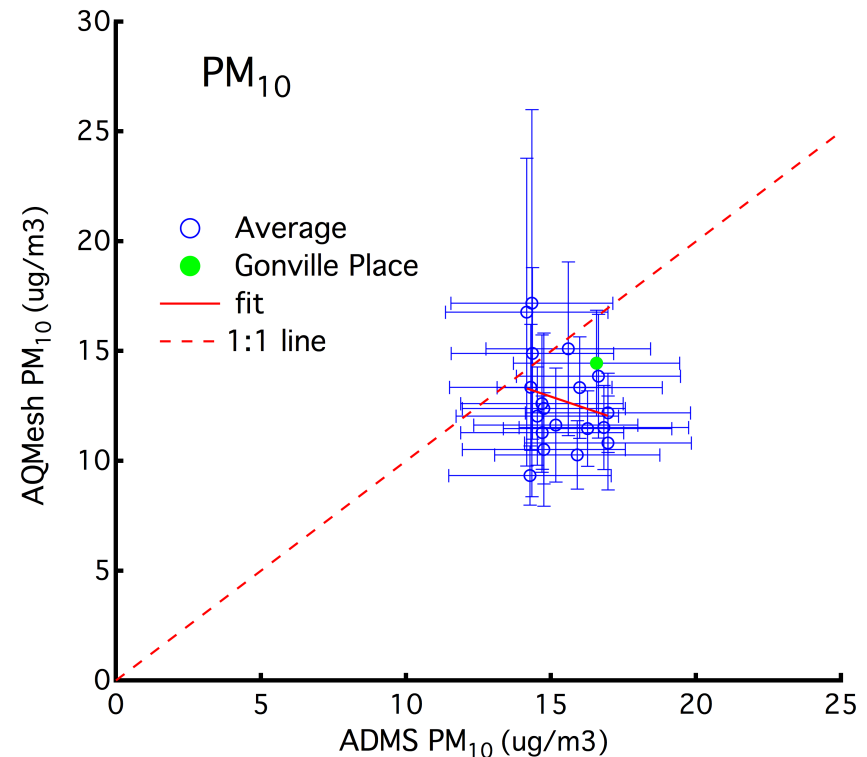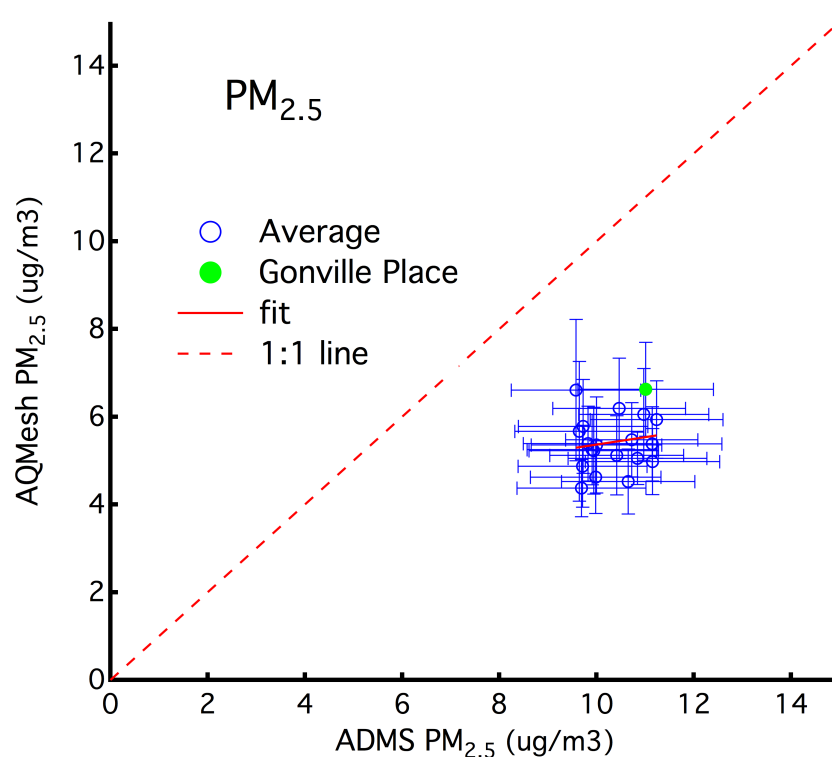

Different traffic queueing assumptions

- Traffic queueing (density/stop-start) and road representation critical for ADMS

NO_x ADMS-AQMesh comparisons – all stations – 3 month average
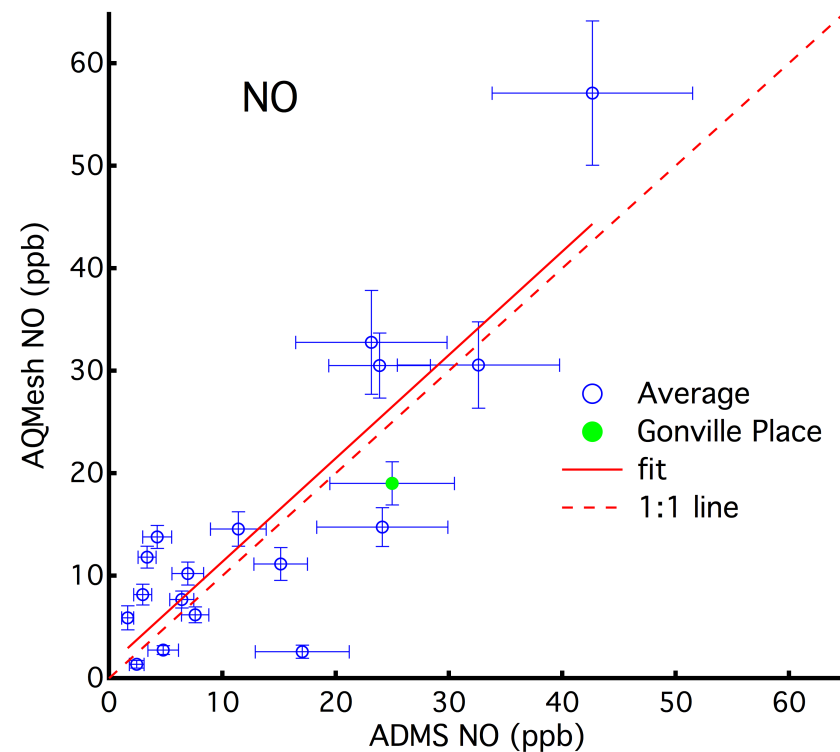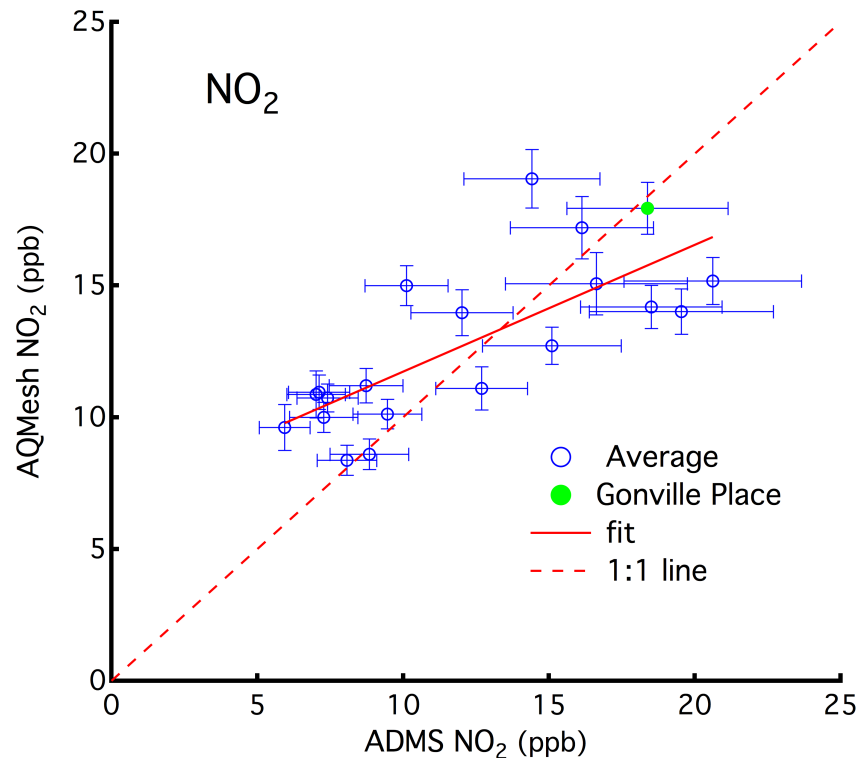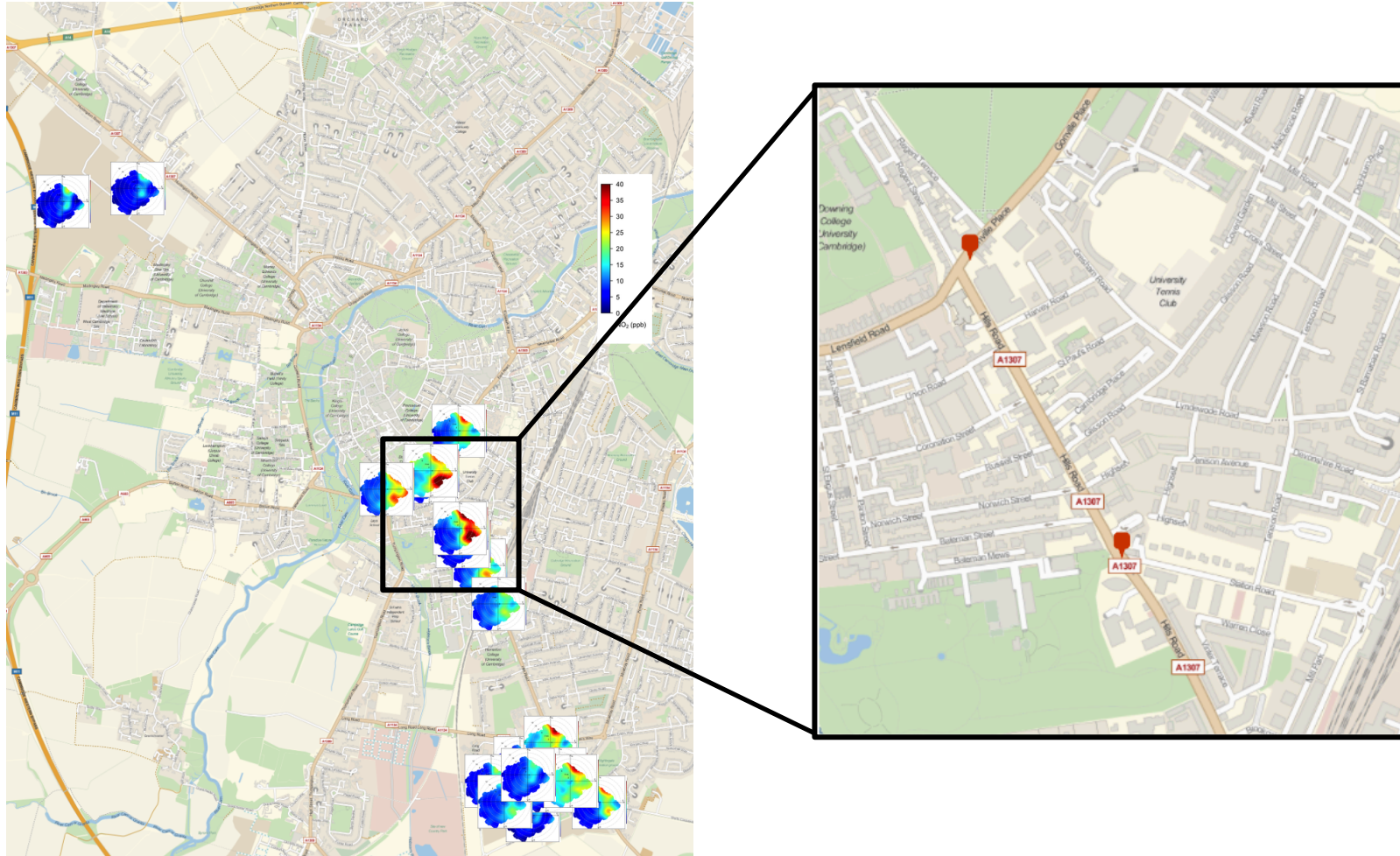

- Model ~ captures AQMesh spatial gradients
- Local (spatially heterogeneous) sources

PM ADMS-AQMesh comparisons – all stations – 3 month average

- Model ~ captures (lack of) spatial gradients
- Averages dominated by non-local sources

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Snapshot of some results

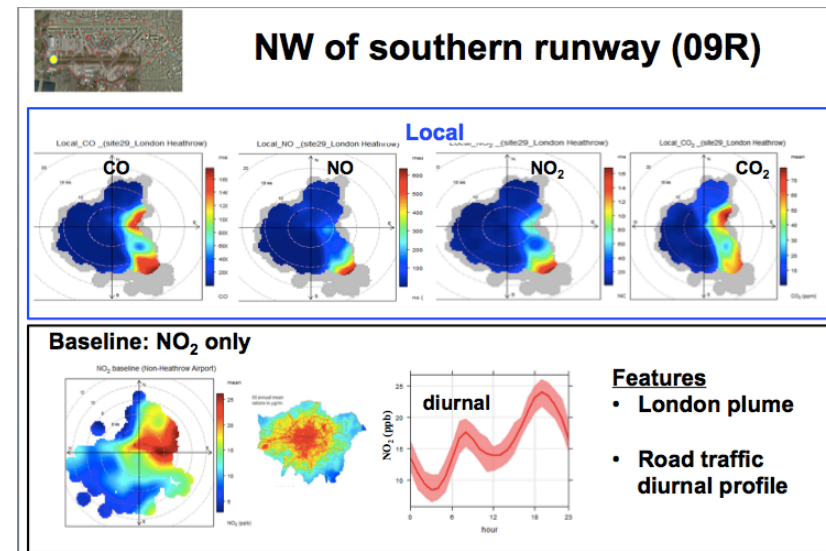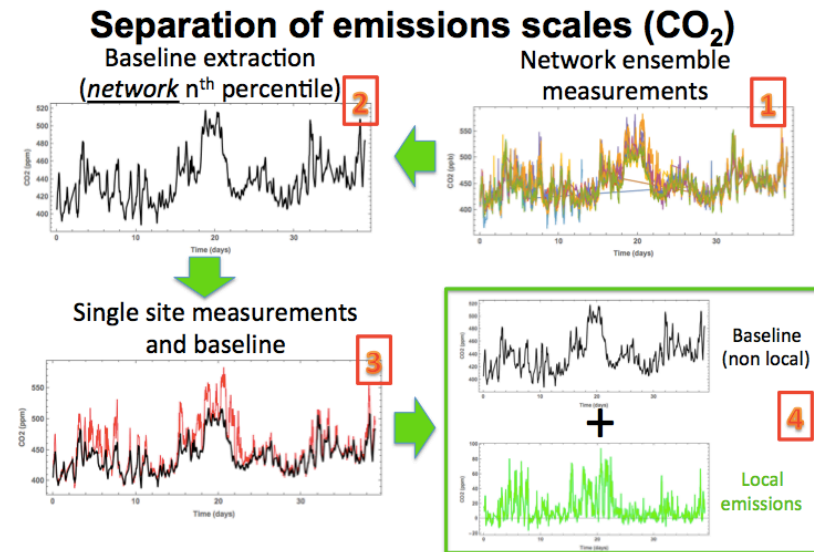# Snapshot of some results (NO$_2$,PM$_{2.5}$)

⇒ Source apportionment etc.

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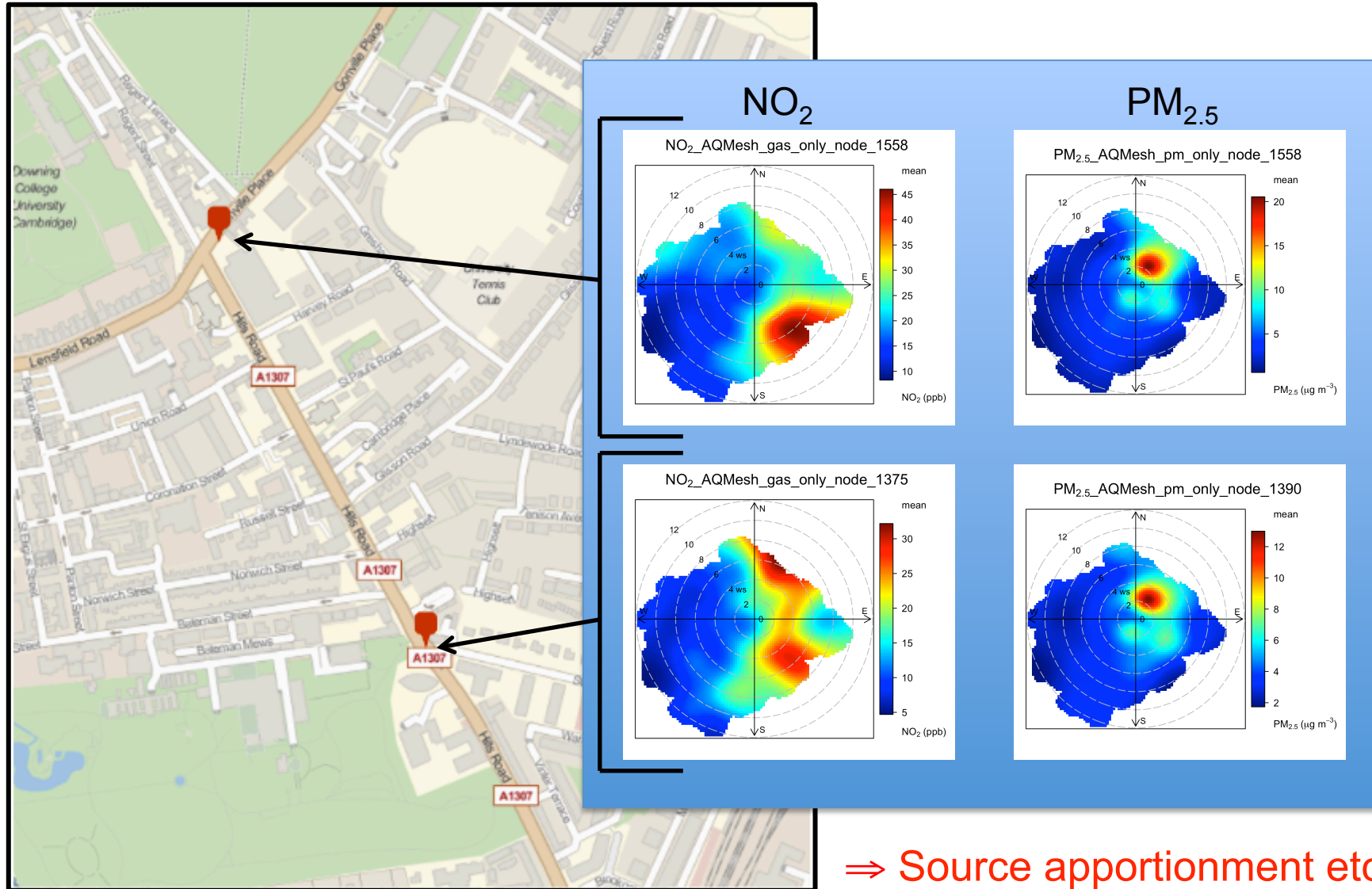
Next steps

- Cross network calibration/QC

- Measurement scaling, PM deliquescence effects

- Inclusion of CO_2 measurements

- Source apportionment studies

- Separation of scales

- *Methodologies for assimilation into ADMS*

- ....

Conclusions/inferences

- AQMesh sensor performance 'out of box' – no scaling, no use of local measurements.
    - Sensor- sensor reproducibility very good (important first step, but….)
    - AQMesh $NO/NO_2/NOx$ inter-comparison with ratified measurements extremely encouraging.
    - AQMesh PM measurements capture events, but poor scaling (esp. PM_{10}).
    - Hotspot detection (NO_2 short term exceedences).

- Ratification process produces some rather surprising results……

- ADMS model captures general AQMesh picture reasonably well, but fails to capture local spatial/temporal detail.
    - Consequence of traffic flow assumptions?

- Yet to apply pan-network analysis/local calibration techniques
    - Clear improvements in prospect.

- Not without issues, but demonstrated potential to provide real-time high-density measurements needed e.g. for 'smart cities', pollution hotspot detection etc.
    - Complement/extend AURN network – or 'gold standard' instrument
    - Assimilation of high spatial resolution measurements into models (e.g. ADMS)

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