Laboratory and field evaluation of a low-cost commercial sensor platform in Oslo, Norway

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NILU – Norwegian Institute for Air Research

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Can we use low-cost nodes for air quality management?

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Full length article

Can commercial low-cost sensor platforms contribute to air quality monitoring and exposure estimates?

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The AQMesh platform v3.5

Information extracted from AQMesh documentation in CITI-SENSE project
Environmental Instruments Ltd, UK, www.aqmesh.com

Parameter	Symbol	Range	Units	Limit of detection
Pod Temperature		-20 – 100 °C	°C	0.1 °C
Pressure		500 – 1500 mb	mb	1 mb
Relative Humidity		0 – 100 %RH	%RH	1 %RH
Nitric Oxide	NO	0-2000 ppb	ppb / ug/m^3	<5 ppb
Nitrogen Dioxide	NO2	0 – 200 ppb	ppb / ug/m^3	<5 ppb
Ozone	O3	0 – 200 ppb	ppb / ug/m^3	<5 ppb
Carbon Monoxide	CO	0 – 5000 ppb	ppb / ug/m^3	<5 ppb
Particulate Count		1-30 µm	Particles/cm3	1 µm
Noise (Peak)		35 – 100 dB SPL	dB SPL	<35 dB SPL
Noise (Average)		35 – 100 dB SPL	dB SPL	<35 dB SPL

Key Points

- Excellent NO correlation: Typical R^2 >0.85
- Very good NO2 correlation: Typical R^2 >0.75
- Very good O3 correlation: Typical R^2 >0.7
- Very good CO correlation: Typical R^2 >0.7
- Excellent Particle Count correlation: Typical R^2 Versus FIDAS >0.85
- Excellent pod to pod correlation for all parameters : Typical R^2 >0.9

Can we reproduce those values?

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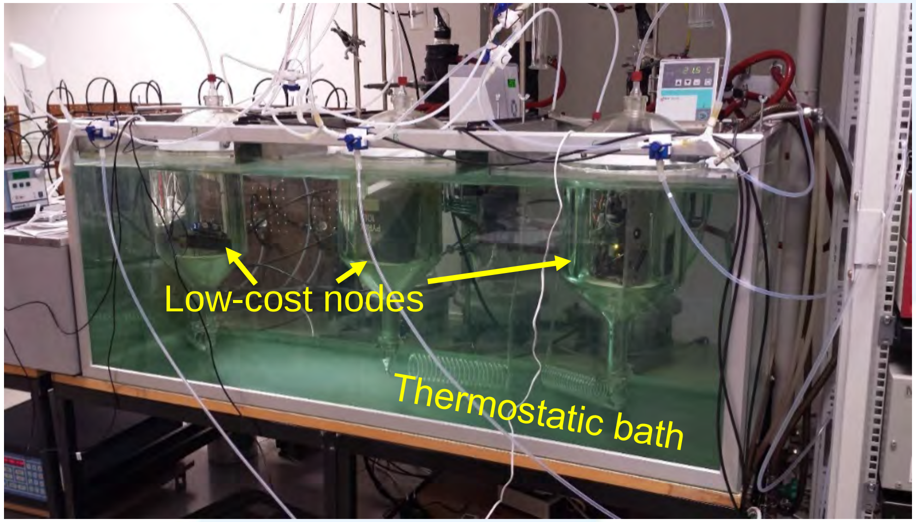
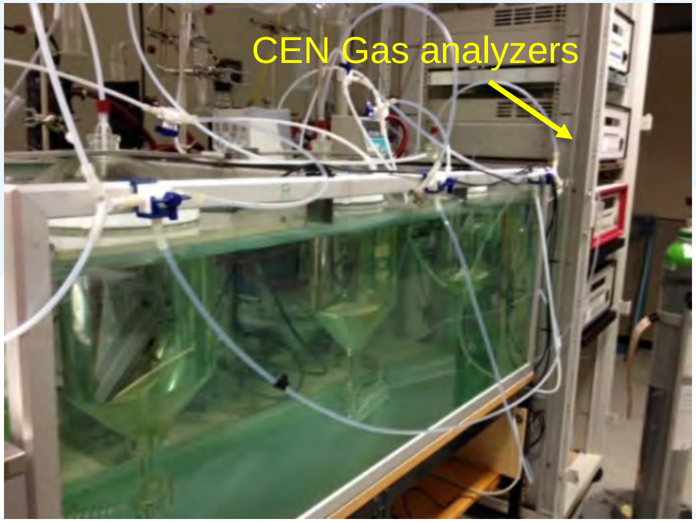
Laboratory evaluation: set-up





Gas	Sensor type
CO	Electrochemical CO-B4
NO_2	Electrochemical NO2-B42F
NO	Electrochemical NO-B4
O_3	Electrochemical OX-B421

Gas	Analyzer
CO	Teledyne API 300E (EN14626)
NO_x	Teledyne API 200A (EN 14211)
O_3	Teledyne API 400 (EN 14625)

Performance of the sensor nodes against traceable gas standards under reproducible and accurately controlled ambient conditions.

- Two sensor nodes: 688150 and 864150.
- 864150 was tested after 3 months of field deployment.

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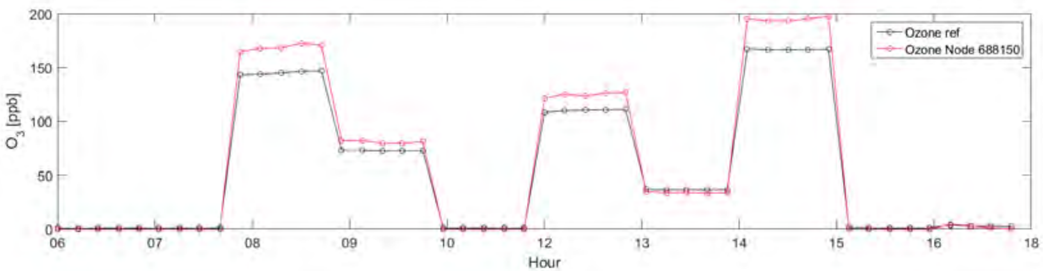
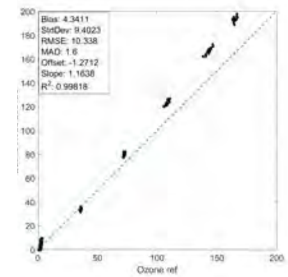
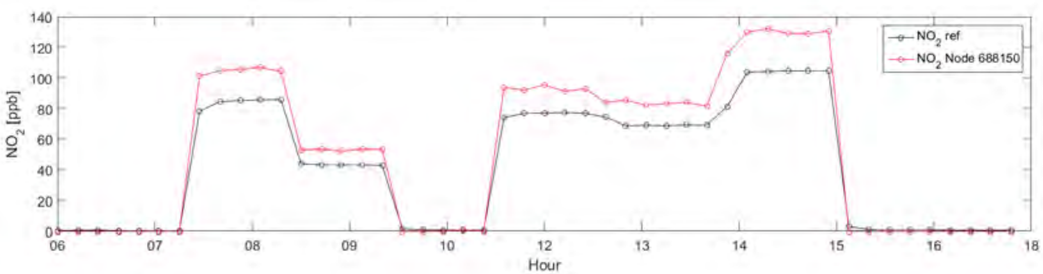
Laboratory evaluation: results

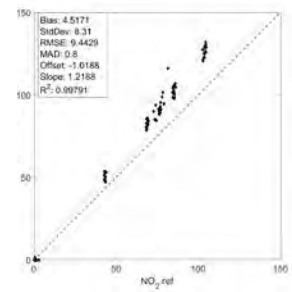




Cross-sensitivity: NO_2 (Low-High)

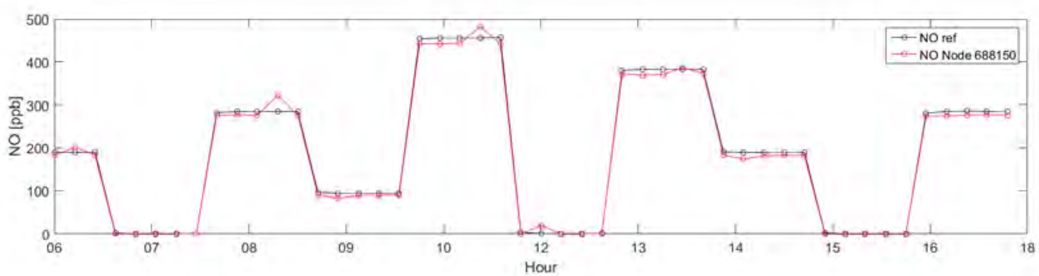
LOD: 1.8 ppb

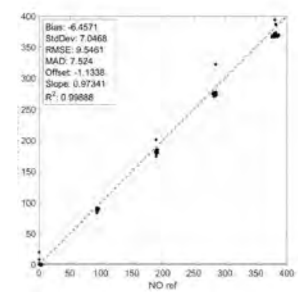




Cross-sensitivity: No

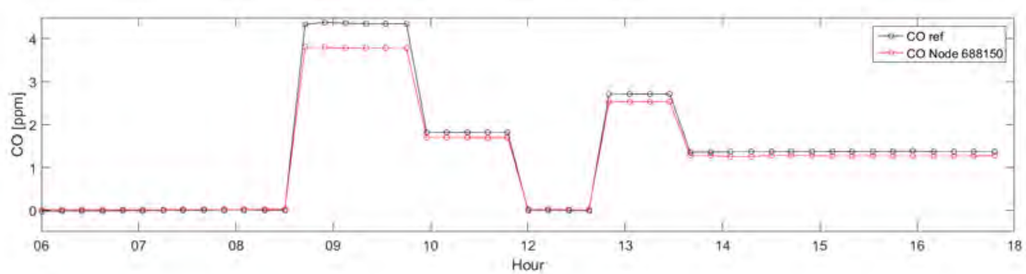
LOD: 2.7 ppb

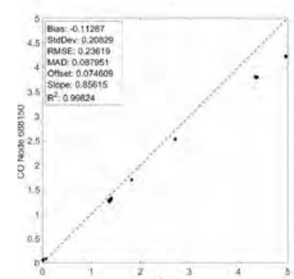




Cross-sensitivity: No

LOD: 2.4 ppb





Cross-sensitivity: No

LOD: 21 ppb

Field evaluation: set-up

Kirkeveien
street

	712150	828150	750150	743150	715150	856150
	846150	864150	863150	855150	764150	850150
				X	Gas inlet	
	737150	746150	849150	751150	862150	861150
	688150	744150	718150	733150	756150	785150
X PM inlet						
					Monitoring station	

Gas	Sensor type
CO	Electrochemical CO-B4
NO_2	Electrochemical NO2-B42F
NO	Electrochemical NO-B4
O_3	Electrochemical OX-B421

Gas	Analyzer
CO	EC Serinus 30 (EN14626)
NO_x	EC Serinus 40 (EN 14211)
O_3	Teledyne API 400 (EN 14625)

Performance of the sensor nodes when exposed to a range of different environmental conditions (e.g. weather, traffic).

- 13th April – 24th June 2015: 24 AQMesh nodes at Kirkeveien AQM
- 1st July – 22nd September 2015: Kirkeveien (10 nodes), Manglerud (4 nodes), Åkebergveien (5 nodes) and Alnabru (4 nodes)

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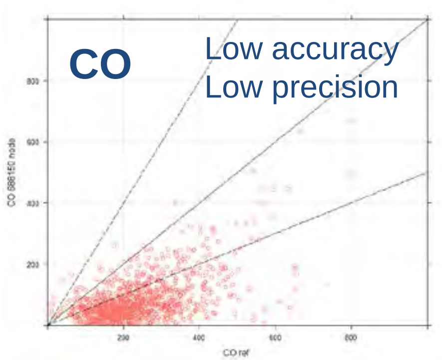
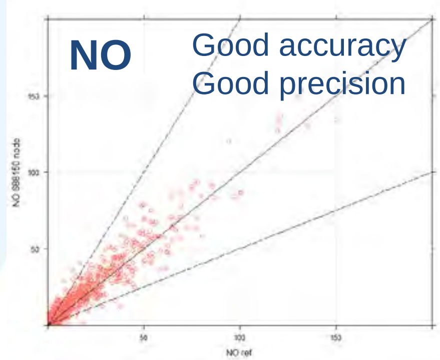
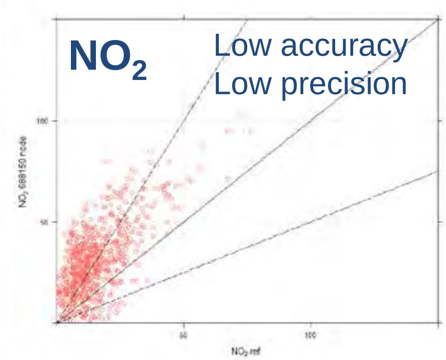
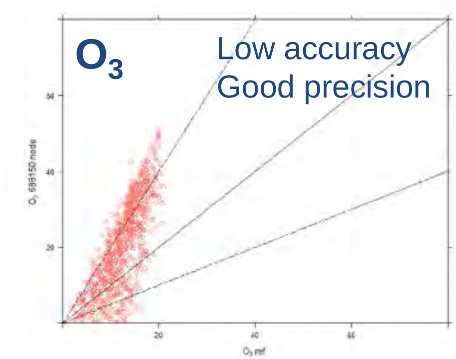
Field evaluation results: calibration

AQMesh unit	Species/ parameter	Correlation (laboratory)	Correlation (field)	Slope (laboratory)	Slope (field)	Intercept (laboratory) [ppb]	Intercept (field) [ppb]
688150	CO	0.99	0.58	0.86	0.88	0.07	166
	NO	0.99	0.96	0.97	0.93	-1.13	-0.12
	NO_2	0.99	0.65	1.22	0.38	-1.02	3.8
	O_3	0.99	0.81	1.16	0.26	-1.27	7.2
864150	NO_2	0.96	0.30	1.21	0.2	3.85	16
	O_3	0.99	0.32	0.99	0.11	3.25	9









- A good performance in the laboratory is not indicative of a good performance in field.
- Correlations significantly lower in the field than in the laboratory.
- Necessary to calibrate the sensors in the field.

Field evaluation results: sensor to sensor variability

Species		MB	RMSE	r
CO	Average	-147.21	170.99	0.60
	Max	-132.90	181.28	0.67
	Min	-156.21	159.04	0.47
NO	Average	-0.54	16.35	0.86
	Max	12.75	30.94	0.98
	Min	-15.05	6.97	0.60
NO_2	Average	13.30	30.27	0.49
	Max	74.66	81.60	0.72
	Min	-22.73	15.52	0.21
O_3	Average	6.76	22.20	0.54
	Max	40.71	44.27	0.81
	Min	-28.66	11.77	0.09
PM_{10}	Average	-2.00	18.50	0.56
	Max	1.31	64.38	0.73
	Min	-8.12	13.82	0.19
$PM_{2.5}$	Average	-0.03	5.57	0.51
	Max	0.56	6.55	0.63
	Min	-2.00	4.13	0.42

- The results show that even for identical sensors and platform, the performance can vary sensor to sensor.
- Challenge in ensuring sensor measurement repeatability.

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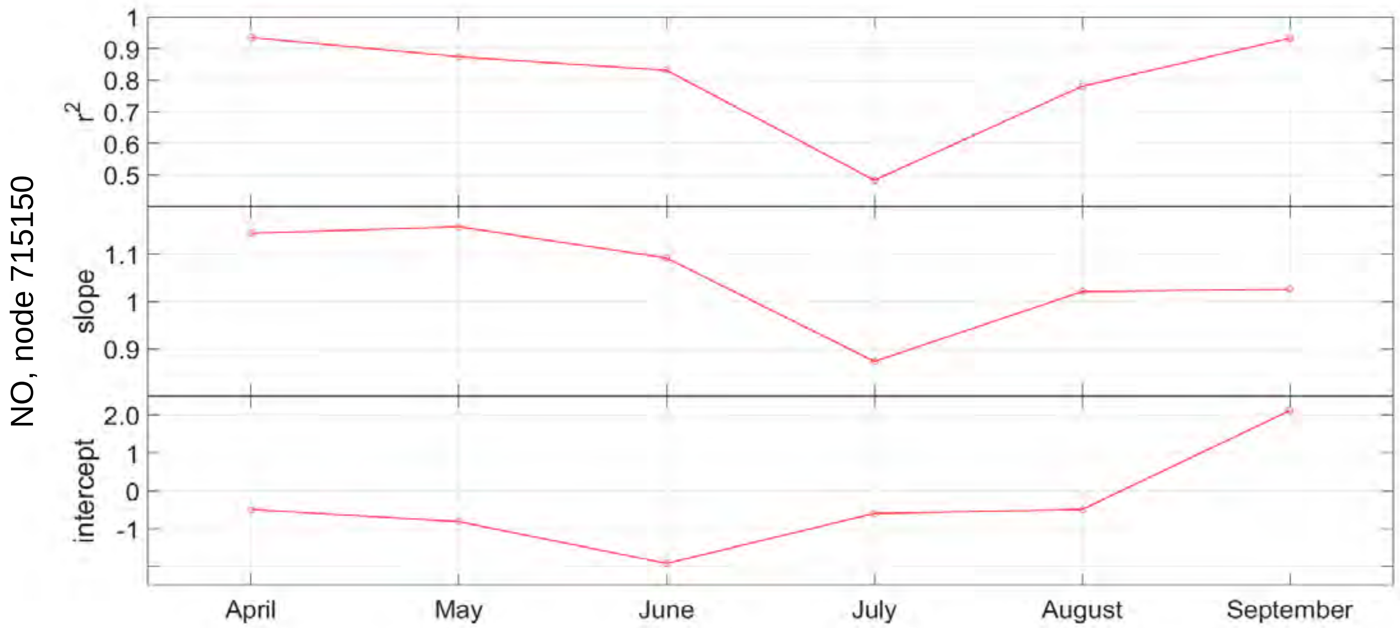
Field evaluation results: long-term performance



- Clear change in the behaviour during the 6 months co-location period due to varying weather conditions and atmospheric concentrations.
- The variation in the calibration parameters month to month can be significant.
- This can lead to increased errors and biases that can pass unnoticed once the nodes are deployed in the field.

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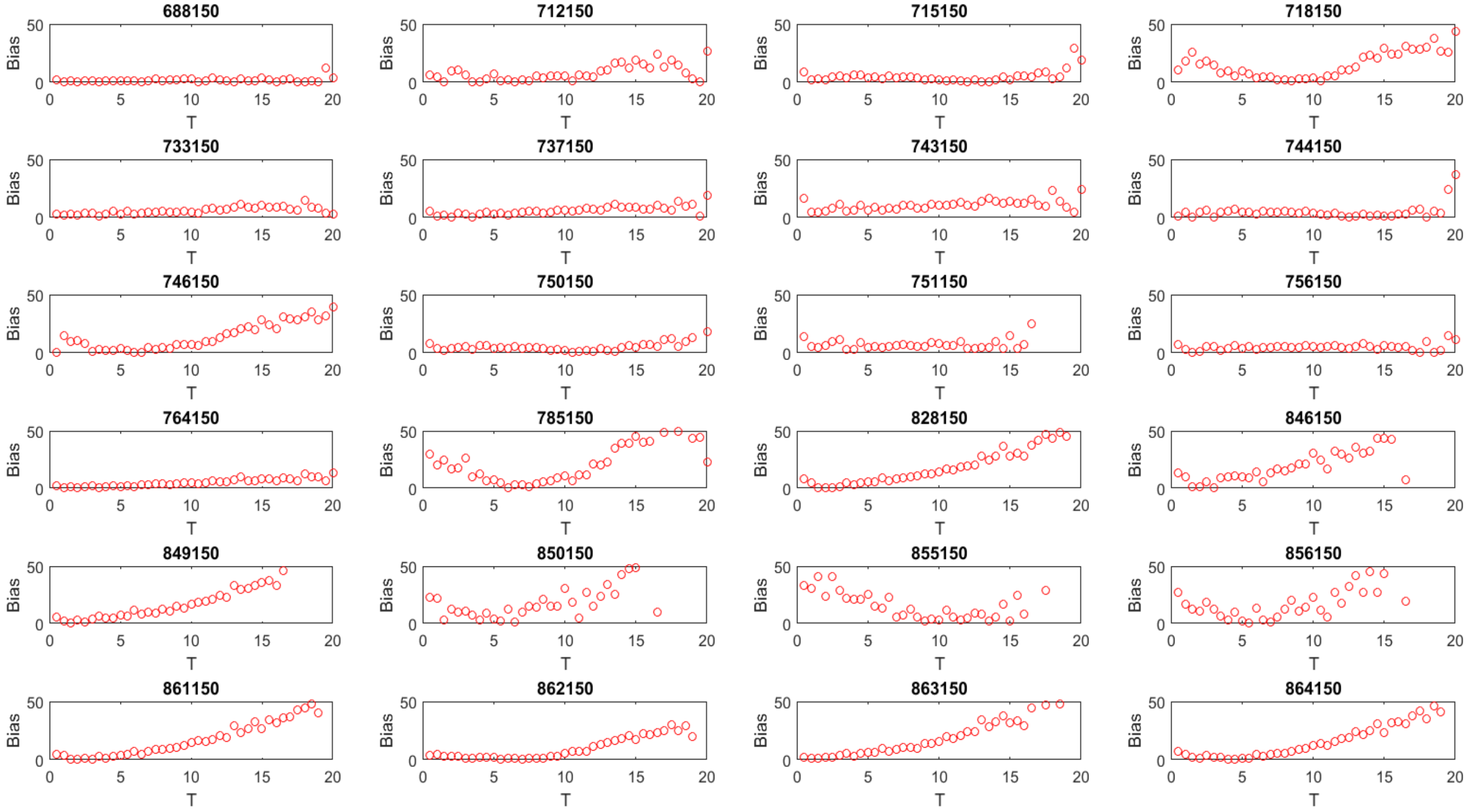
Field evaluation results: dependence on meteorological conditions



- The response of each sensor to weather conditions is unique, and it is necessary to evaluate each sensor individually.
- We can have false increases in concentrations due to changes in temperature.

Field evaluation results: dependence on the location

Node 688150	CO	NO	NO_2	O_3	PM_{10}	$PM_{2.5}$
Coef. determination (r^2) Lab	0.99	0.99	0.99	0.99	-	-
Coef. determination (r^2) Field (dense traffic)	0.34	0.92	0.42	0.65	0.53	0.40
Coef. determination (r^2) Field (calm traffic)	-	0.24	0.15	-	0.68	0.84
Slope Lab	0.86	0.97	1.22	1.16	-	-
Slope Field (dense traffic)	0.88	0.93	0.38	0.26	1.30	0.51
Slope Field (calm traffic)	-	0.27	0.087	-	2.10	1.90
Intercept Lab	0.07	-1.13	-1.02	-1.27	-	-
Intercept Field (dense traffic)	166	-0.12	3.80	7.20	5.60	3.30
Intercept Field (calm traffic)	-	4.20	6.90	-	-1.30	0.98

- The linear calibration parameters are different when the node is located in a traffic-saturated environment or at a traffic-calm environment.
- It is important to calibrate the nodes in an environment similar to the one in which they would be deployed (or better, to perform in-situ calibration at the deployment site).

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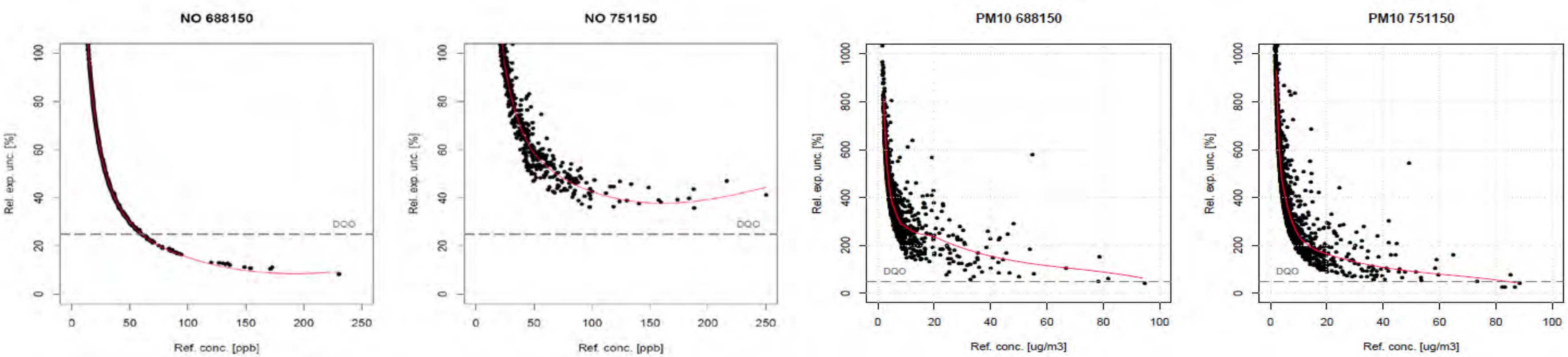
Field evaluation results: data quality objective (DQO)

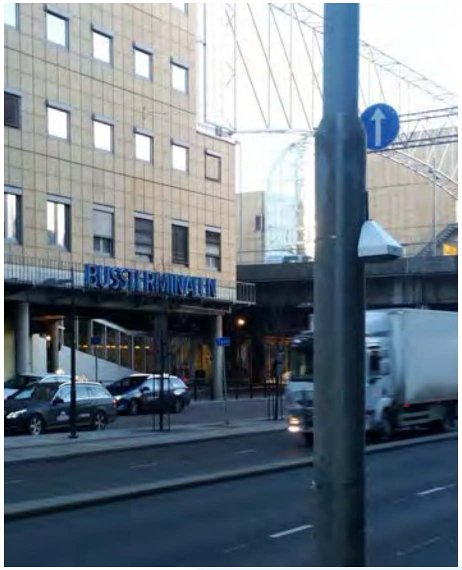
The use of low-cost sensor nodes as indicative measurements could reduce the cost of air pollution monitoring. However, to be used for regulatory purposes, sensor nodes should comply with the DQOs.

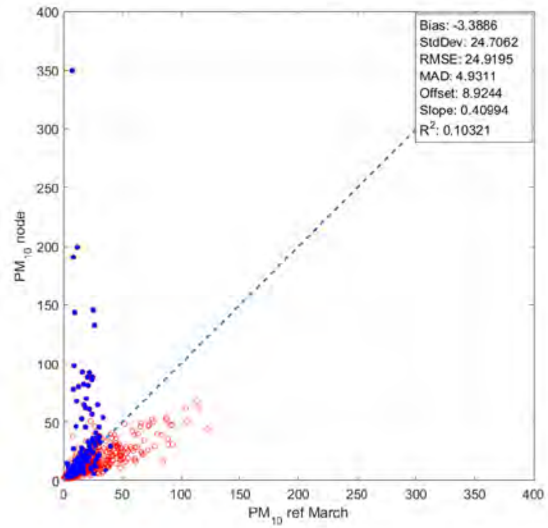
DQO	SO_2, NO_2, NO_x, CO	PM10, PM2.5	O_3
Fixed measurements	15%	25%	15%
Indicative measurements	25%	50%	30%



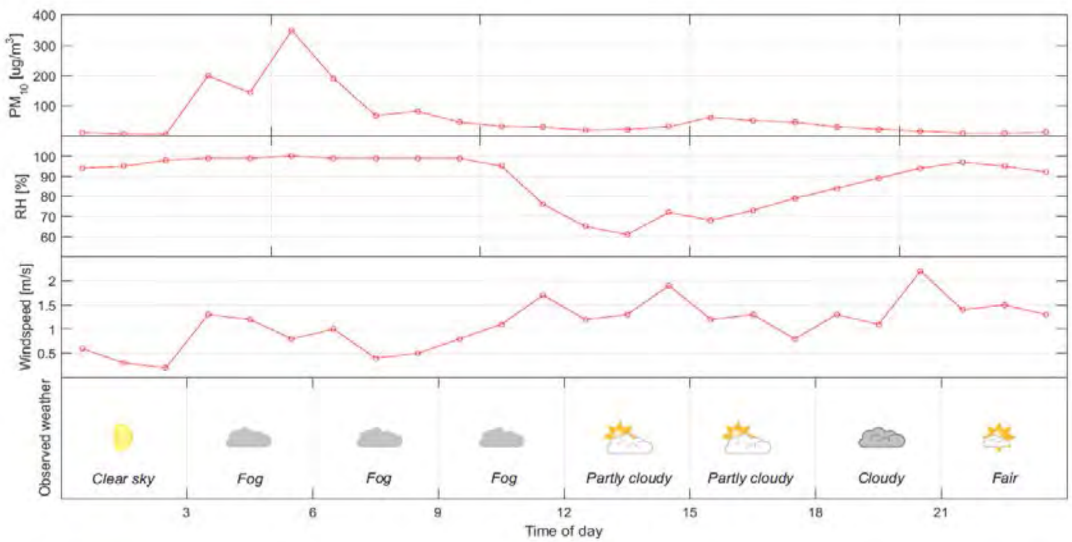
- For some pollutants and nodes, as NO, PM10 and PM2.5, the expanded uncertainty meets the DQO criteria.

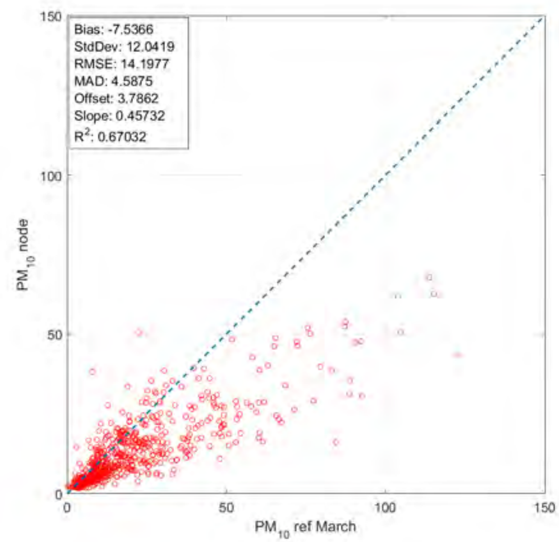
Low-cost platforms as complementary information: PM_{10}





- PM node is very sensitive to relative humidity.
- Fog/water droplets of particles sizes below 10µm can be falsely characterized as PM particles.





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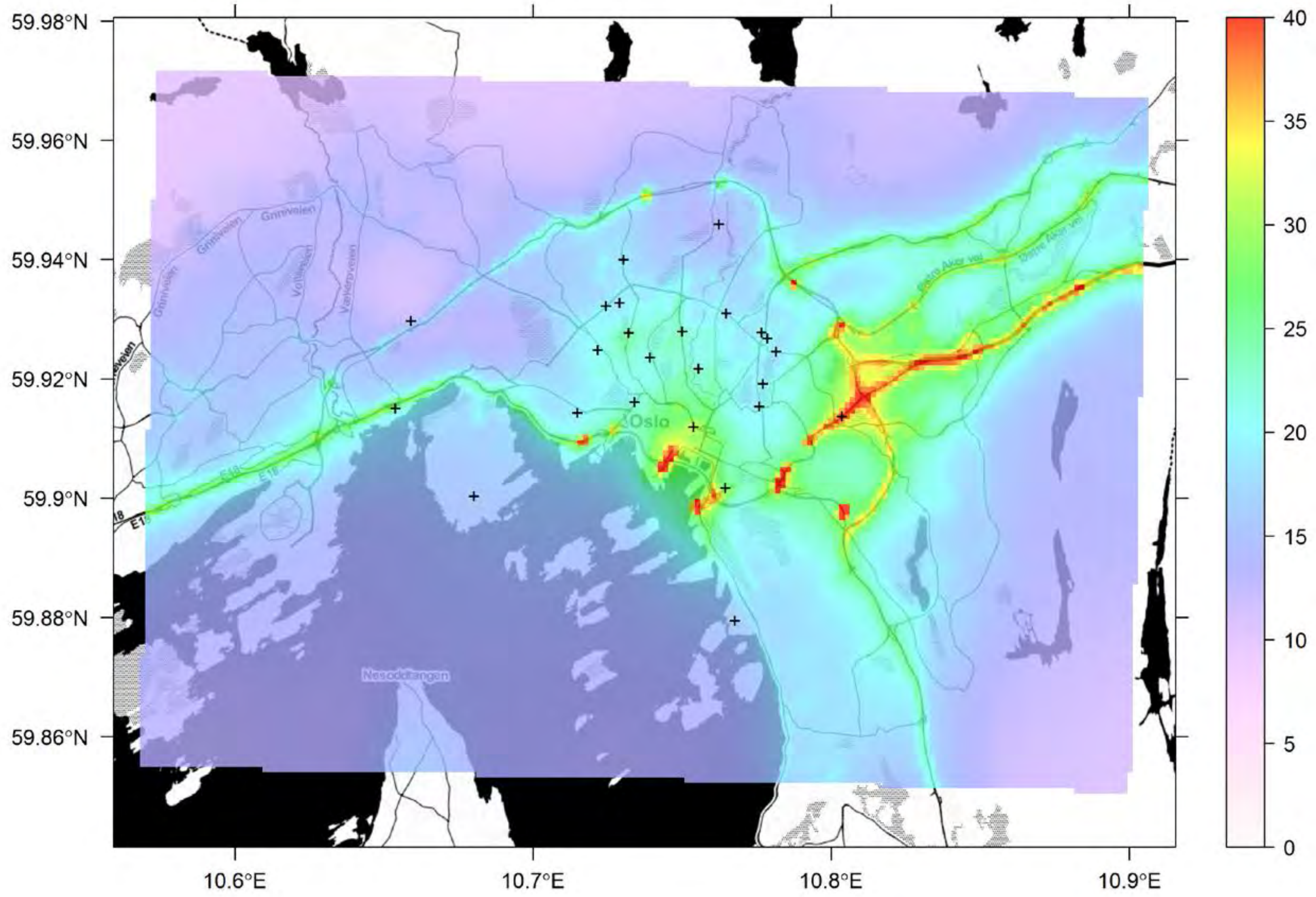
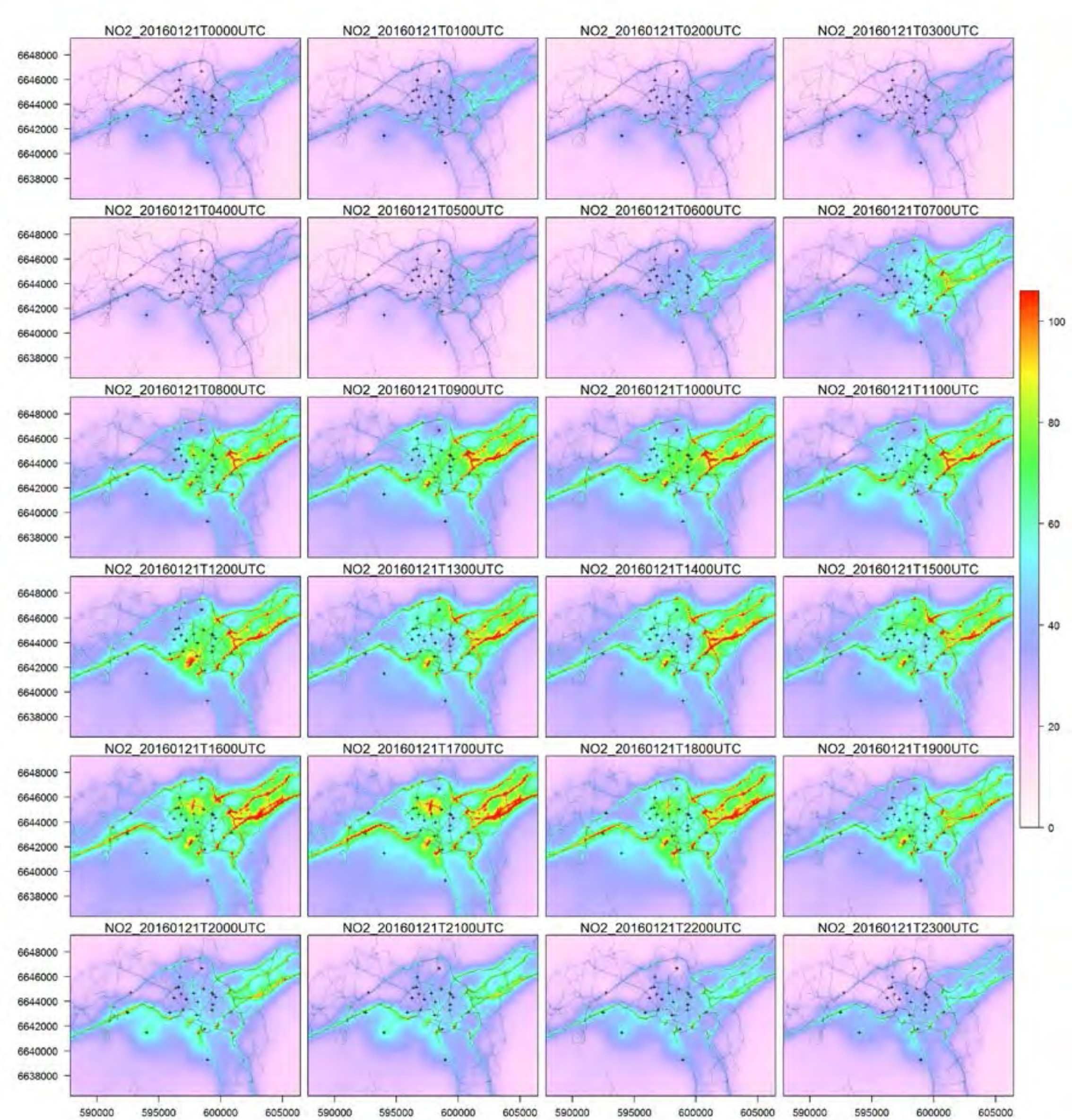
Low-cost platforms as complementary information: Mapping PM_{10}



Low-cost platforms as complementary information: NO_2



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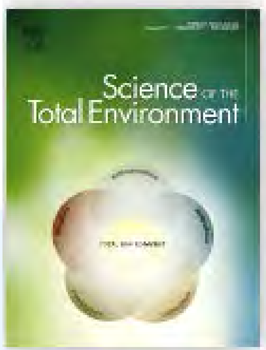
Forthcoming papers

Localized real-time information on outdoor air quality at kindergartens in Oslo, Norway using low-cost sensor nodes

Nuria Castell, Philipp Schneider, Sonja Grossberndt, Mirjam. F. Fredriksen, Gabriela Sousa-Santos, Mathias Vogt and Alena Bartonova

NILU – Norwegian Institute for Air Research, Kjeller, Norway.



Continuous real-time measurement of particulate matter (PM_{10}) in Oslo, Norway using a network of low-cost sensor nodes

Nuria Castell, Philipp Schneider, Mathias Vogt, William Lahoz and Alena Bartonova

NILU – Norwegian Institute for Air Research, Kjeller, Norway.

Mapping urban air quality in near real-time using crowdsourced observations from low-cost sensors and model information

Philipp Schneider, Nuria Castell, Mathias Vogt, William Lahoz and Alena Bartonova

NILU – Norwegian Institute for Air Research, Kjeller, Norway.

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Key messages

- A good performance in the laboratory is not indicative of a good performance under real-world conditions.
- Necessary to perform field calibration for each sensor node individually.
- Performance and field calibration parameters vary spatially and temporally, as they depend of the meteorological conditions and the atmospheric composition.
- We can not ensure absolute values (e.g. the concentrations are lower or higher than the limit value), but for some pollutants and nodes we can get coarse information (e.g. the air pollution is lower or higher than yesterday).
- Field calibration still represents a challenge. Necessary to employ more sophisticated techniques than linear calibration.
- After data processing we can extract useful information and generate detailed air quality maps.

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Can we use low-cost nodes for air quality management?

- The high sensor-to-sensor variability and the variations in the node's response to varying weather conditions or emissions patterns, makes them unsuitable for air quality legislative compliance or applications that require high accuracy, precision and reliability.
- The outlook is promising and we can already extract valuable information. This type of information can be suitable for applications aiming at raising awareness, educating, engaging the community by monitoring local air quality, and with appropriate communication, protecting public health.

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Thank you for your attention

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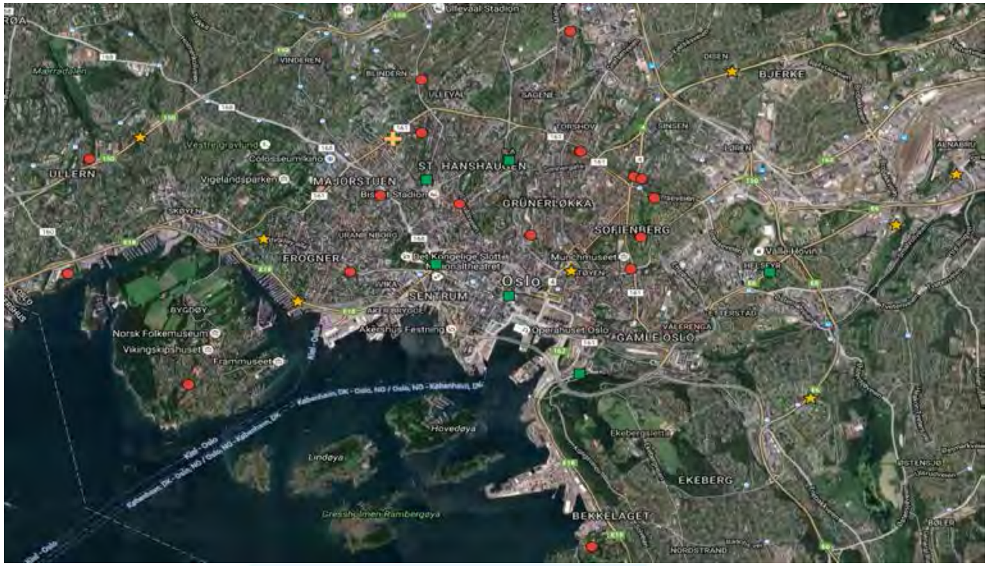
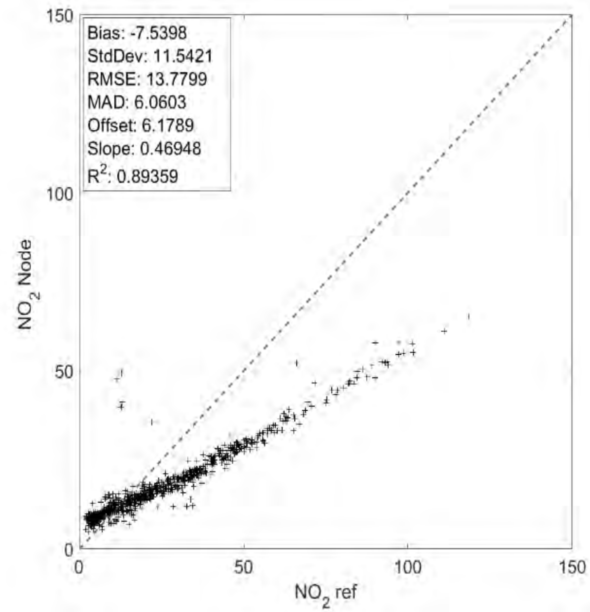
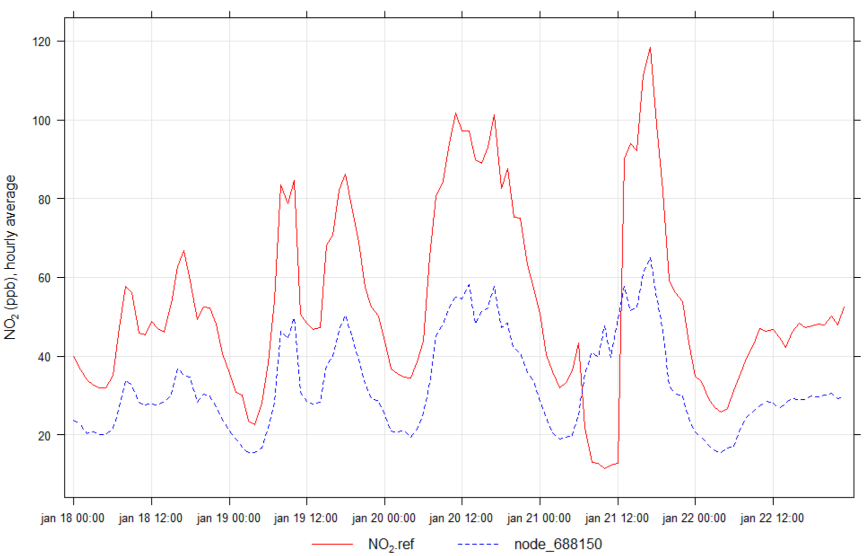
Philipp Schneider, ps@nilu.no

Low-cost platforms as complementary information: NO_2







- During January 2016, the precision of NO_2 sensor was higher than for other periods.
- The linear calibration applied was not enough and the node underestimated NO_2 concentrations.
- The nodes captured the NO_2 episode.