

What is the status of sensor technology today?

The hard truth, experience from laboratory and field

Contents

- Can we use low-cost nodes for air quality management?
 - Laboratory evaluation
 - Field evaluation
 - Examples of two real-world applications
 - Conclusions

CITI-SENSE and Citi-SENSE-MOB projects



Portable LEO platform
Portable CairSense unit



Static AQMesh platform



Mobile DunavNet platform



Mobile NanoSensAir platform

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?

Nuria Castell ^{a,*}, Franck R. Dauge ^a, Philipp Schneider ^a, Matthias Vogt ^a, Uri Lerner ^b, Barak Fishbain ^b, David Broday ^b, Alena Bartonova ^a

^a NILU – Norwegian Institute for Air Research, Kjeller, Norway

^b Faculty of Civil and Environmental Engineering, Technion – Israel Institute of Technology, Haifa, Israel



Low-cost sensor platforms are available to the public but information about performance is lacking

Vaisala Air Quality Transmitter AQT410

Overview Technical Specifications Documents

Overview

Vaisala Air Quality Transmitter AQT410 measures the most common gaseous pollutants nitrogen dioxide (NO₂), sulphur dioxide (SO₂), carbon monoxide (CO) and ozone (O₃). The AQT410 measurement performance is based on proprietary advanced algorithms that enable ppb measurements at an affordable price using electrochemical sensors.

AQT410 has been specifically designed for air quality monitoring networks in urban areas, road networks or around industrial sites and airports. Thanks to its small weight and compact size it is ideally suited for deployment even in large air quality networks.



A revolution in air quality monitoring

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3 JANUARY 2017 — PLUME LABS

Meet Flow, your smart mobile air quality tracker

For the past two years, Plume Labs has had one mission: helping you stay ahead of air pollution to improve your environmental health.

Today we are incredibly proud to **unveil the design of Flow by Plume Labs**, the first smart, mobile air quality tracker.



THE AIRCASTING PLATFORM

HOW IT WORKS



your air quality sensor

AIRBEAM

The AQMesh platform v3.5

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



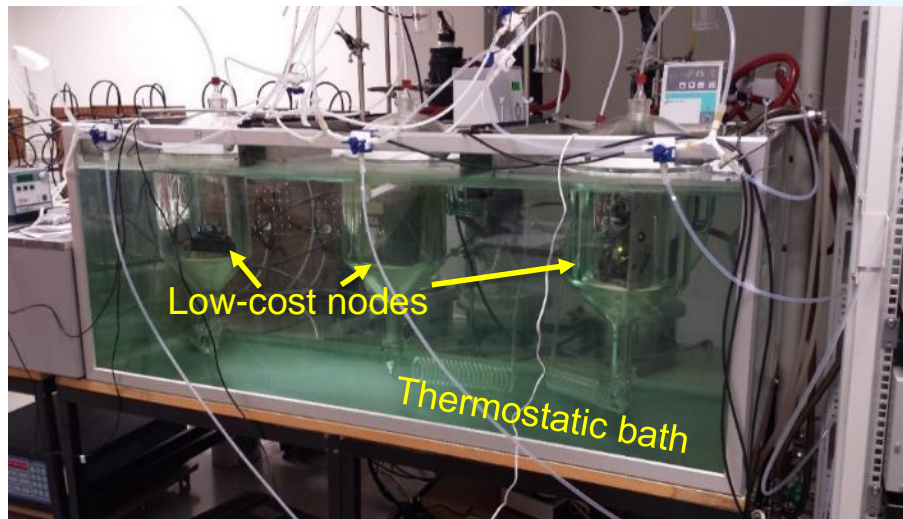
Parameter	Symbol	Range	Units	Limit of detection
Pod Temperature		-20 – 100 °C	°C	0.1 °C
Pressure		500 – 1500 mb	mb	1 mb
Relative Humidity		0 – 100 %RH	%RH	1 %RH
Nitric Oxide	NO	0-2000 ppb	ppb / ug/m ³	<5 ppb
Nitrogen Dioxide	NO ₂	0 – 200 ppb	ppb / ug/m ³	<5 ppb
Ozone	O ₃	0 – 200 ppb	ppb / ug/m ³	<5 ppb
Carbon Monoxide	CO	0 – 5000 ppb	ppb / ug/m ³	<5 ppb
Particulate Count		1-30 µm	Particles/cm ³	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

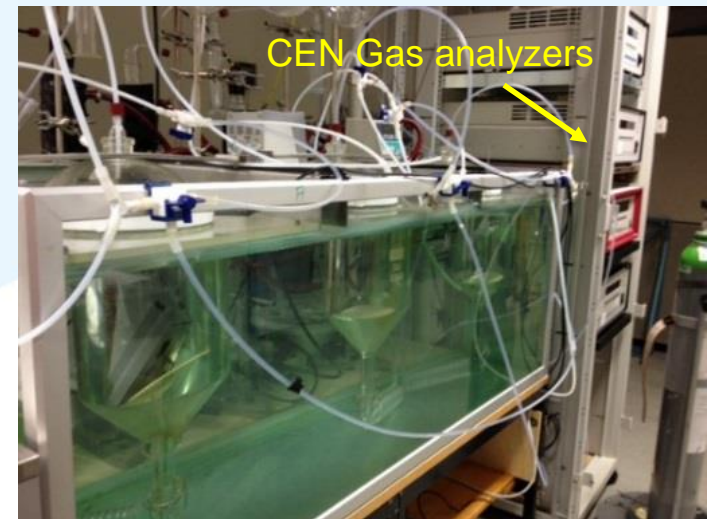
- Excellent NO correlation: Typical $R^2 > 0.85$
- Very good NO₂ correlation: Typical $R^2 > 0.75$
- Very good O₃ correlation: Typical $R^2 > 0.7$
- Very good CO correlation: Typical $R^2 > 0.7$
- Excellent Particle Count correlation: Typical R^2 Versus FIDAS > 0.85
- Excellent pod to pod correlation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

Can we reproduce those values?

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

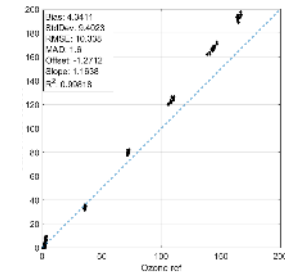
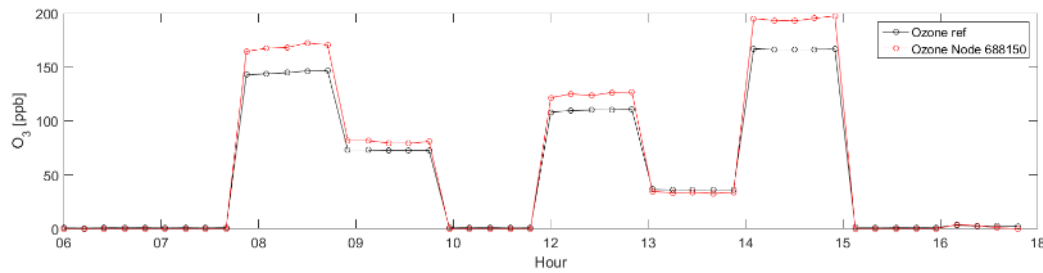


Gas	Analyzer
CO	Teledyne API 300E (EN14626)
NO _x	Teledyne API 200A (EN 14211)
O ₃	Teledyne API 400 (EN 14625)

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

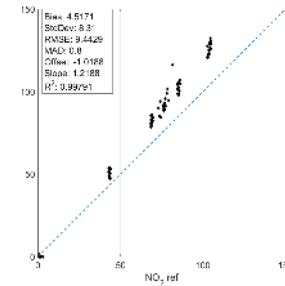
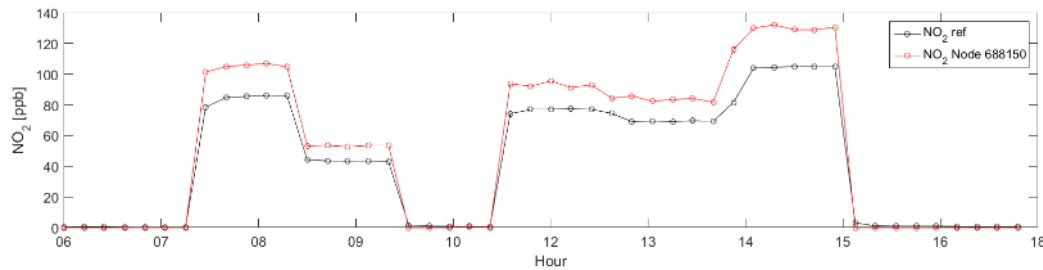
- Two sensor nodes: 688150 and 864150.
- 864150 was tested after 3 months of field deployment.

Laboratory evaluation: results



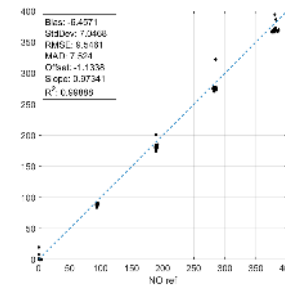
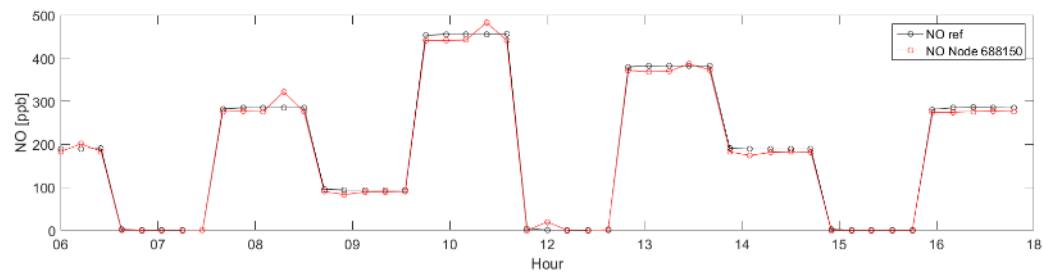
Cross-sensitivity: NO₂ (Low-High)

LOD: 1.8 ppb



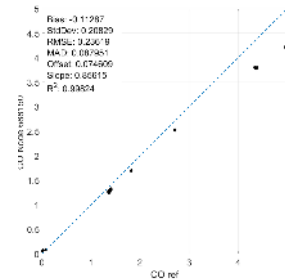
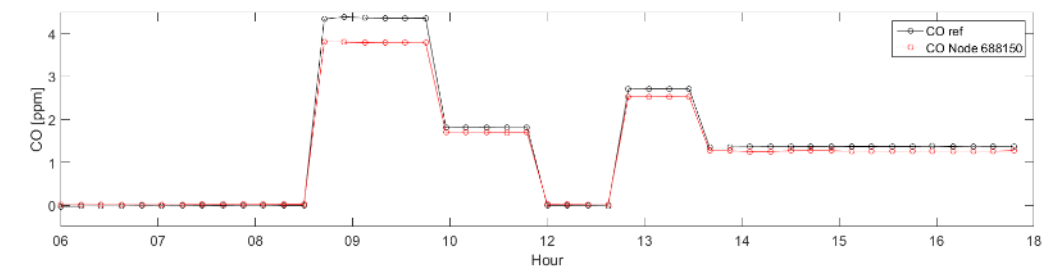
Cross-sensitivity: No

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

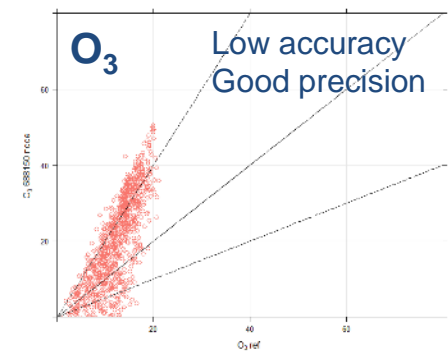
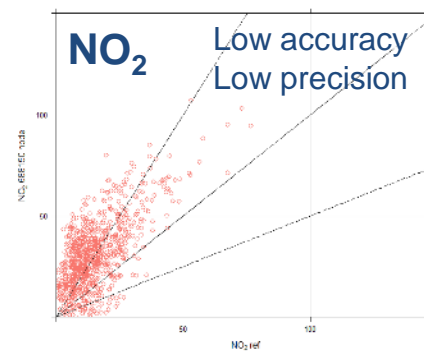
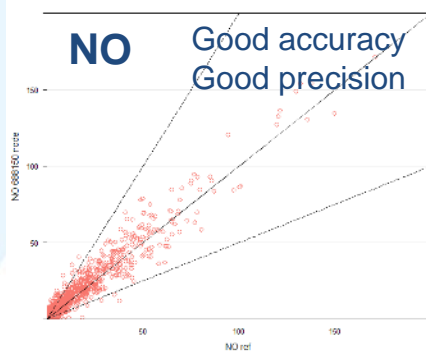
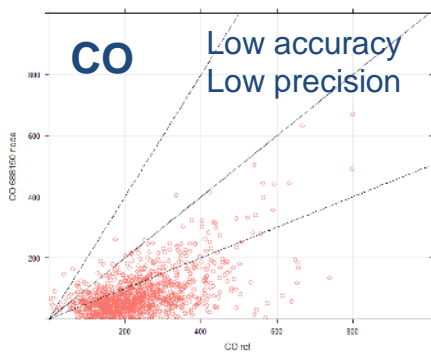
Gas	Analyzer
CO	EC Serinus 30 (EN14626)
NO _x	EC Serinus 40 (EN 14211)
O ₃	Teledyne API 400 (EN 14625)

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)

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



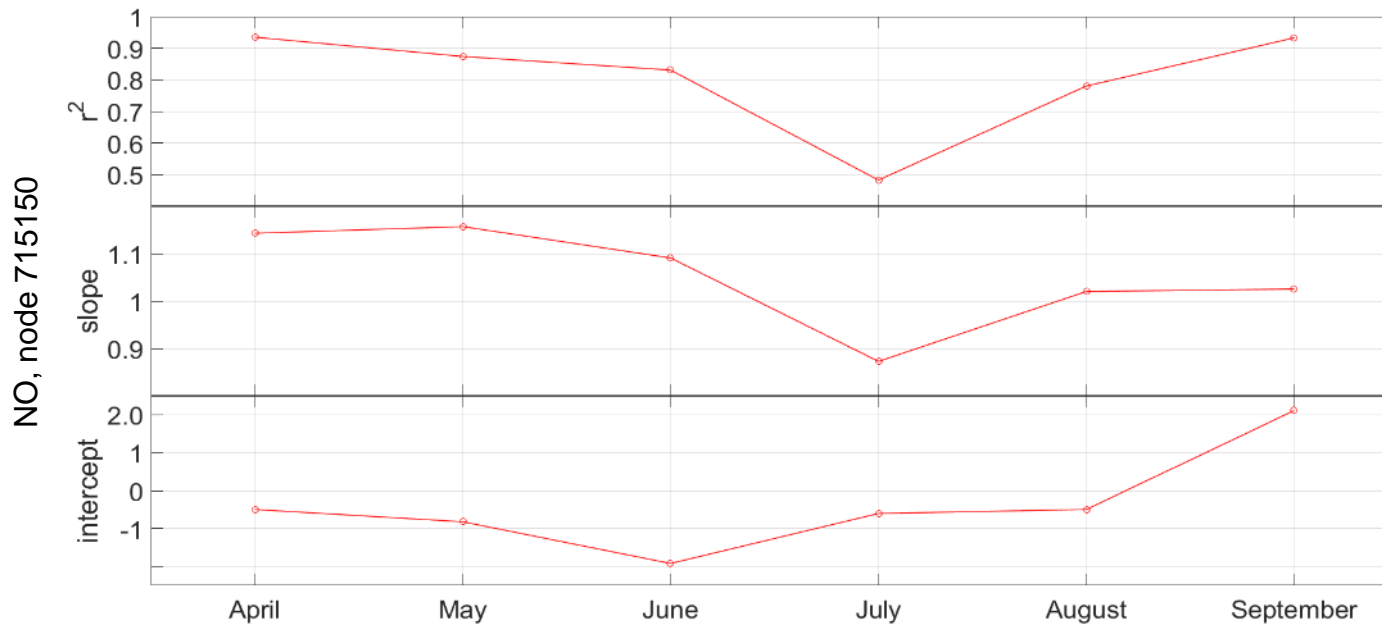
- A good performance in the laboratory is not indicative of a good performance in field.
- Correlations significantly lower in the field than in the laboratory.
- Necessary to calibrate the sensors in the field.

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

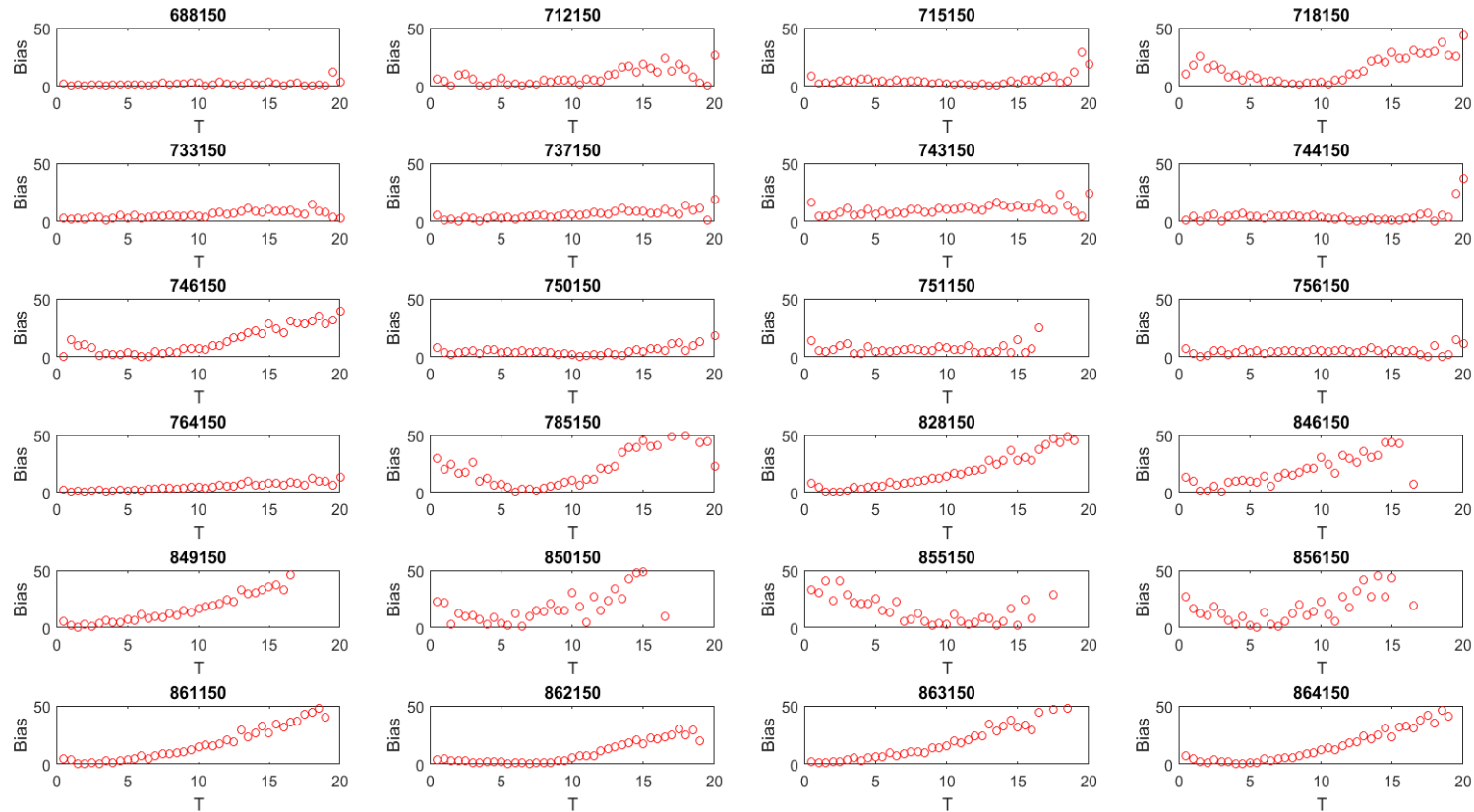
- The results show that even for identical sensors and platform, the performance can vary sensor to sensor.
- Challenge in ensuring sensor measurement repeatability.

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.

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

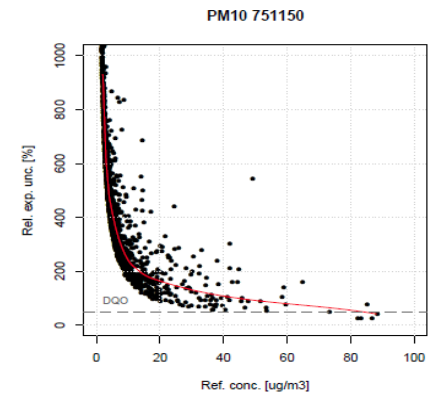
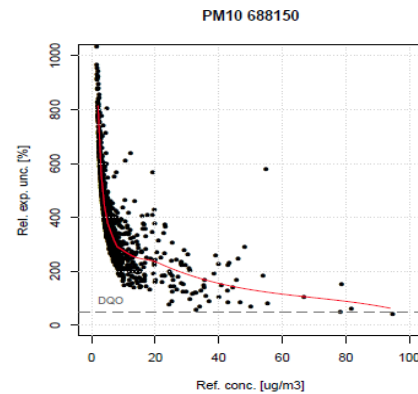
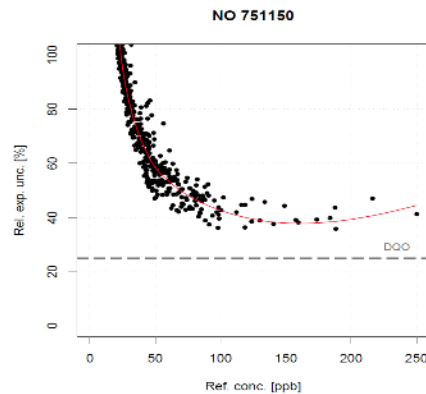
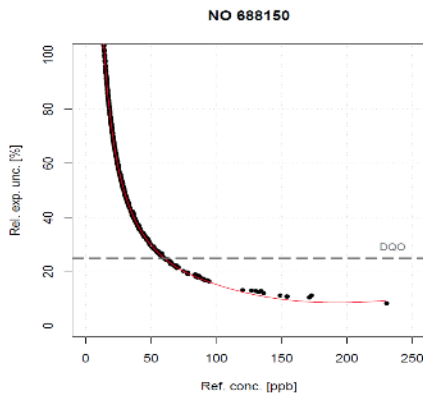
Node 688150	CO	NO	NO ₂	O ₃	PM ₁₀	PM _{2.5}
Coef. determination (r ²) Lab	0.99	0.99	0.99	0.99	-	-
Coef. determination (r ²) Field (dense traffic)	0.34	0.92	0.42	0.65	0.53	0.40
Coef. determination (r ²) Field (calm traffic)	-	0.24	0.15	-	0.68	0.84
Slope Lab	0.86	0.97	1.22	1.16	-	-
Slope Field (dense traffic)	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).

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.

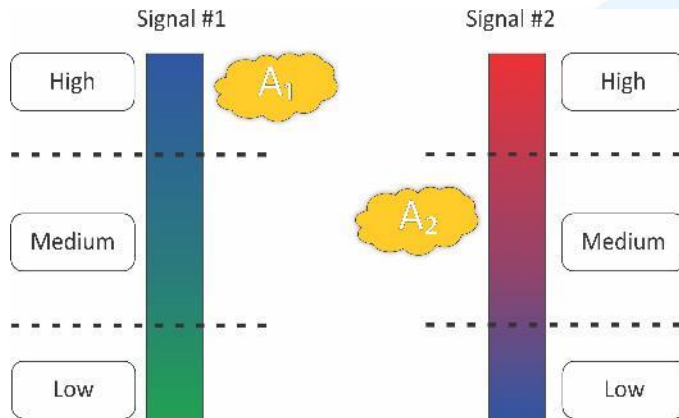
DQO	SO ₂ , NO ₂ , NO _x , CO	PM10, PM2.5	O ₃
Fixed measurements	15%	25%	15%
Indicative measurements	25%	50%	30%



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

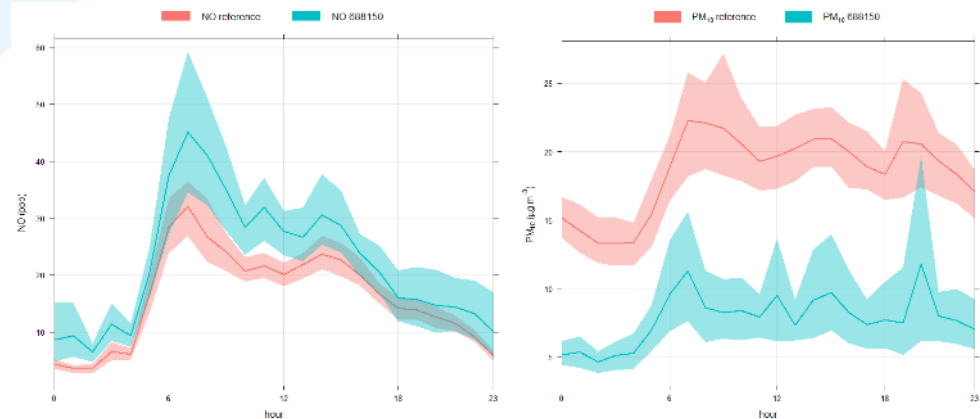
Field evaluation results: match score analysis

For most citizen applications (eg. awareness raising and education) data quality does not need to reach the same standards necessary for air quality management.



$A_1(t)$ & $A_2(t)$ in the same segment \rightarrow Match score = 1
 $A_1(t)$ & $A_2(t)$ not in the same segment \rightarrow Match score = 0

Match	CO	NO	NO ₂	O ₃	PM ₁₀	PM _{2.5}
Average	0.44	0.79	0.46	0.32	0.91	0.48
Max	0.50	0.92	0.52	0.54	0.93	0.52
Min	0.33	0.47	0.37	0.13	0.87	0.39



- For NO and PM10 the average match score is above 0.7.
- For some pollutants, the nodes can provide an indication if the air pollution is low, medium or high.

Low-cost platforms as complementary information

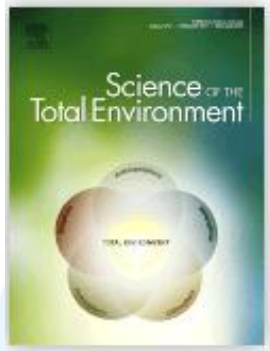
The outlook for commercial low-cost sensors is promising, and our results show that after data processing they are already capable of offering useful information.



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.

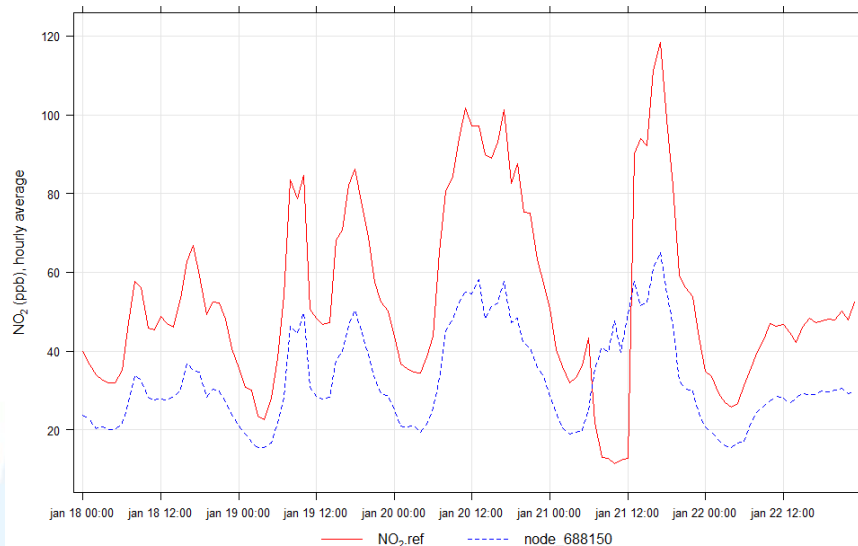
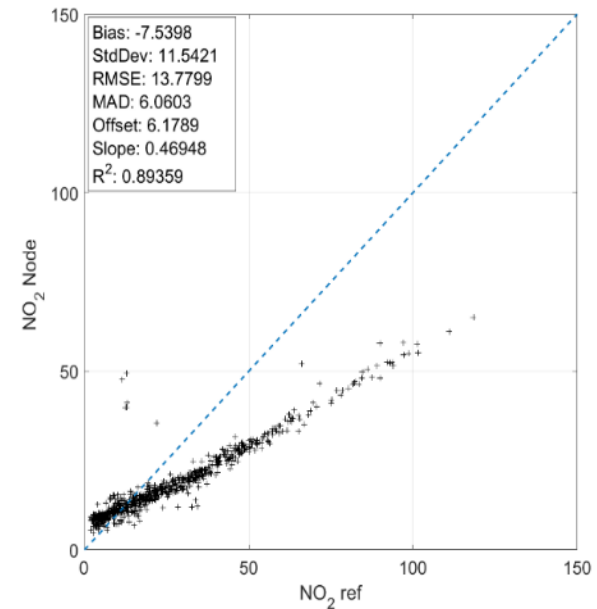
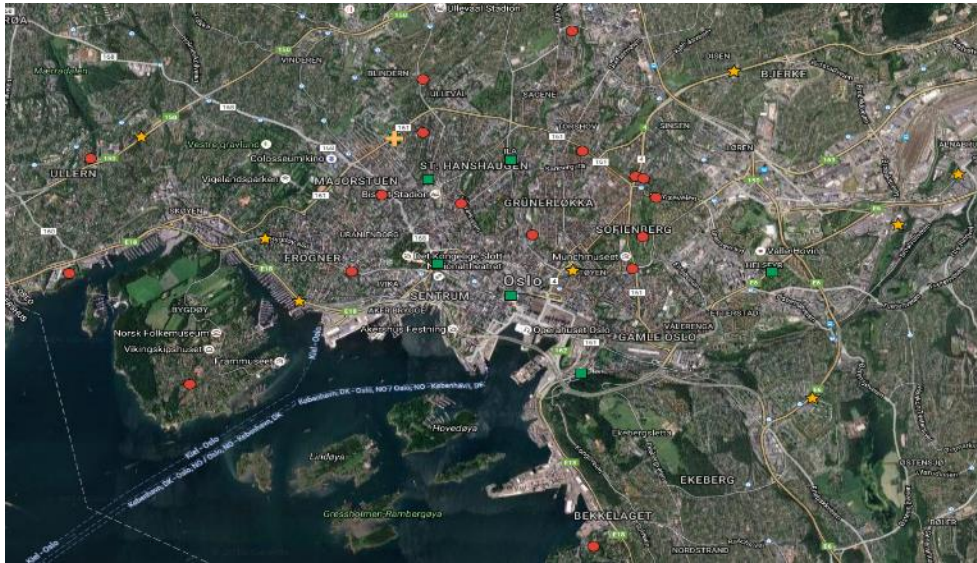


Continuous real-time measurement of particulate matter (PM₁₀) in Oslo, Norway using a network of low-cost sensor nodes

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

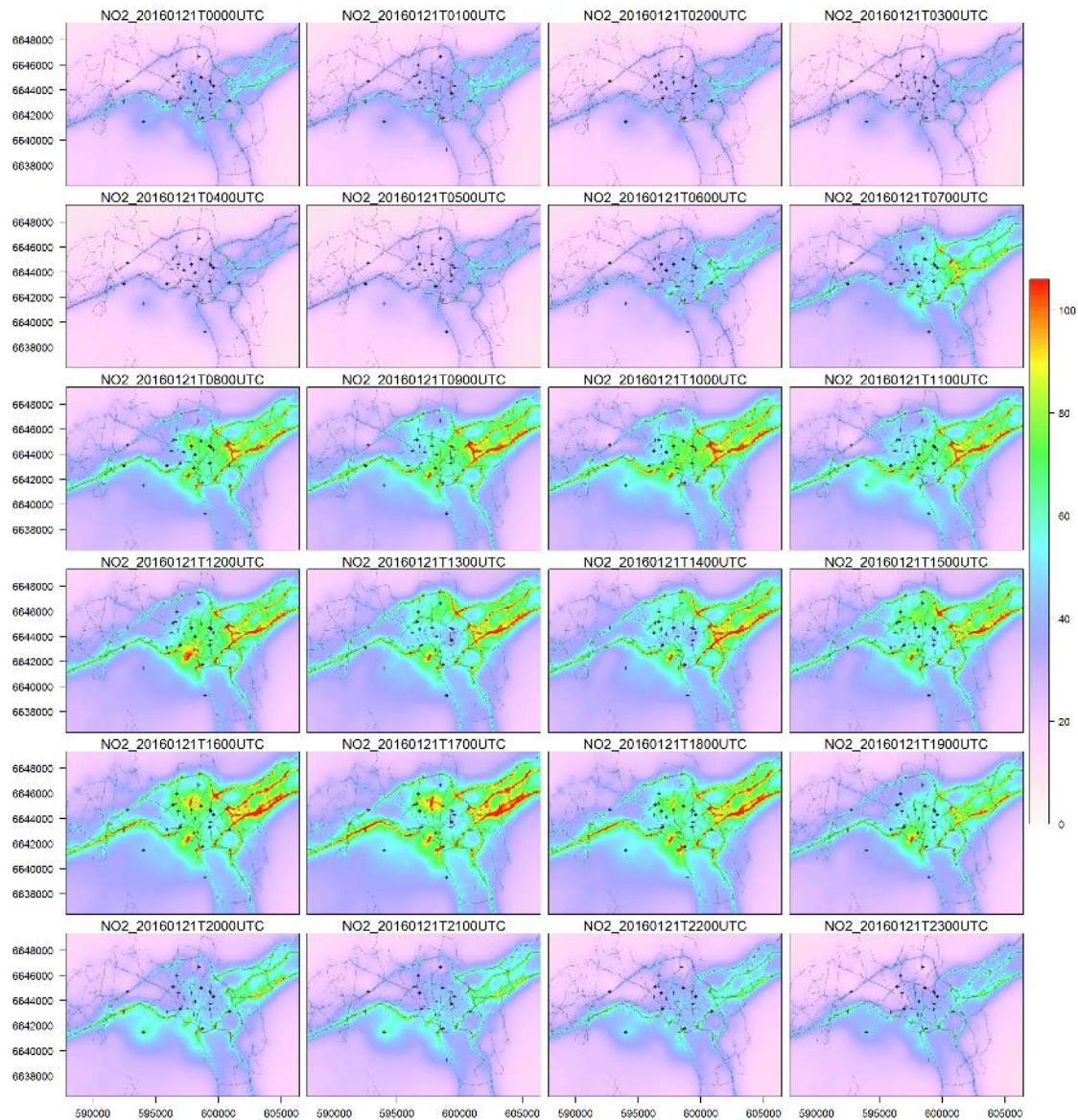
NILU – Norwegian Institute for Air Research, Kjeller, Norway.

Low-cost platforms as complementary information: NO₂

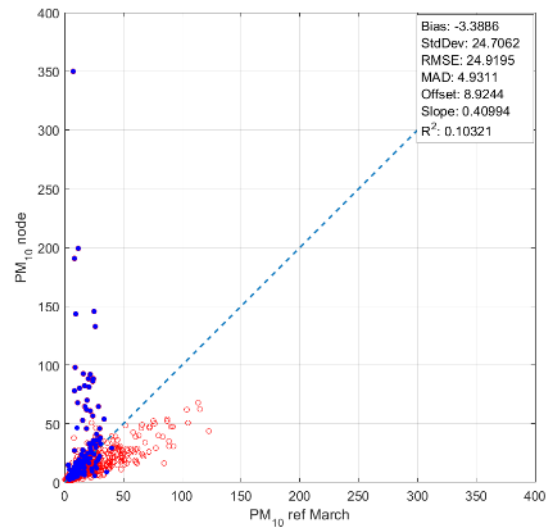


- During January 2016, the precision of NO₂ sensor was higher than for other periods.
- The linear calibration applied was not enough and the node underestimated NO₂ concentrations.
- The nodes captured the NO₂ episode.

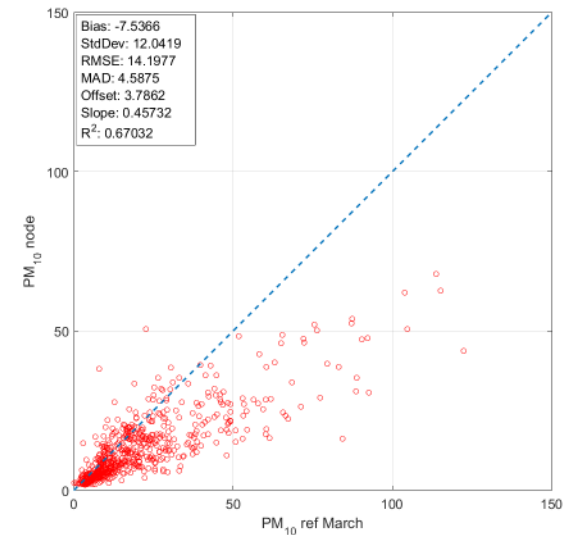
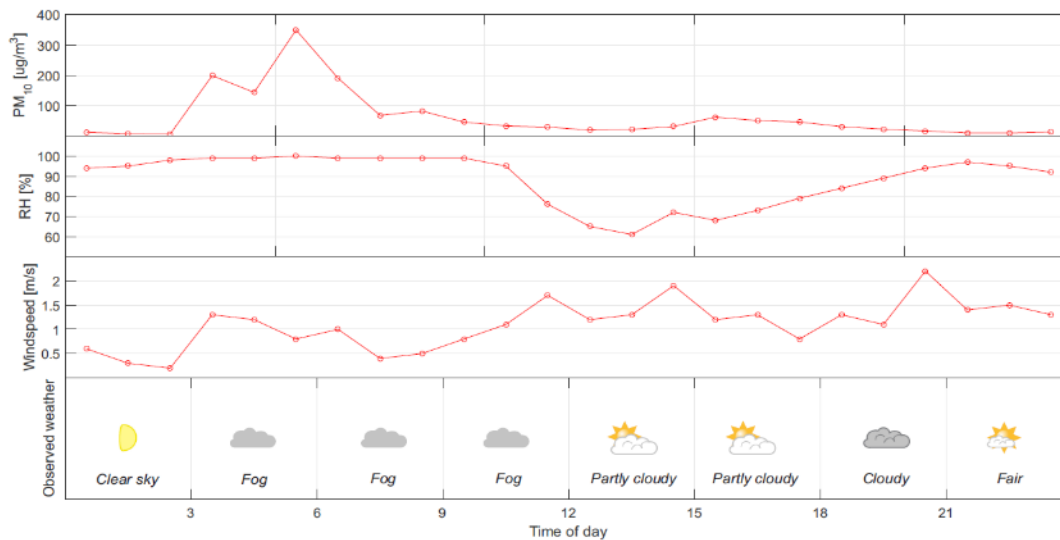
Low-cost platforms as complementary information: NO₂



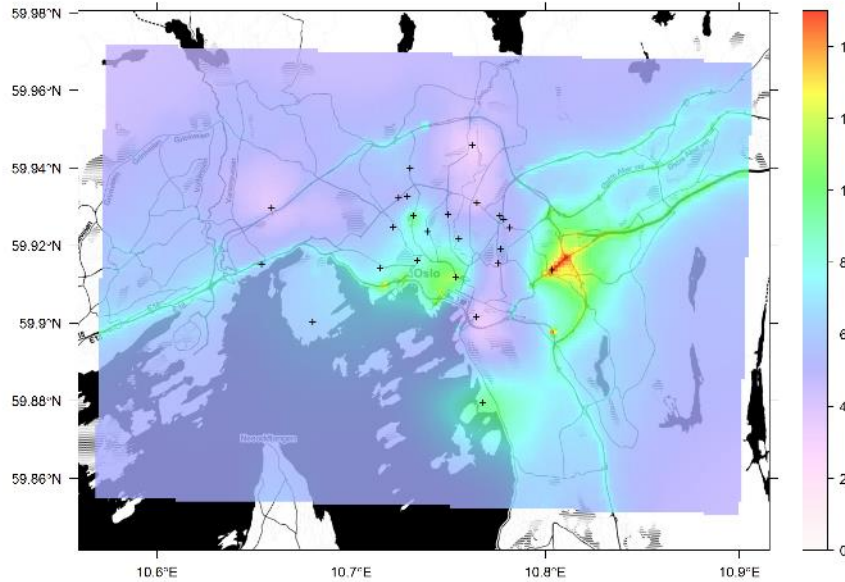
Low-cost platforms as complementary information: PM₁₀



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

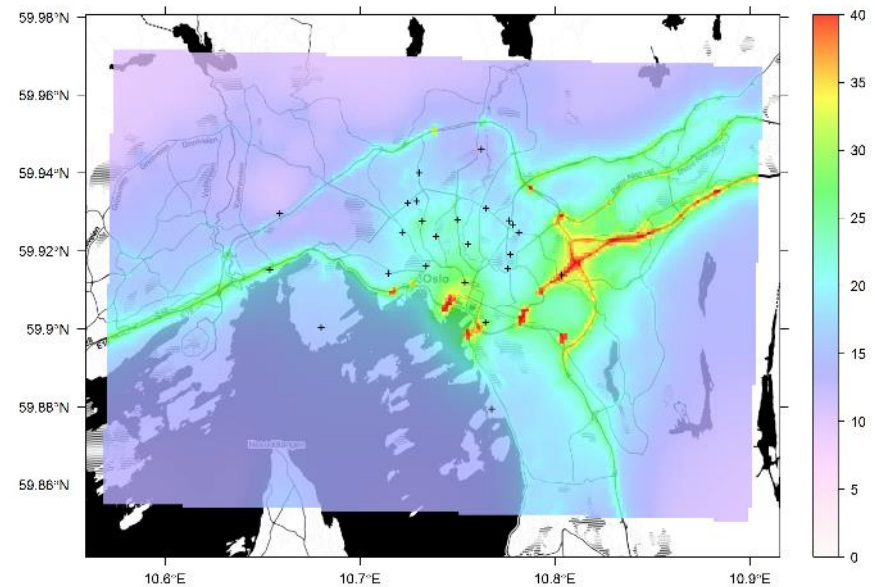


Low-cost platforms as complementary information: PM₁₀



A day with precipitation and low PM₁₀ concentrations

A day after a period without precipitation and high PM₁₀ concentrations



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.

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.

Thank you for your attention

Nuria Castell, ncb@nilu.no

