Air quality sensors: potential & Challenges

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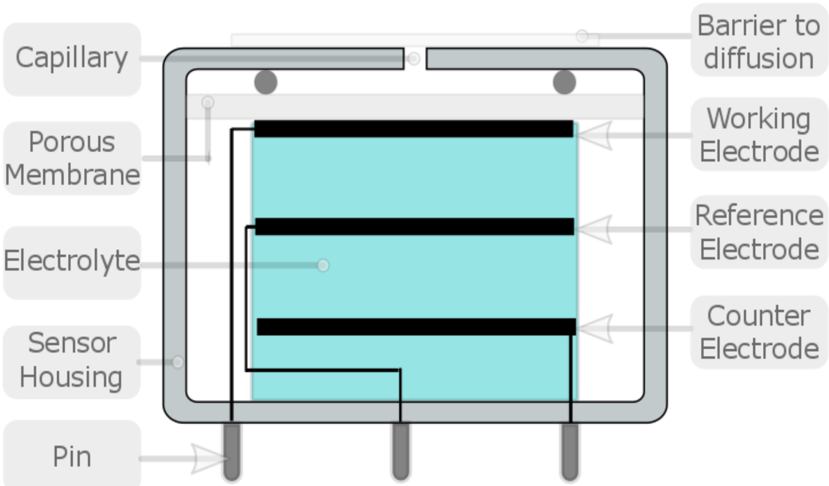
Fairmode-Aquila joint session
16 February 2016
Baveno - Italy

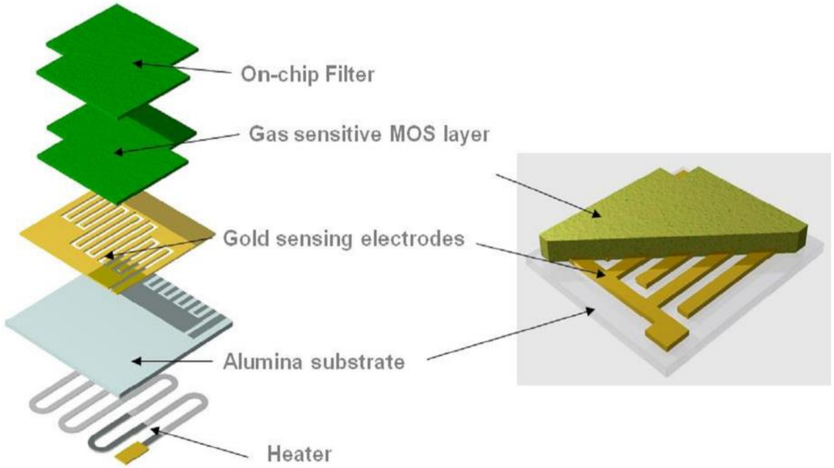
Main types of low-cost sensors for inorganic compounds

Amperometric

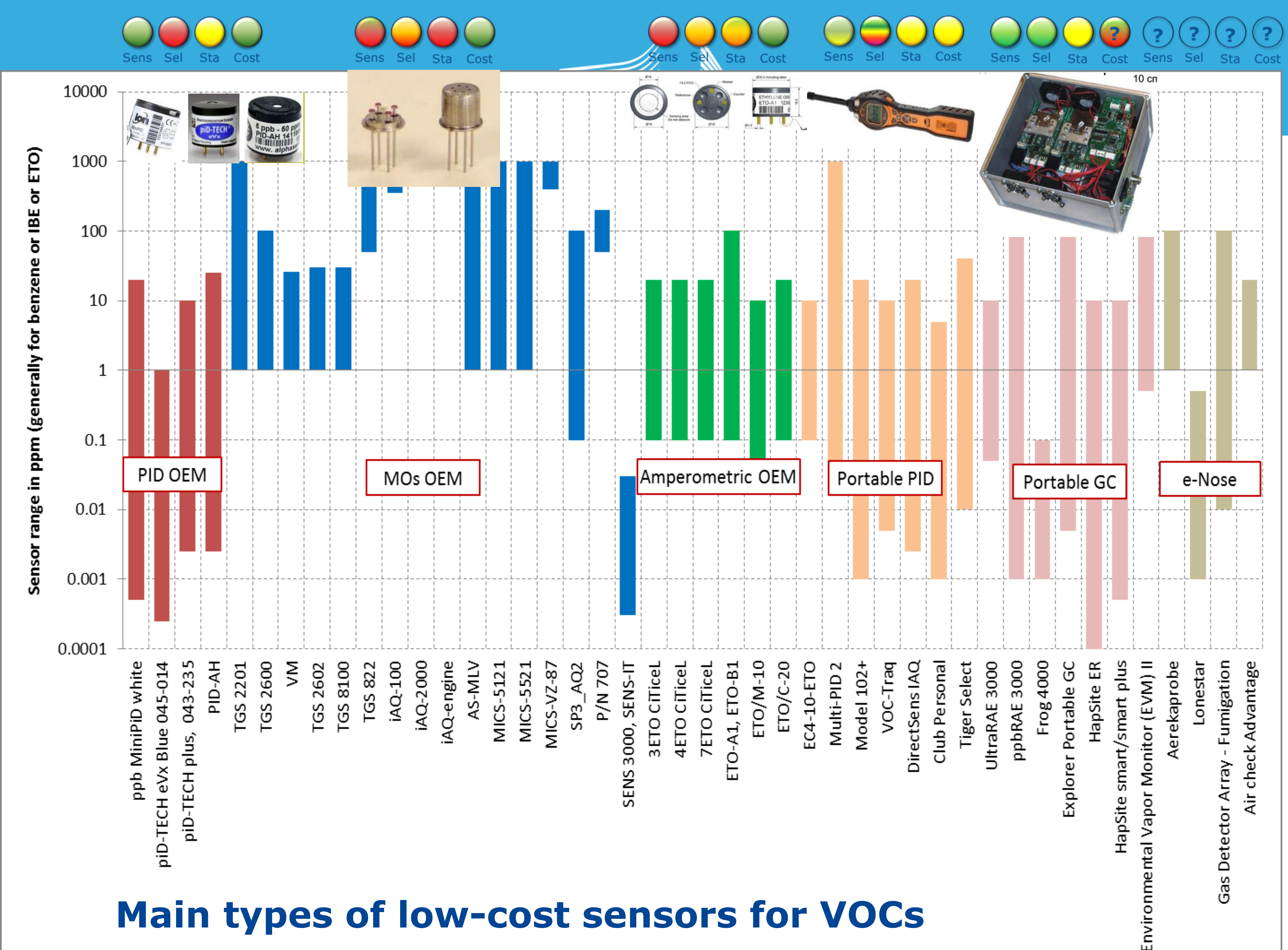


- The current of an oxido-reduction reaction that is proportional to the gas concentration is measured under constant difference of potential
- Sensitivity: applied potential, amplification, Rload
- Selectivity: applied potential, add chemical filters

Metal Oxide



- Modification of electrical conductivity due to adsorbed gas species
- Sensitivity: size layer, grain sizes, surface to volume ratio
- Selectivity: varying crystal structure and morphology, dopants, contact geometries, operation temperature or mode of operation.



Main types of low-cost sensors for VOCs

Optical sensors for PM monitoring

Sensor	Method	Size Fraction	Measurement Unit	Weight (kg)	Shortest Time Resolution	Base Power Accessory	Data Retrieval Method
AirBase CanarIT	Optical	Undefined	ug/m^3	~2.5	20 sec	AC/DC Adapter	Proprietary Web Server
CairClip PM	Optical	$PM_{2.5}$	ug/m^3	~0.2	1 min	Battery	Proprietary Software
Carnegie Mellon Speck	Optical	Undefined	Particle counts	~0.25	1 sec	USB	Proprietary Software
Dylos DC1100	Optical	Undefined	Particle counts	~2	1 min	AC/DC Adaptor	Proprietary Software
Met One 831	Optical	<10μm	ug/m^3	~2	1 min	Battery	Proprietary Software
RTI MicroPEM	Optical	$PM_{2.5}$	ug/m^3	~0.5	10 sec	Battery	Proprietary Software
Sensaris Eco PM	Optical	$PM_{2.5}$	ug/m^3	~0.25	<1 min	USB	Proprietary Web Server
Shinyei PMS-SYS-1	Optical	$PM_{2.5}$	ug/m^3	~0.25	1 sec	Power Circuit Board	Proprietary Software

Williams, R., Kaufman, A., Hanley, T., Rice, J., Garvey, S., 2014. Evaluation of Field-deployed Low Cost PM Sensors, Office of Research and Development National Exposure Research Laboratory.

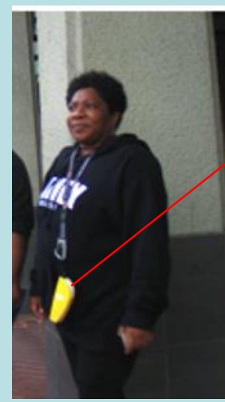
Use of Sensors

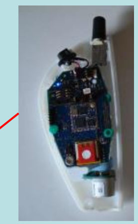
Low cost fixed monitoring station

Unitec srl, ETL3000 multi sensor station

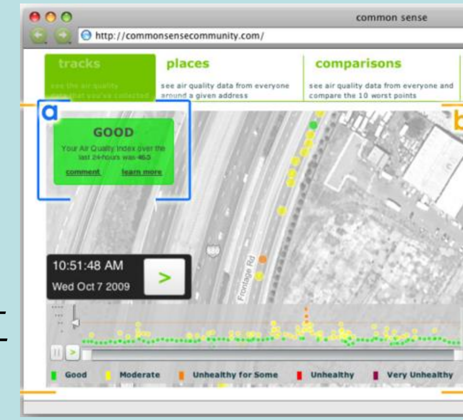
Aeroqual, AQM 60 Air Quality station

Mobile sensor for exposure monitoring



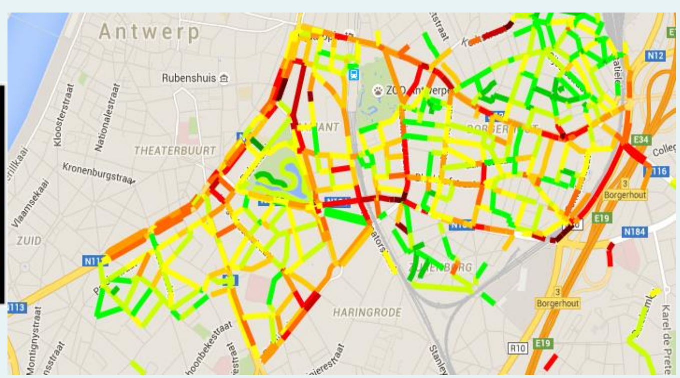


Common sense, INTEL Lab Berkley - USA

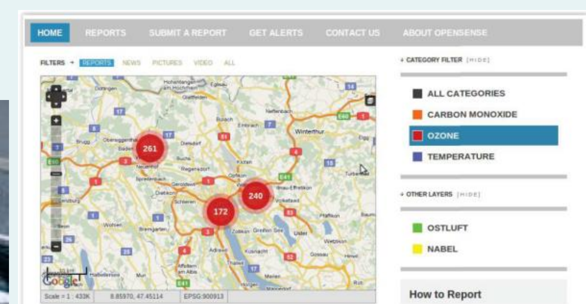


Sensors on bike for road profiles

Unitec srl ETLbike



Sensors on bus for real time mapping



OpenSense instance of Ushahidi collects and visualizes air pollution data

OpenSence (ETH-CH), http://www.opensense.ethz.ch

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The legal framework and sensor evaluations

- No defined EC policy for the use of low-cost sensors for ambient air monitoring
- The legal framework is the one of the air quality Directive: DQO for indicative measurements and objectives estimations. Really adapted for low-cost sensors?
- Research on sensors is mainly financed with public call for projects: FP7, H2020, life projects (many projects > 30, e. g. Castell et al., 2013). Mainly about sensor material research or sensor applications. Data quality is not the main focus.
- Little information is publically available about independent sensor evaluation, correction algorithms and software/electronic design of sensor platforms (a few exceptions as EveryAware …)
- EURAMET projects MACPoll and Key-VOCs focus on protocols and sensor evaluation
- In the CEN TC264 (Air Quality), Working Group 42 (Sensors), a protocol of evaluation of sensor is being developed.
- Looking for independent evaluation of sensors ….

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Independent evaluation of sensors,

	Manufacturer (Model)	Type	Pollutant(s)	Approximate Cost	Time Resolution	Sensor vs FRM/FEM Method[1]
	**Dylos** (DC1100)	Optical	$PM_{(0.5-2.5)}$	~$300	1 min	R^2 ~ 0.65 to 0.85
	**Shinyei** (PM Evaluation Kit)	Optical	$PM_{2.5}$	~$1,000	1 min	R^2 ~ 0.80 to 0.90
	**RTI** (MicroPEM)	Optical	$PM_{2.5}$	~$2,000	10 sec	R^2 ~ 0.65 to 0.90
	**HabitatMap** (AirBeam)	Optical	$PM_{2.5}$	~$200	1 min	R^2 ~ 0.65 to 0.70
	**Met One** (Neighborhood Monitor)	Optical	$PM_{2.5}$	~$1,900	15 min	R^2 ~ 0.53 to 0.67
	**Speck**	Optical	$PM_{2.5}$	~$200	1 min	R^2 ~ 0
	**Naneos** (Partector)	Electrical	PM (LDSA: Lung-Deposited Surface Area)	~$7,000	1 min	$PM_{1.0}$: R^2 ~ 0.1 $PM_{2.5}$: R^2 ~ 0.2
	**AethLabs** (microAeth)	Optical	BC (Black Carbon)	~$6,500	1-300 sec	R^2 ~ 0.79 to 0.94
	**Air Quality Egg** (Version 1)	Optical, Metal oxide	PM, CO, NO_2 and O_3	~$200	1 min	PM: R^2 ~ 0 CO: R^2 ~ 0 NO_2: R^2 ~ 0.40 O_3: R^2 ~ 0.85
	**Perkin Elmer** (ELM)	Optical, Metal oxide	PM, NO, NO_2 and O_3	~$5,200	1 min	PM: R^2 ~ 0 NO: n/a NO_2: R^2 ~ 0 O_3: R^2 ~ 0.89 to 0.96
	**2B Technologies** (PO_3M)	UV absorption (FEM Method)	O_3	~$4,500	10 sec	R^2 ~ 1.00
	**Aeroqual** (S-500)	Metal oxide	O_3	~$500	1 min	R^2 ~ 0.85
	**Smart Citizen Kit**	Metal oxide	CO, NO_2	~$200	1 min	CO: R^2 ~ 0.50 to 0.85 NO_2: R^2 ~ 0
	**AQMesh** (v.3.0)	Electrochem	CO, NO, NO_2, SO_2, and O_3	~$10,000	1-15 min	CO: R^2 ~ 0.75 to 0.90 NO: R^2 ~ 0.75 to 0.90 NO_2: R^2 ~ 0 SO_2: R^2 ~ 0 O_3: R^2 ~ 0.25 to 0.55
	**AQMesh** (v.4.0)	Electrochem	CO, NO, NO_2 and O_3	~$10,000	1-15 min	CO: R^2 ~ 0.42 to 0.80 NO: R^2 ~ 0.0 to 0.44 NO_2: R^2 ~ 0.0 to 0.46 O_3: R^2 ~ 0.46 to 0.83
	**UNI-TEC** (SENS-IT)	Metal oxide	CO, NO_2 and O_3	~$2,200	1 min	CO: R^2 ~ 0.33 to 0.43 NO_2: R^2 ~ 0.60 to 0.65 O_3: R^2 ~ 0.72 to 0.83

Air Quality Sensors Performance Evaluation Center, South Coast AQMD

http://www.aqmd.gov/aq-spec/evaluations#&MainContent_C001_Col00=2

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US –EPA: Air Sensor Toolbox for Citizen Scientists: Resources

http://www.epa.gov/air-research/air-sensor-toolbox-citizen-scientists-resources

MACPOll: evalaution of single sensors, rural site

Ozone:

- Amperometric: Good: precise, linear, long term stability, little matrix effect, hysteresis and temperature effect

  Less good: interference NO_2, humidity effect

- MOx: Good: low gaseous interference, precise, sensitive, humidity and temperature effect can be corrected

  Less good: calibration, lack of linearity, long term stability, matrix effect, response time

- DQO: Found Ok for one chemical sensor (NO2 interference and humidity effect solved)

- Calibration: field calibration better as lab calibration is not reproducible

Nitrogen dioxide: O_3 interference for amperometric sensors, matrix effect and humidity, gaseous interference on res. sensors – no good field results with chemical sensors (sensitive to O_3)

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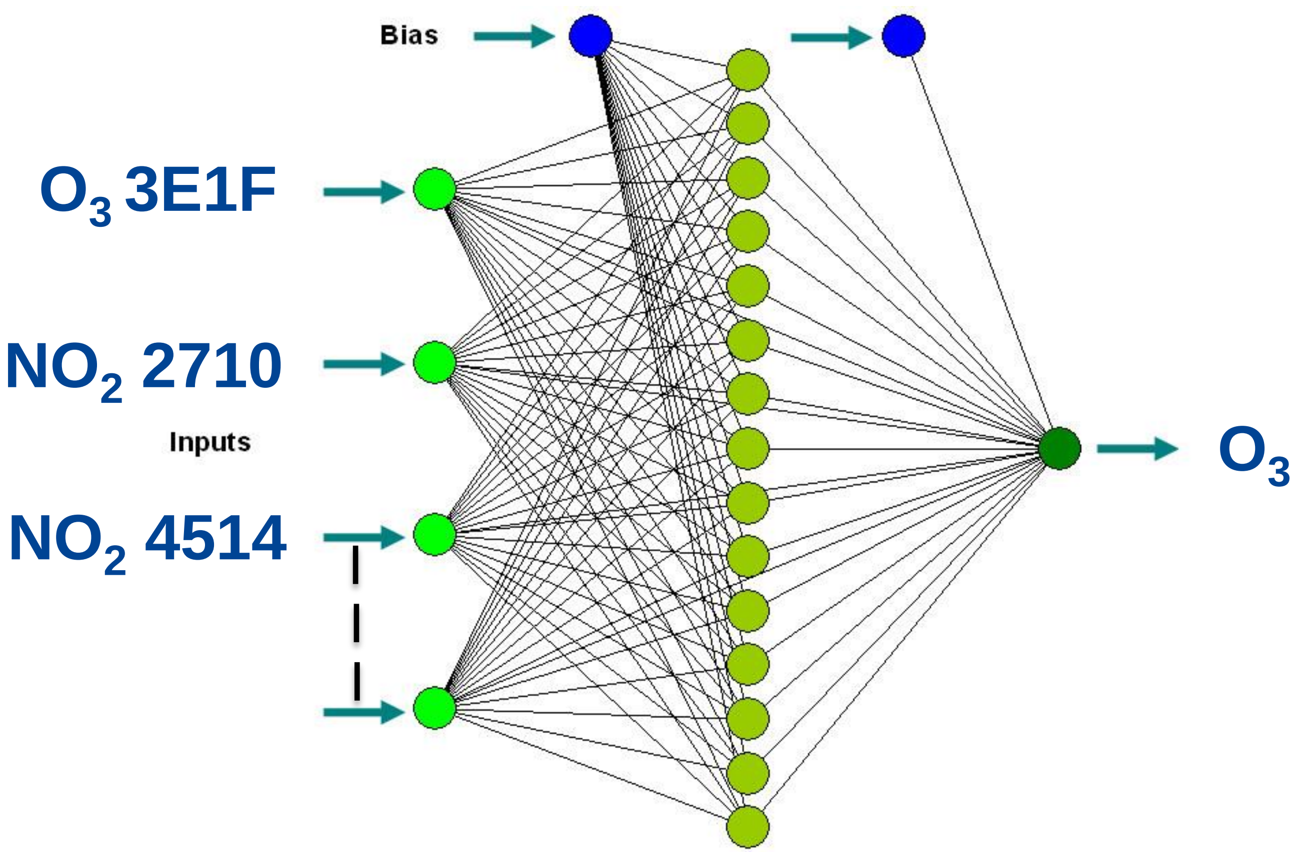
Artificial Neural network

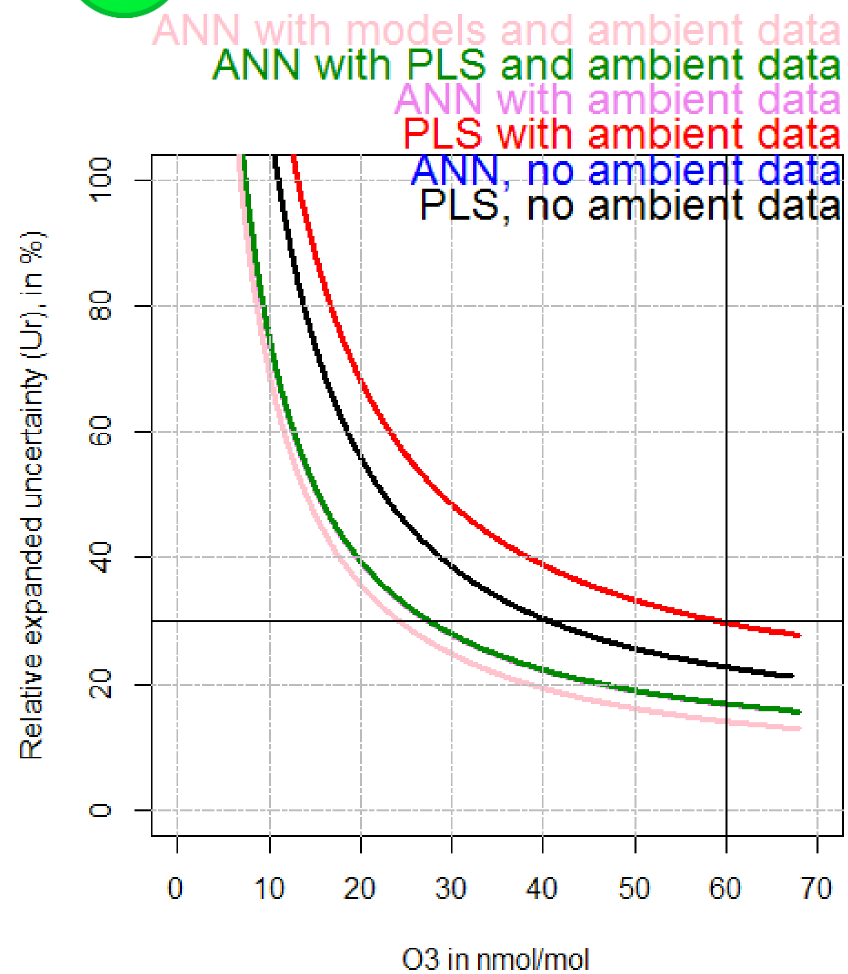


Model Uncertainty

O_3 NO_2 NO CO CO_2

Algorithms	Ambient parameters	Inputs
Phys. Model (PLS)	No	Sensors
~~ANN~~	~~No~~	~~Sensors~~
PLS + Ambient	Yes	Sensors + Ambient
ANN + Ambient	Yes	Sensors + Ambient
ANN + PLS	Yes	Sensors + Ambient
ANN + MLR	Yes	Sensors + Ambient+ Model

$$U_r(y_i) = 2\left(\sqrt{\frac{RSS}{(n-2)} - u^2(x_i) + [a + (b-1)\cdot x_i]^2}\right) / y_i$$



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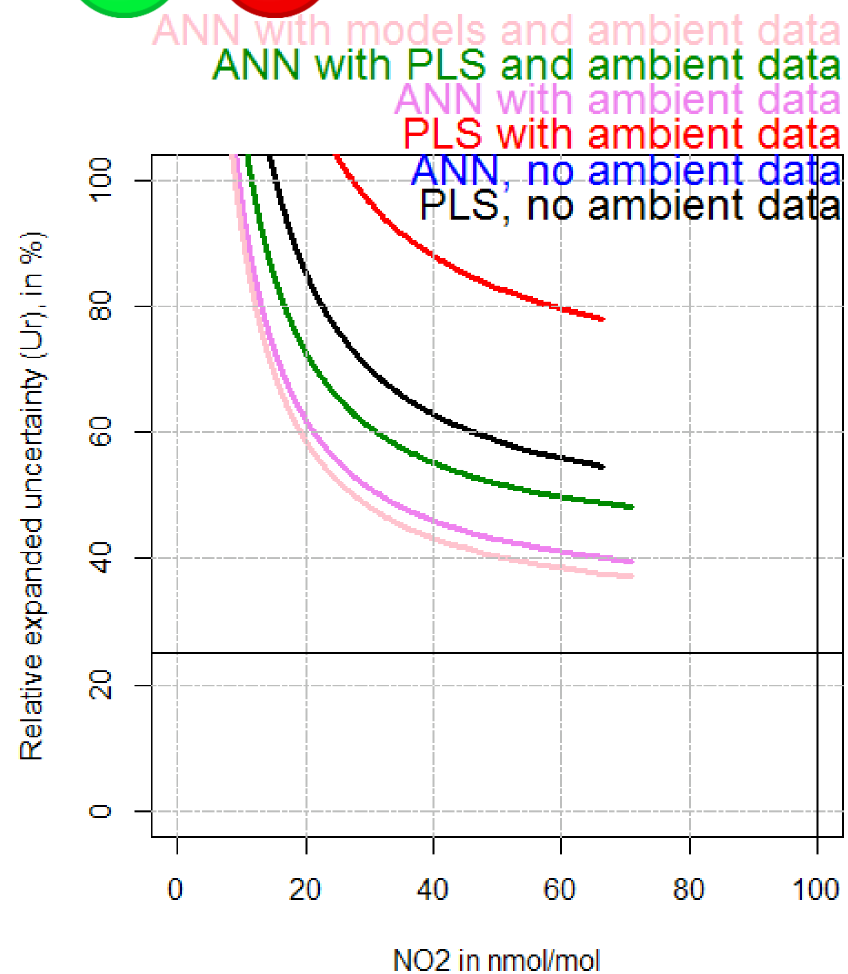

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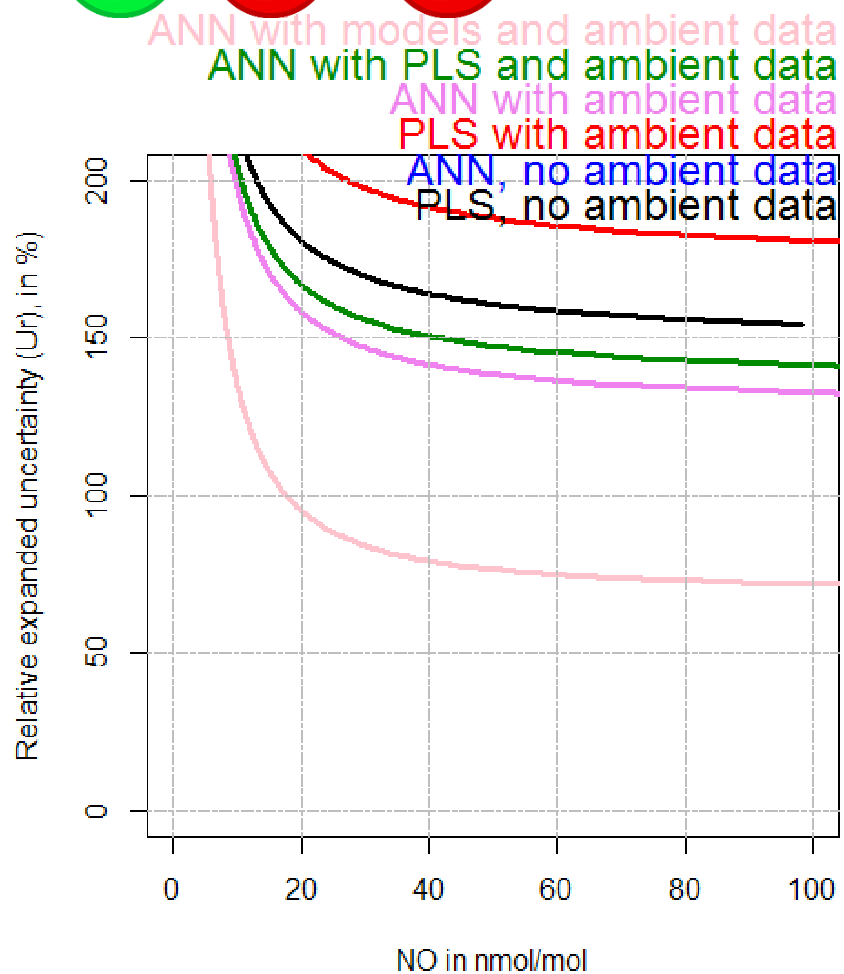
O_3 NO_2 NO CO CO_2



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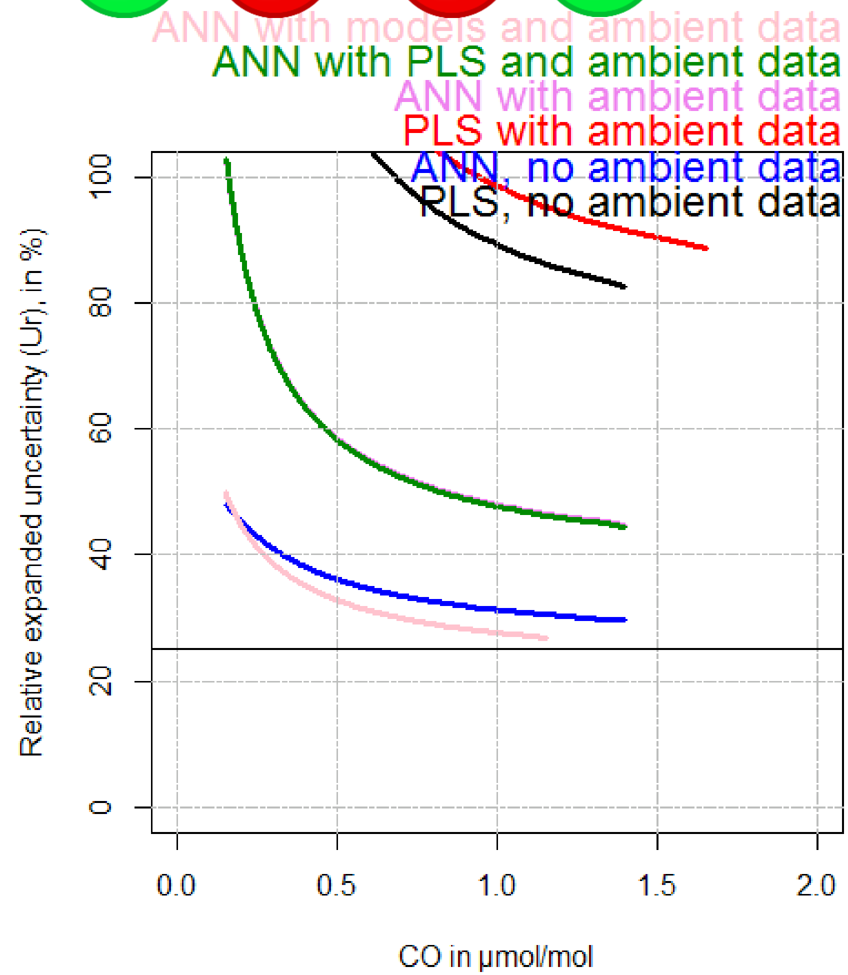

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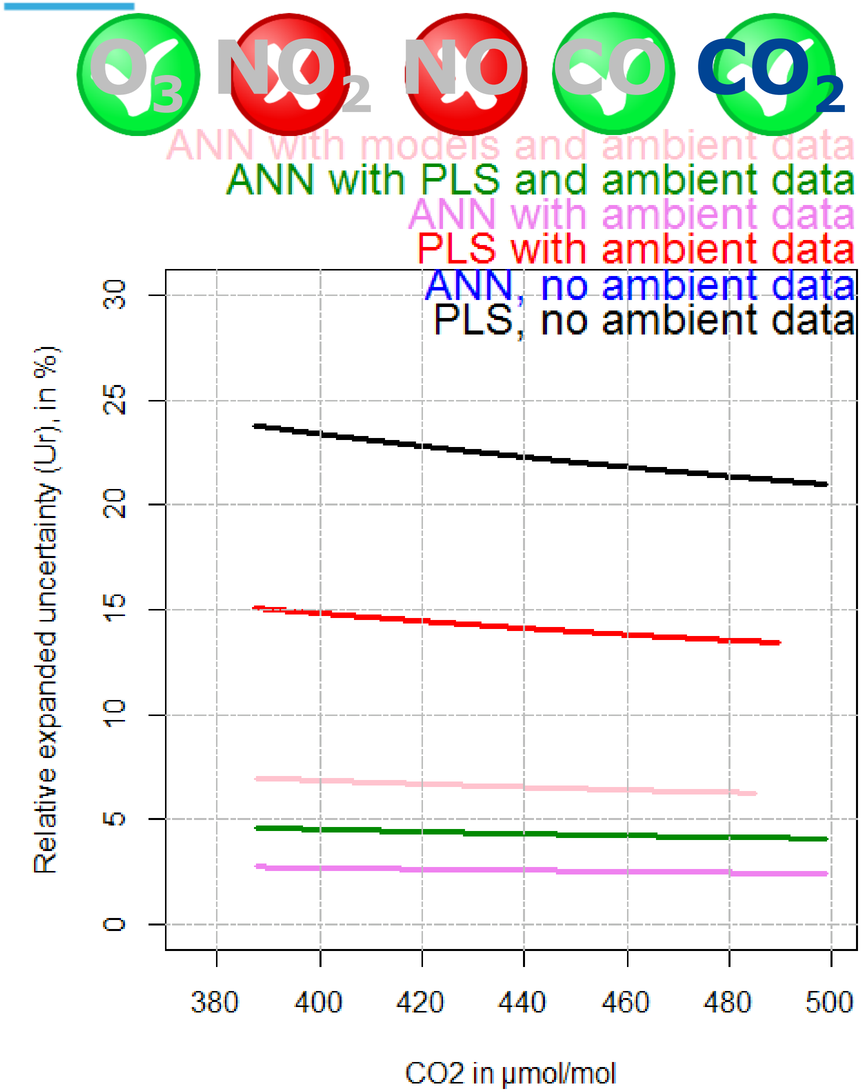

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MACPoll conclusions calibration methods for the cluster of sensors

- The DQO for indicative methods can be met for O_3, likely for CO , not for NO_2 (DQO of 35% > 25%). SO2 too low to be evaluated. High uncertainty for NO (> 75 %). For CO_2, low uncertainty down to about 3%.
- Multivariate PLS regression gives thee highest U (with or without meteo)
- Meteo data does decrease measurement uncertainty for the ANN methods.
- ANN methods: higher R^2 and lower RSS -> lower U
  ANN methods: lower bias to reference data (slopes and intercept nearer to 1 and 0, respectively)
- ANN method with input from the physical model and meteo is the best. The inclusion of the PLS as an input for the ANN does not improve the estimation.

Air quality – Performance evaluation of sensors for the determination of concentrations of gaseous pollutants and particulate matter in ambient air (Doc. N 2274)

Scope of the proposed deliverable :

Description of specific performance requirements and test methods under prescribed laboratory and field conditions for low-cost sensors and sensor arrays that may include a sensor holder and auxiliary systems for sampling, data treatment and/or power supply

Aims of the protocol (request 2364)

- meet the Data Quality Objective (DQO) for "indicative measurements" – Added: "objective estimation" and a new category call "informative method" without DQO

- O_3, NO_2/NO, CO, SO_2, PM10, $PM_{2.5}$, CO_2 and benzene. Avoid VOCs because of cross sensitivities

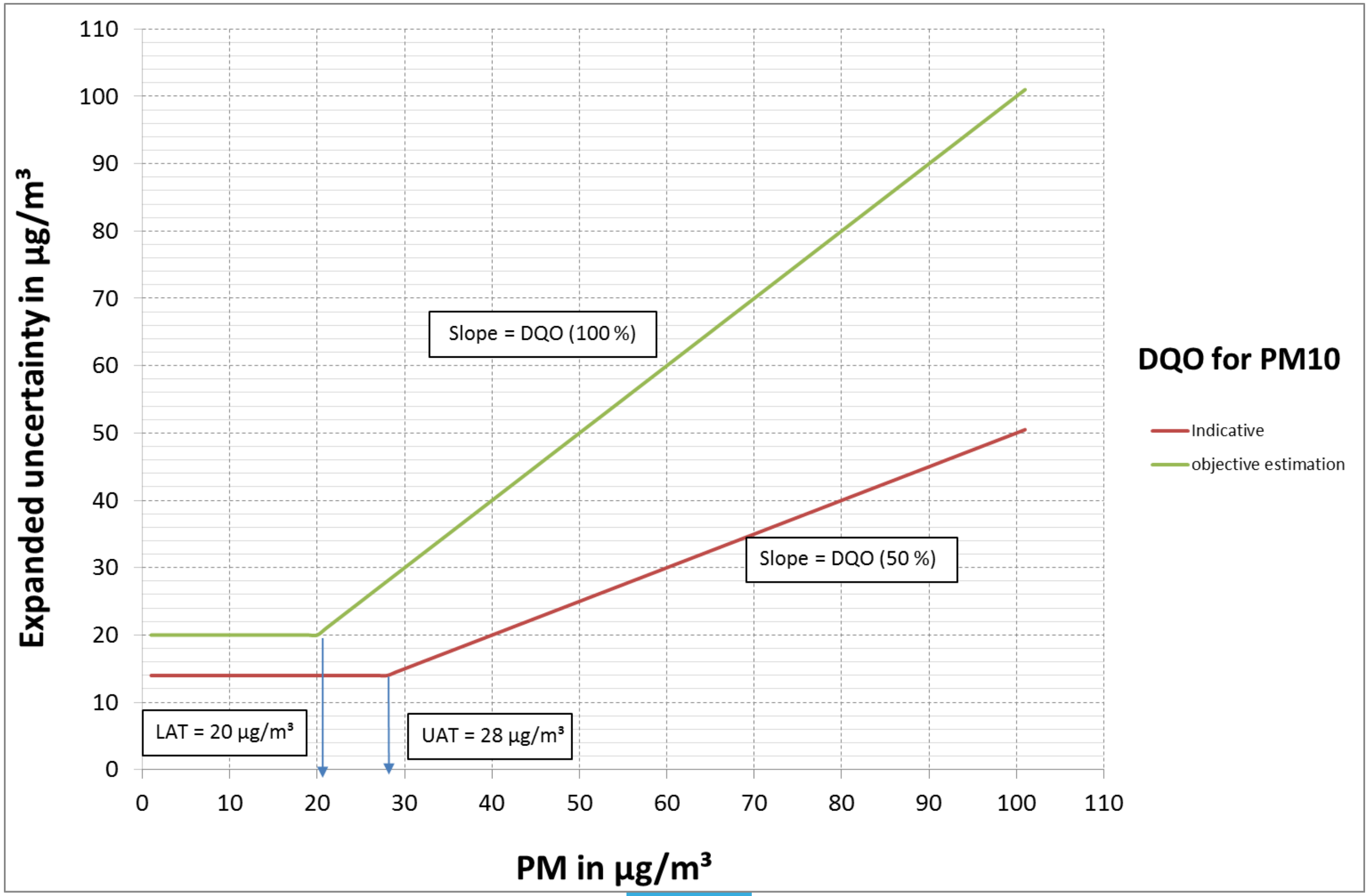
Applications

➢ Fixed measurements	yes for outdoor
➢ Mobile measurements	Only for outdoor monitoring and if we can find supporting data
➢ Indoor	No
➢ Networks of sensors	(not for this standard)

Data Quality Objective (2008/50/EC)

	Indicative	Objective estimation
SO_2, NO_2/NOx, CO	25 %	75 %
Benzene	30 %	100 %
PM_{10}/$PM_{2.5}$	50 %	100 %
O3	30 %	100 %
	LAT<[]<UAT	[]<LAT

Data quality objectives



Parameters to be evaluated (E), corrected (C)

Parameters to be tested (significant ones: in bold)	Indicative method	Objective estimation	Informative method
Response time (at controlled conditions)	E (in lab.)	E (lab.)	E (in lab.)
Calibration at constant Temp. and RH	E/C (in lab.)	E/C (lab.)	E/C (in lab.)
Repeatability for 0 and span at constant Temp. and RH	E (in lab.)	E (lab.)	E (in lab.)
Short and **long term** drifts	E/C (in lab. or field)	E (lab or field)	E (only long term drift) (in field)
Cross sensitivities	E/C (in lab.)	E (in lab.)	E (in field)
Temperature (Temp.) and humidity (RH)	E/C (in lab.)	E (in lab.)	E (in field)
Hysteresis (concentration levels, Temp., RH), transient effects of humidity	E/C (in lab.)	E (in lab) (temp., RH), not transient	E (in field)
Wind velocity	E/C (in lab.)	E (in lab.)	E (in field)
Power supply	E/C (in lab.)	E (in lab.)	
Active sampling, loses … only for some sensors	E/C (in lab.)	E (in lab.)	
Electromagnetic fields …	E/C (in lab.)	E (in lab.)	
Pressure effect	E/C (in lab.)	E (in lab.)	E (in field)
Solar heating	E (in field)	E (in field)	

AirSensEUR: An open source sensor platform

JRC & partners are working on the AirSensEUR project since spring 2015

- Objective: "Create open and interoperable sensor nodes which provide observation data", and meet the requirements of
  - A) Air Quality Directive
  - B) INSPIRE Directive

- **Specifications, data quality and calibration:** JRC Air and Climate Unit (ERLAP, Michel Gerboles, Laurent Spinelle)
- **Data management:** JRC Digital Earth Unit (Sven Schade, Max Craglia, Alex Kotsev)
- **Platform design and software:** Liberaintentio srl (Marco Signorini)
- **Growing community of sensor testers**: RIVM-NL, NILU-NO, AIRPARIF-FR …

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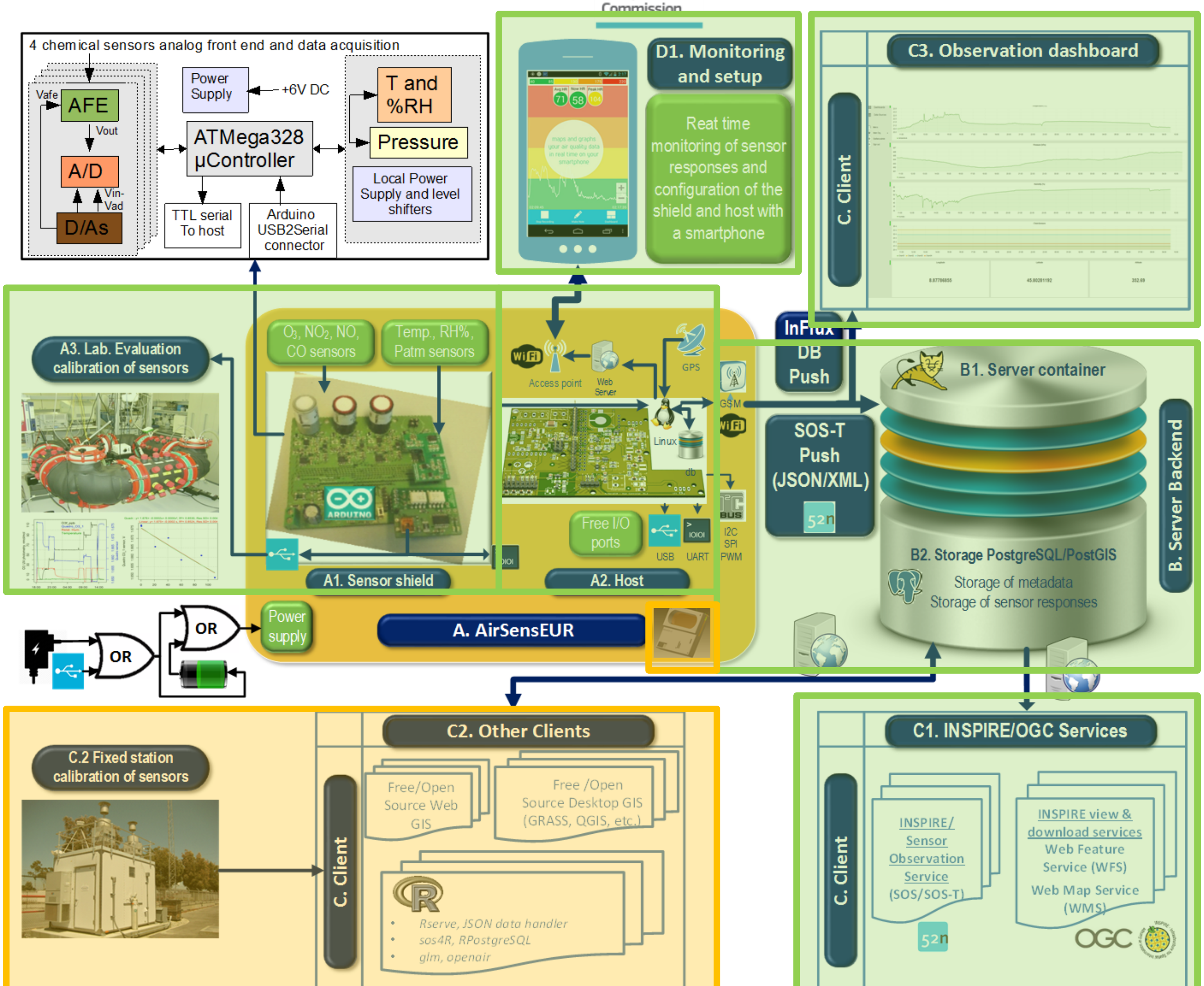

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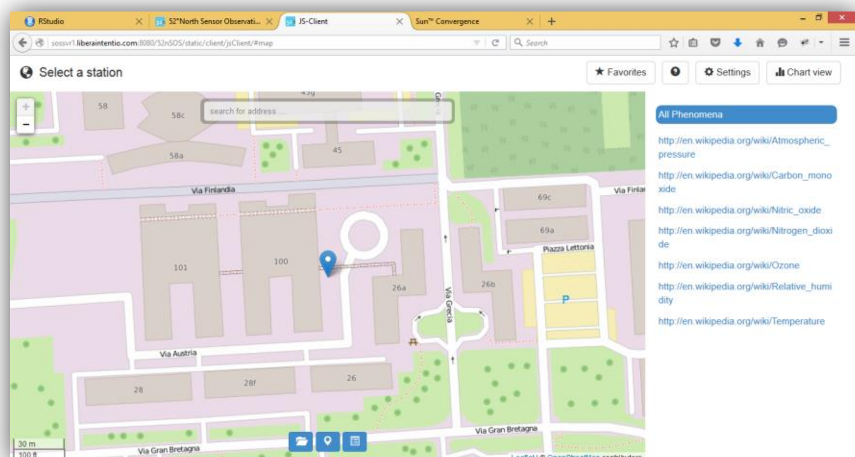
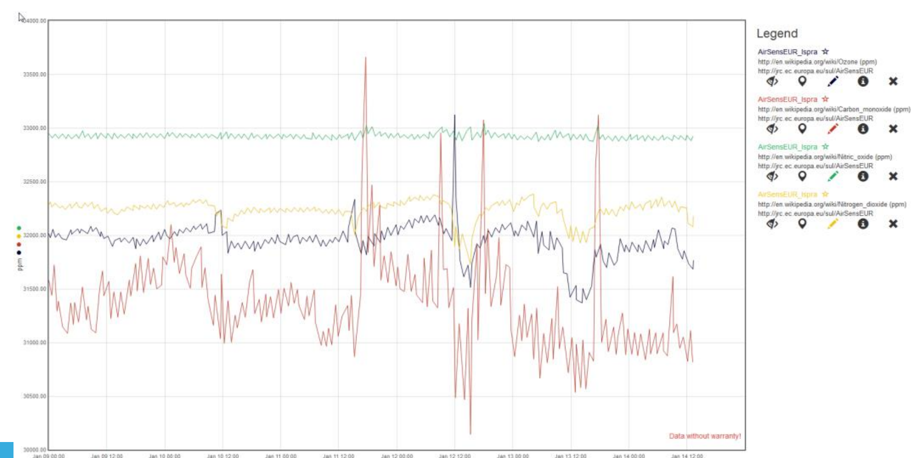
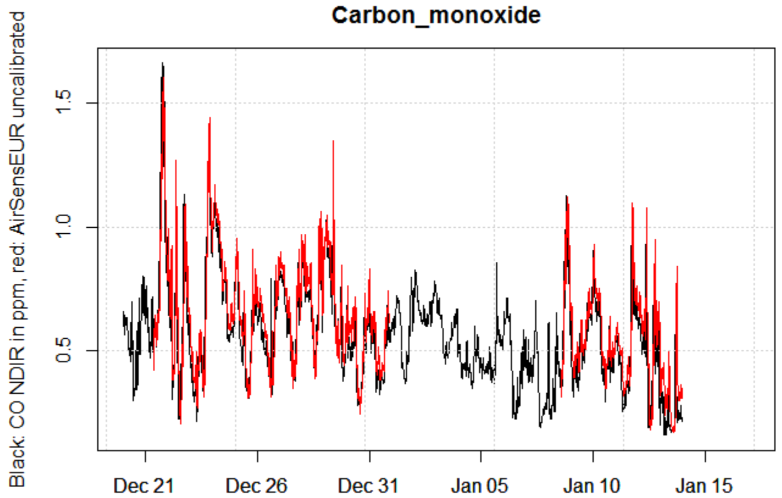
AirSensEUR uses Public licenses

- low cost open source sensor platform, battery operated, for air quality monitoring
- 4 chemical sensors (e.g O3, NO, NO2, CO or SO2) from several manufacturers including AlphaSense, City technology, Membrapor and SGX SensorTech
- auxiliary sensors for temperature, pressure and relative humidity
- Aggregate samples with GPS information, periodically update an external server through WiFi or GPRS channels
- Own SOS-T Java client (open source, EUPL) – consistent with the Inspire Directive







Photos: L. Spinelle (H02)

Thank you

Gerboles M., et al, AirSensEUR: an open data/software /hardware multi-sensor platform for air quality monitoring. Part A: sensor shield, doi: 10.2788/30927, http://publications.jrc.ec.europa.eu/repository/handle/JRC97581

Spinelle L., et al., Sensitivity of VOC Sensors for Air Quality Monitoring within the EURAMET Key-VOC project, http://dx.doi.org/10.5162/4EuNetAir2015/02

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Spinelle, L. et al., Field calibration of a cluster of low-cost available sensors for air quality monitoring. Part A: Ozone and nitrogen dioxide, Sensors and Actuators B, http://www.sciencedirect.com/science/article/pii/S092540051500355X

Gerboles, M.,et al., "AirSensEUR: An Open-Designed Multi-Sensor Platform for Air Quality Monitoring." http://dx.doi.org/10.5162/4EuNetAir2015/03

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Aleixandre, M. et al., 2013. Calibration of small resistive commercial sensors to measure ozone with the interference of temperature and humidity. In *2013 IEEE Sensors*. 2013 IEEE Sensors. pp. 1–4. http://ieeexplore.ieee.org/search/searchresult.jsp?newsearch=true&queryText=%20Calibration%20of%20small%20resistive%20commercial%20sensors%20to%20measure%20ozone%20with%20the%20interference%20of%20temperature%20and%20humidity

Karagulian, F., et al., Evaluation of a portable nephelometer against the Tapered Element Oscillating Microbalance method for monitoring PM 2.5, J. Environ. Monit., 2012, 14, 2145, *http://dx.doi.org/*10.1039/c2em30099k

Manuel Aleixandre, Michel Gerboles, Review of Small Commercial Sensors for Indicative Monitoring of Ambient Gas, VOL. 30, 2012, Chemical Engineering Transactions, http://www.aidic.it/cet/12/30/029.pdf

Report of laboratory and in-situ validation of micro-sensor for monitoring ambient air - Ozone micro-sensors, AlphaSense, model B4-O3 sensors (UK), L. Spinelle et al., http://publications.jrc.ec.europa.eu/repository/handle/JRC90463

Report of laboratory and in-situ validation of micro-sensor for monitoring ambient air pollution - NO9: CairclipNO2 sensor of CairPol (F), Spinelle et al., http://publications.jrc.ec.europa.eu/repository/handle/JRC86499

Report of the laboratory and in-situ validation of micro-sensors for monitoring ambient air pollution - O12: CairClipO3/NO2 of CAIRPOL (F), Spinelle et al., http://publications.jrc.ec.europa.eu/repository/handle/JRC86479

Protocol of evaluation and calibration of low-cost gas sensors for the monitoring of air pollution, Spinelle et al., http://publications.jrc.ec.europa.eu/repository/handle/JRC83791

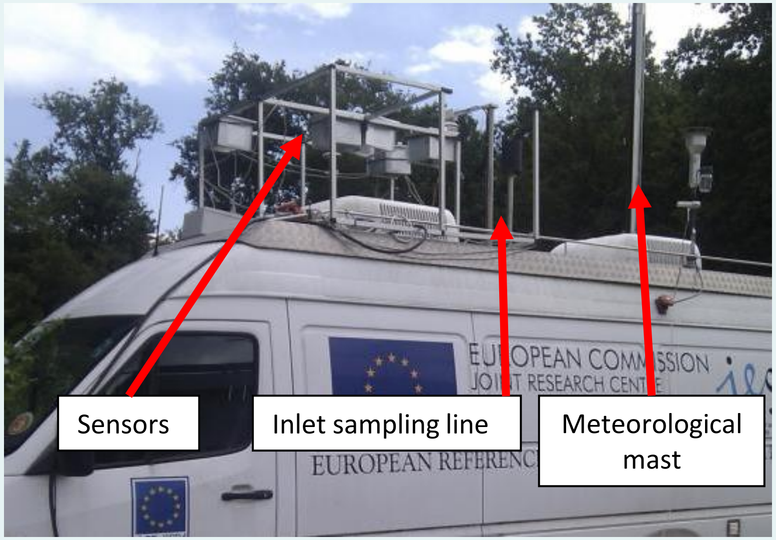
Field evaluation of NanoEnvi microsensors for O3 monitoring, Gerboles et al., http://publications.jrc.ec.europa.eu/repository/handle/JRC68169

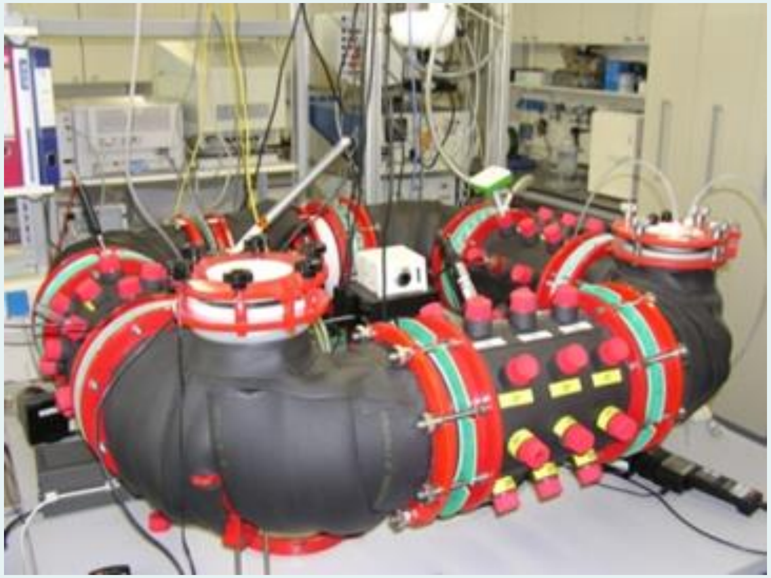
Evaluation of Micro-Sensors to monitor Ozone in Ambient Air, Gerboles et al., http://publications.jrc.ec.europa.eu/repository/handle/JRC48905

These reports are available at: ftp://ftp_erlap_ro:3rlapsyst3m@s-jrciprvm-ftp-ext.jrc.it/ERLAPDownload.htm

Call for interest, IE with low-cost sensors

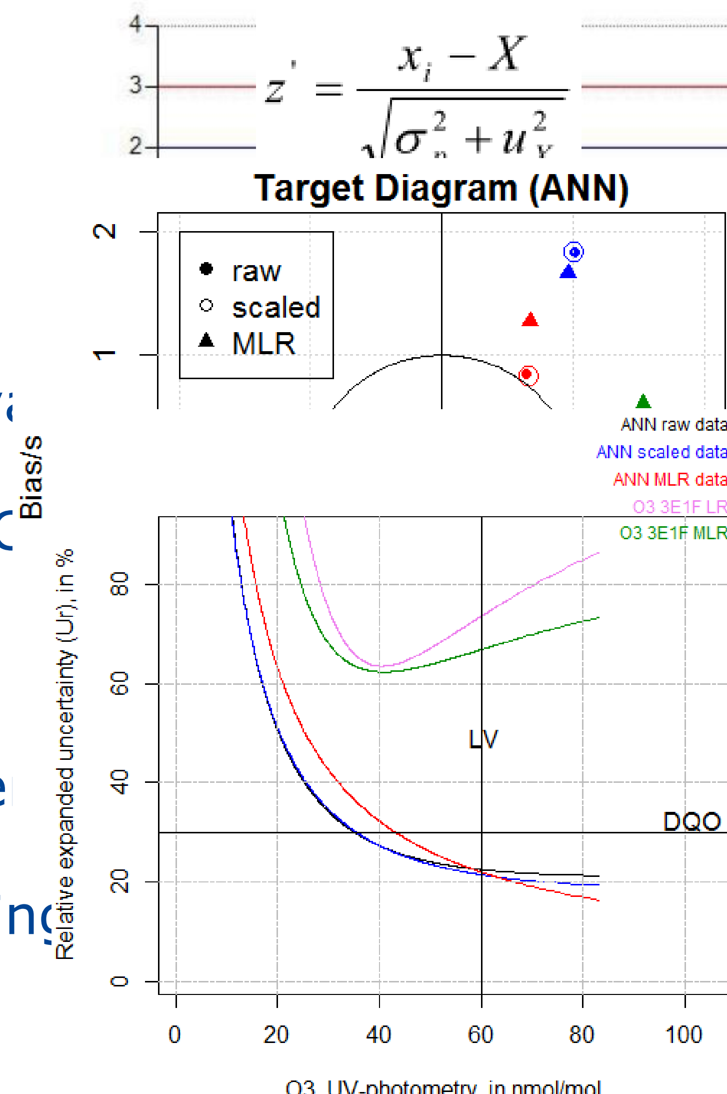
Field test	Lab tests





To be discussed

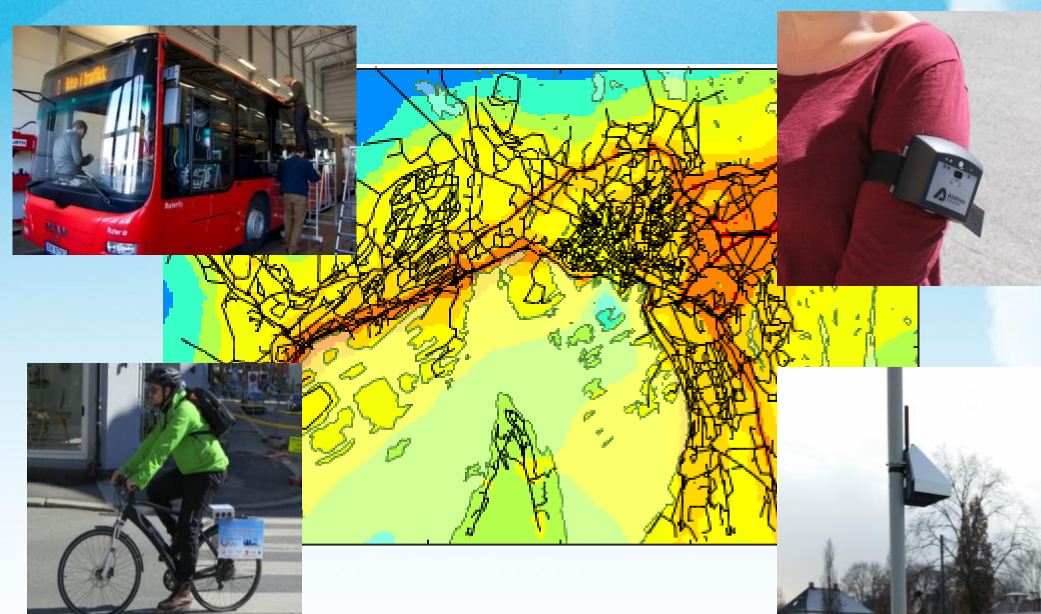
- Possible evaluation of results:
  - ➢Aquila N37 document, Z_{score} and σ_p?
  - ➢Target diagram ?
  - ➢Guide for the demonstration of equiva
- Pollutants to be included: O_3, NO_2, NO, C
- Duration of tests?
- Proposed time table: > Nov 2016 (winte
- Participants responsible for the maintening



FAIRMODE-AQUILA Baveno, 16th February 2016

Can low-cost sensor data be used to support urban air quality assessments?

Nuria Castell and Franck R. Dauge



Citi-Sense-MOB

NILU

CITI-SENSE and Citi-Sense-MOB projects

CITI-SENSE

- Development of sensor-based Citizen's Observatories for improving the quality of life in cities
- Collaborative Project funded by FP7
- 27 project partners from Europe, South Korea, and Australia
- Case studies at 9 locations throughout Europe

Citi-Sense-MOB

- Mobile services for environmental and health citizens' observatory
- EMMIA project
- 5 project partners from Norway
- Case study in Oslo

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Low-cost sensor technologies: opportunities and challenges

New opportunities

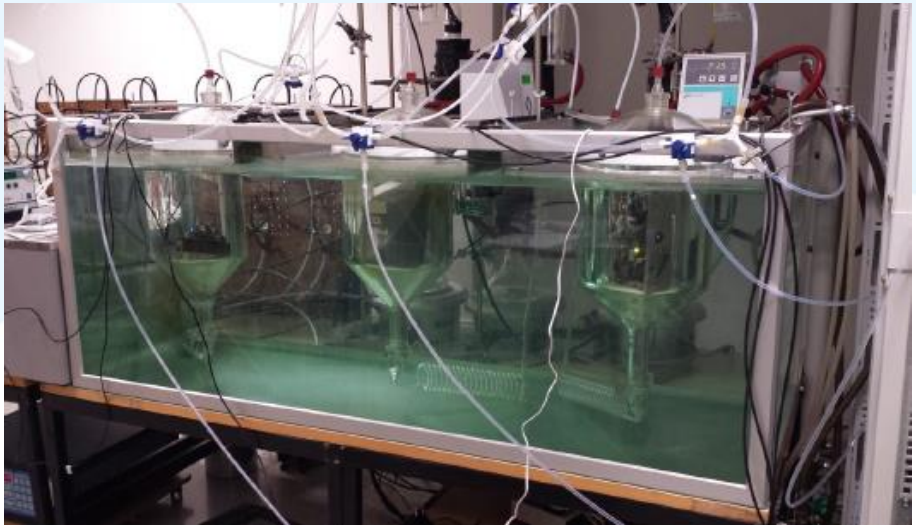
Observations at **high resolution**
Monitoring at **points of interest**
Citizen engagement
Personalized data

Challenges

Data quality: error characteristics, long-term measurement capability
Maintenance of large sensor platform networks: sensor failures, data storage, data treatment, re-calibration.
Privacy and security: personal sensors (linked with position data)

What data quality can we expect from low-cost sensors?

- Test in laboratory
  - Controlled conditions of temperature and humidity
  - Critical atmospheric conditions are accurately measured
  - Known concentrations of gases
  - Analysis: pre-calibration, repeatability, short/long term drifts, interference



- Co-location with reference stations
  - Real world conditions
  - Identify additional errors that can appear when sensors are exposed to uncontrolled conditions
  - Recommended to have long field comparisons (approx. 3 months)

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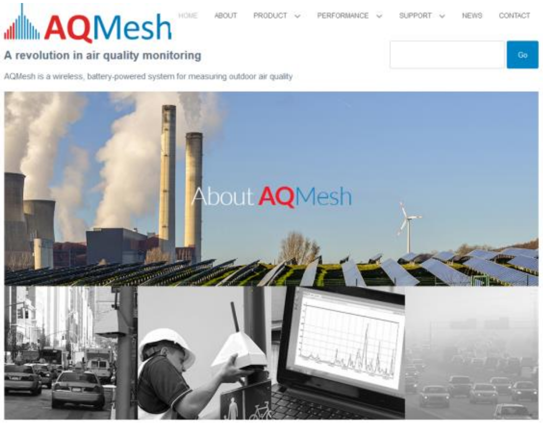
AQMesh manufacturer information

Gas	CO	NO	NO_2	O_3
Sensor technology	Electrochemical	Electrochemical	Electrochemical	Electrochemical
Measuring range	0-5000 ppb	0-2000 ppb	0-200 ppb	0-200 ppb
Limit of detection	< 5 ppb	< 5ppb	< 5ppb	< 5ppb
Sensor provider	Alphasense	Alphasense	Alphasense	Alphasense
Sensor type	CO-B4	NO-B4	NO2-B42F	OX-B421

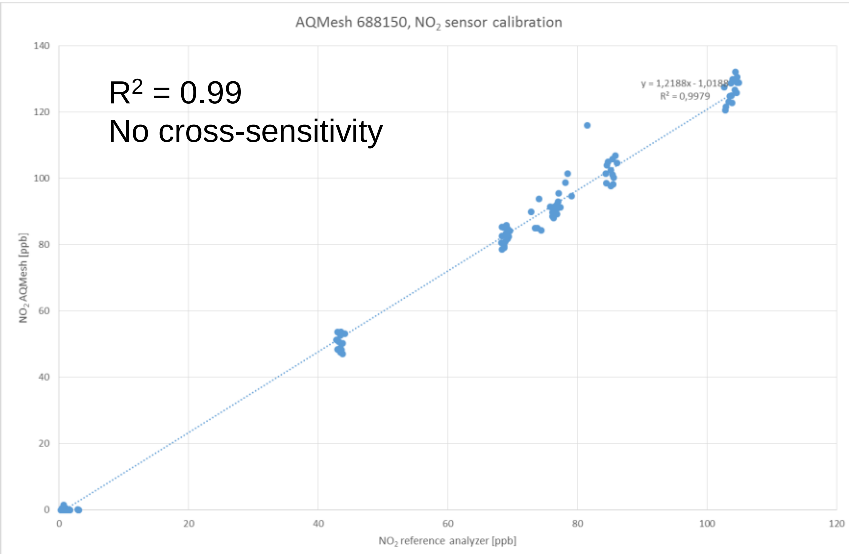
Information extracted from AQMesh documentation submitted to the CITI-SENSE project

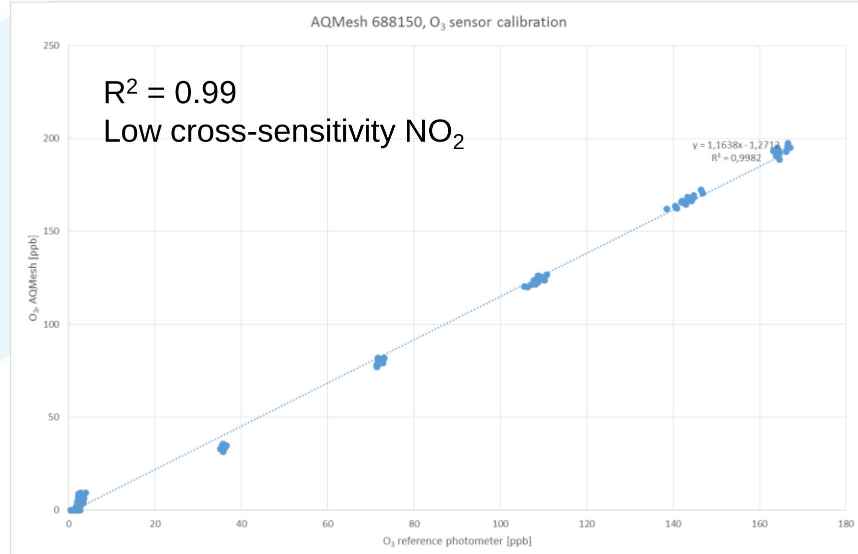
Key Points

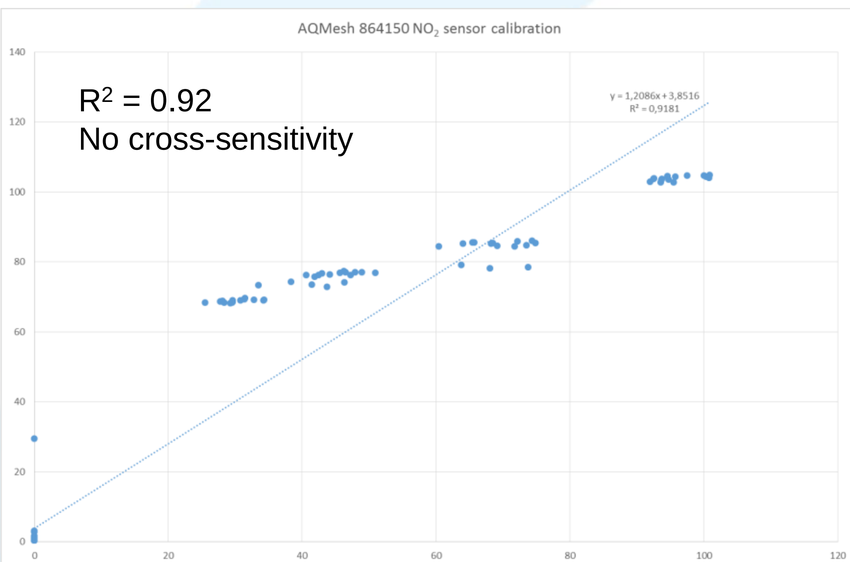
- Excellent NO correlation: Typical R^2 >0.85
- Very good NO2 correlation: Typical R^2 >0.75
- Very good O3 correlation: Typical R^2 >0.7
- Very good CO correlation: Typical R^2 >0.7
- Excellent Particle Count correlation: Typical R^2 Versus FIDAS >0.85
- Excellent pod to pod correlation for all parameters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

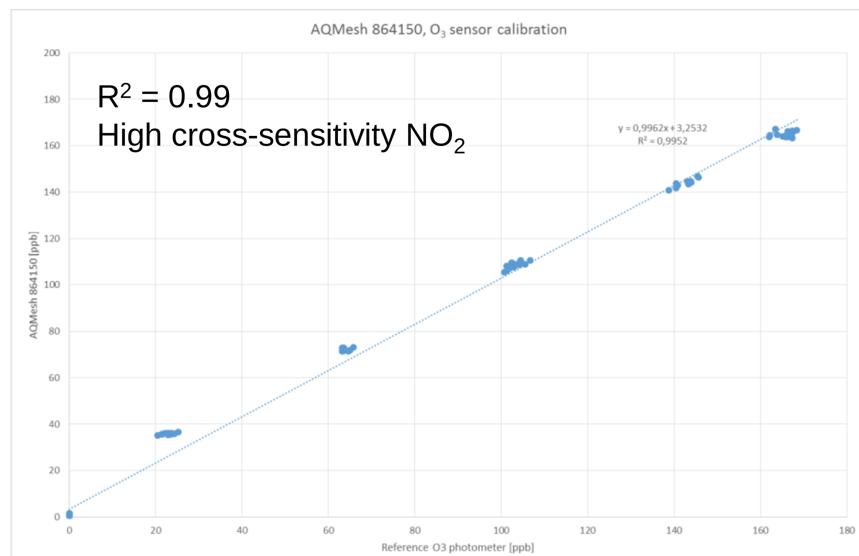


AQMesh performance evaluation: laboratory









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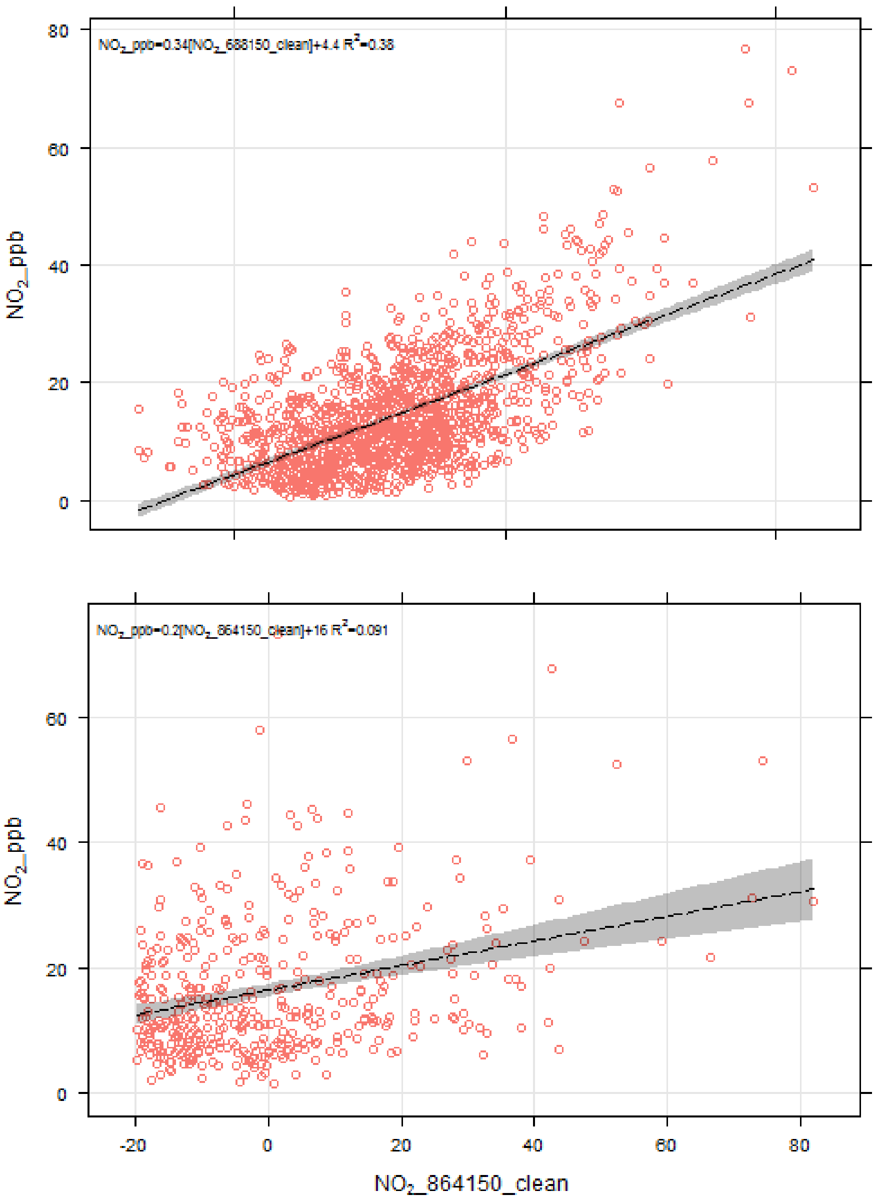
AQMesh performance evaluation: field co-location



24 AQMesh platforms
13 April to 24 June 2015

R^2	NO2	O3	NO	CO
688150	0.42	**0.65**	**0.92**	0.34
712150	0.31	0.3	**0.78**	0.36
715150	0.13	0.27	**0.91**	0.41
718150	0.24	**0.53**	**0.62**	0.32
733150	0.23	0.15	**0.93**	0.38
737150	0.23	**0.57**	**0.94**	0.34
743150	0.16	**0.5**	**0.95**	0.41
744150	0.35	0.048	**0.86**	0.27
746150	0.21	**0.6**	**0.68**	0.39
750150	0.22	**0.61**	**0.87**	0.42
755150	0.29	**0.49**	**0.84**	0.39
756150	0.13	0.23	**0.94**	0.37
764150	0.045	0.0088	**0.95**	0.39
785150	0.28	0.19	0.36	0.25
828150	0.062	0.16	**0.75**	0.35
846150	**0.51**	0.24	**0.63**	**0.45**
849150	0.3	0.3	**0.75**	0.34
850150	0.38	0.26	**0.53**	0.43
855150	0.32	0.29	0.41	0.22
856150	0.37	0.27	**0.55**	0.35
861150	0.28	**0.49**	**0.73**	0.35
862150	0.28	0.3	**0.67**	0.34
863150	0.18	0.31	**0.74**	0.36
864150	0.091	0.1	**0.74**	0.43

In bold $r^2 \geq 0.5$

$R^2 > 0.5$

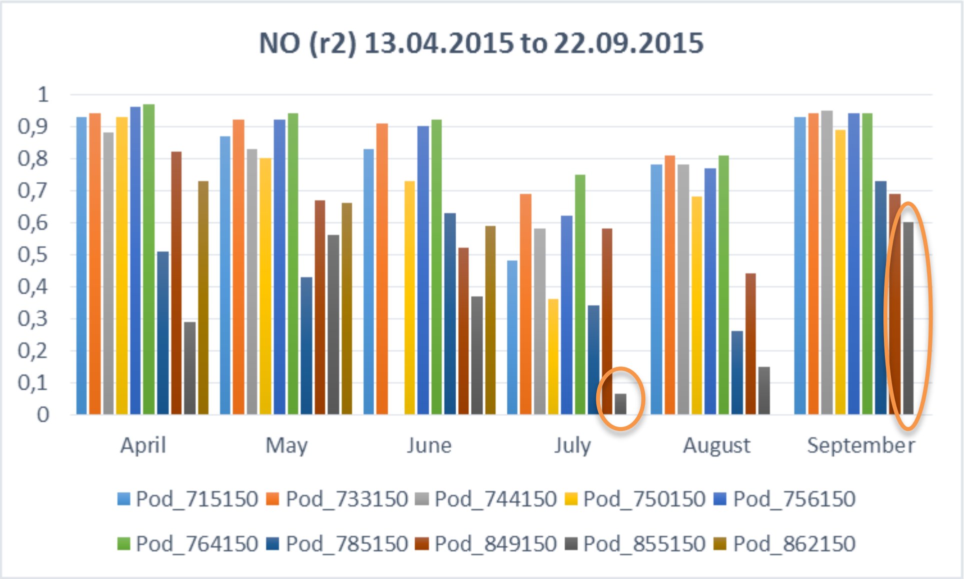
NO_2: 1 unit
O_3: 8 units
NO: 22 units
CO: 1 unit

AQMesh performance evaluation: variability

The performance of the sensors varies with:

1. The location (background / traffic).
   - Lower performance in background stations for NO.
   - Improved performance in background stations for PM10 and PM2.5
2. The meteorological conditions
   - Variation month to month in r^2, gradient and offset

Monthly variation r^2 for NO



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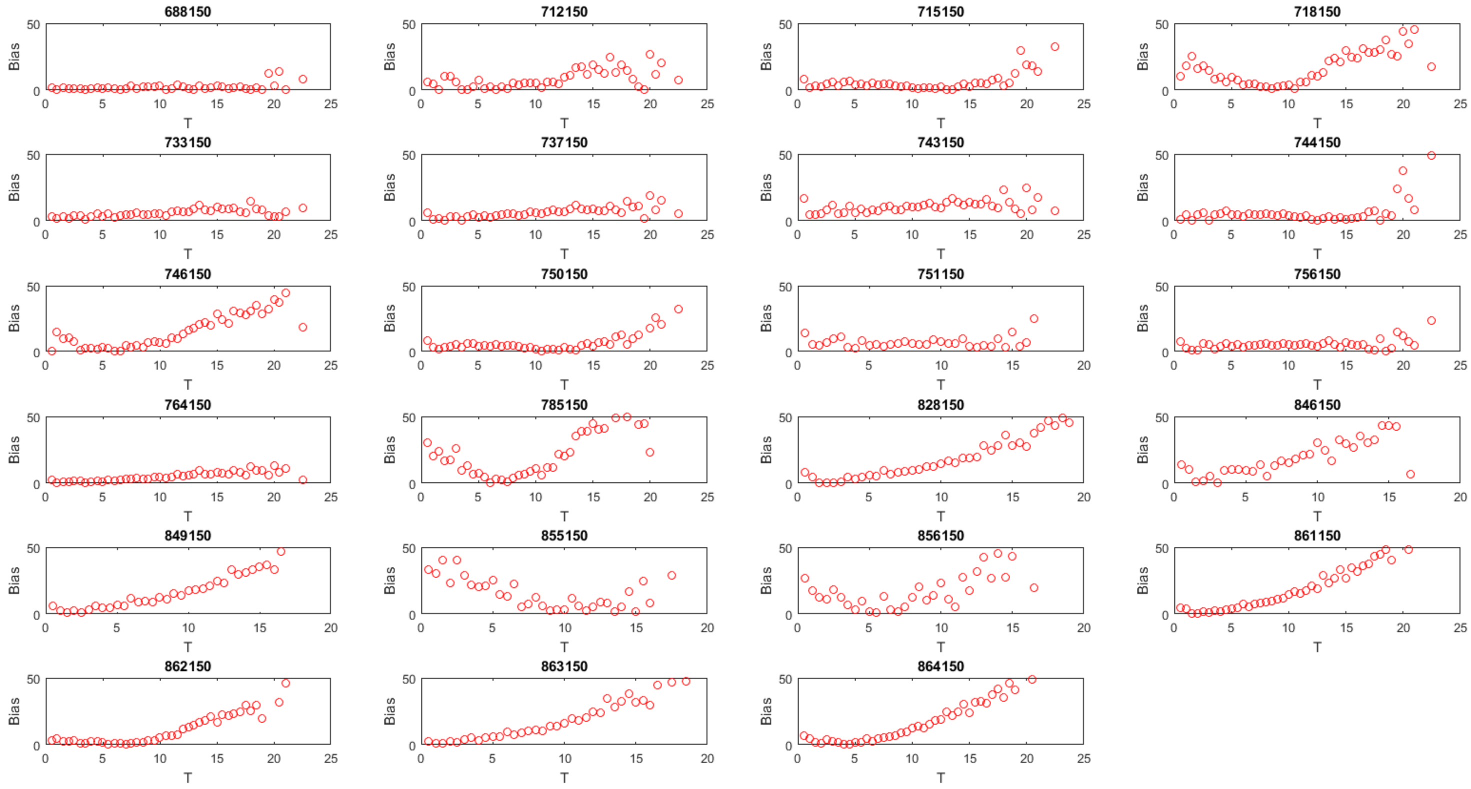
AQMesh performance evaluation: temperature dependence

Variation of the NO bias with the temperature



The variation of the absolute bias with the temperature is not the same for all the units. In some units bias increases with temperature

Similar results for RH, some units show higher bias when the relative humidity is below 40%

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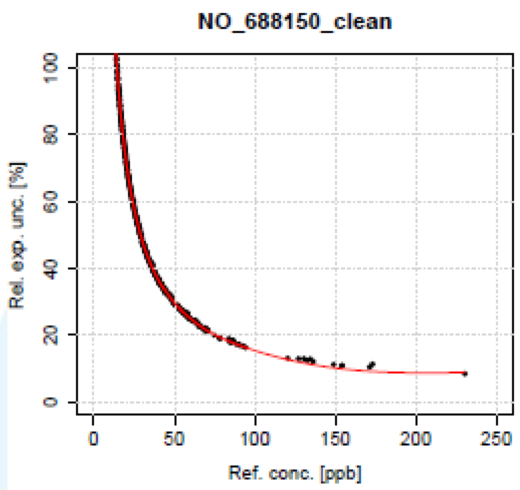
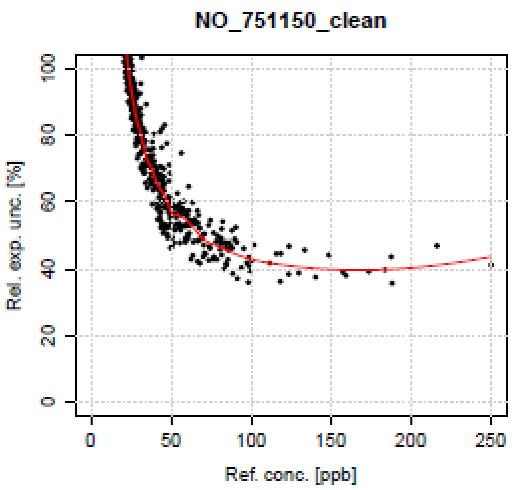
AQMesh performance evaluation: Data Quality Objective

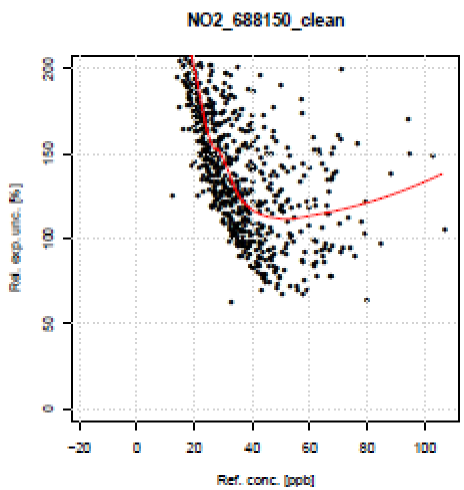
Data quality objectives for ambient air quality assessment defined in the AQD 2008/50/EC

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

To assess the performance of each sensor and sensor platform, the measurement uncertainty has been calculated following the methodology described in Spinelle et al. (2015)







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Spinelle et al. 2015. Sensors and Actuators, 249-257

AQMesh: new developments from the manufacturer

Gas versions – NO2

NO2				
Version	v.3.0	v.3.5	v.4.0	v.4.1
Date	To December 2014	January 2015-October 2015	January 2015 - Q1 2016	Q2 2016 -
NO2 sensor	Significant O3 cross-gas effect	O3-filtered	O3-filtered	O3-filtered
NO2 sensor characterisation	Manufacturer's data	Manufacturer's data	Manufacturer's data plus characterisation at factory	Quality check
Online processing	Correction for cross-gas effects and environmental factors	Correction for cross-gas effects and environmental factors	Correction for cross-gas effects and environmental factors	More sophisticated correction for cross-gas effects and environmental factors
Typical R2 against reference in co-location trials	0 - 0.3	0.1 – 0.7	0.5 - 0.8	0.7 – 0.95
Independent studies	http://www.cert.ucr.edu/events/pems2015/liveagenda/21polidori.pdf (slide 30) http://www3.epa.gov/ttnamti1/files/2014conference/wedngamduvall.pdf	(Citi-Sense)	(EuNetAir) (US EPA – due to be released 2016 following chamber testing)	(US EPA – planned 2016) (UCR – planned 2016)

	R^2 pod vs reference	
	NO	NO2
1 min	0.53	0.11
15 mins	0.70	0.16
30 mins	0.78	0.29
60 mins	0.90	0.25
Daily	0.87	0.48

v.3.0 (from Performance Review April 2014)

First information from manufacturer said typical r^2>0.75

The higher r^2 we found was 0.51

22 out of 24 pods had r^2<0.4

7 out of 24 pods had r^2<0.2

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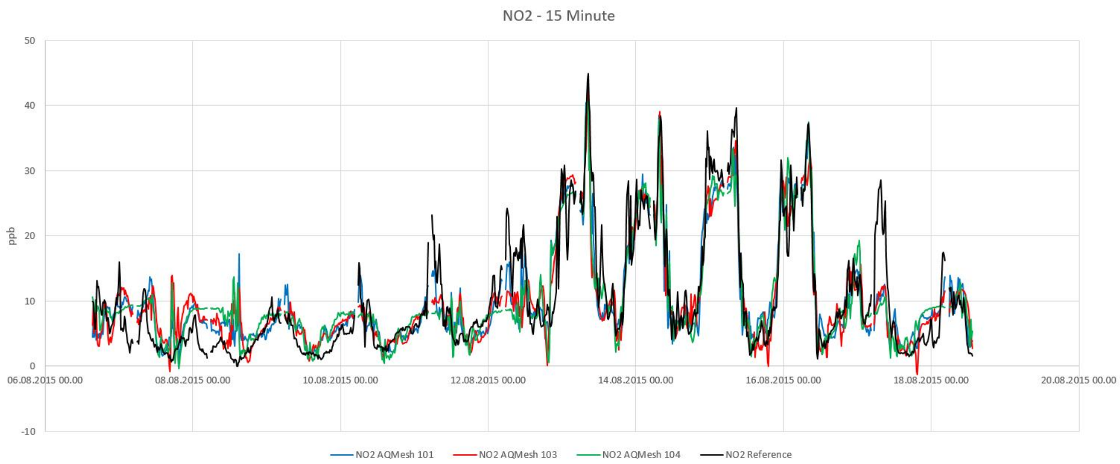
AQMesh: results from V4.5 (information from the manufacturer)

Results from co-location in South-California, 7/8/2015-19/8/2015

AQMesh trial versus co-located reference station in South California, USA. 7/8/2015 – 19/8/2015

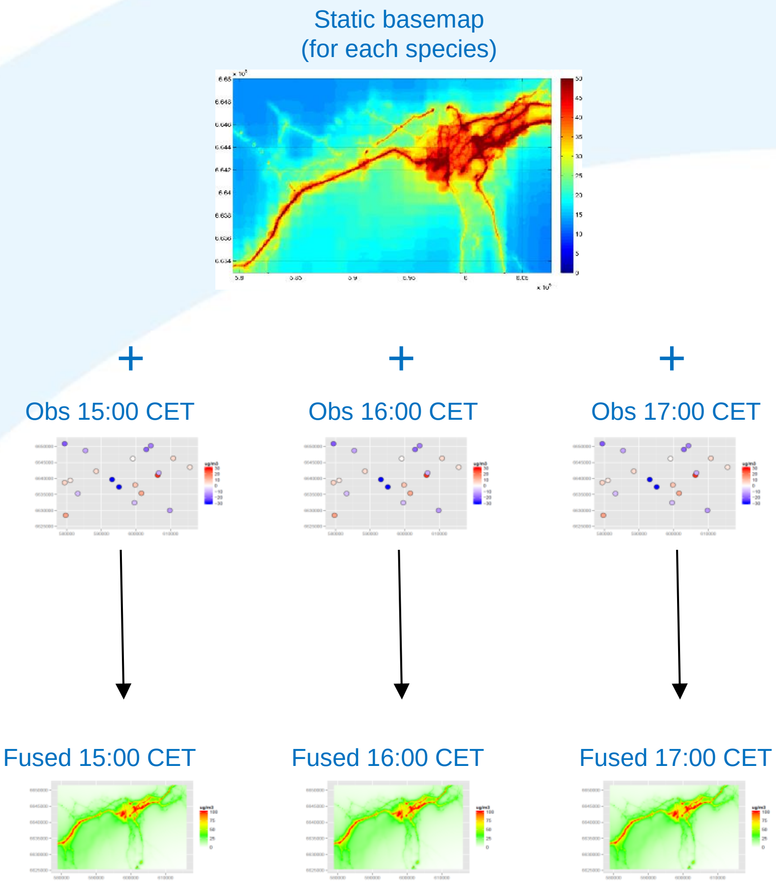


R^2 Summary

Pod	15 Minute	30 Minute	60 Minute	Daily
AQMesh 1	0.8087	0.8229	0.8442	0.9380
AQMesh 2	0.7886	0.8023	0.8221	0.9095
AQMesh 3	0.7607	0.7757	0.7909	0.9005

Applications:
Mapping of urban AQ: data fusion model + sensor

- A static basemap is created for each location and each species of interest to show the long-term spatial patterns
- This basemap is then modified according to the observations made by the static AQMesh sensors
- This is essentially a location-dependent level-shift of the basemap
- The final result are hourly maps with the current best guess for the NO_2/PM_{10}/$PM_{2.5}$ concentration field



Basemap: Provides information about general spatial patterns

AQMesh observations: Provide information about current state of atmosphere at a few sampling locations

Fused map: Value-added product providing a best guess of current state of atmosphere for the entire domain

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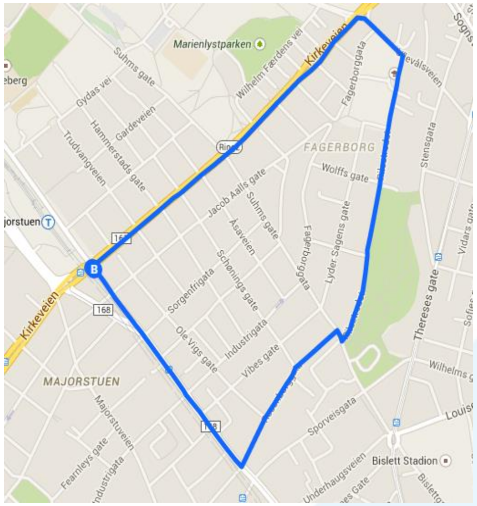
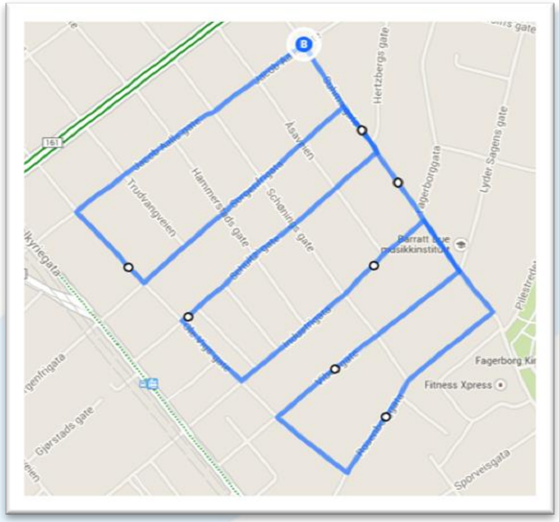
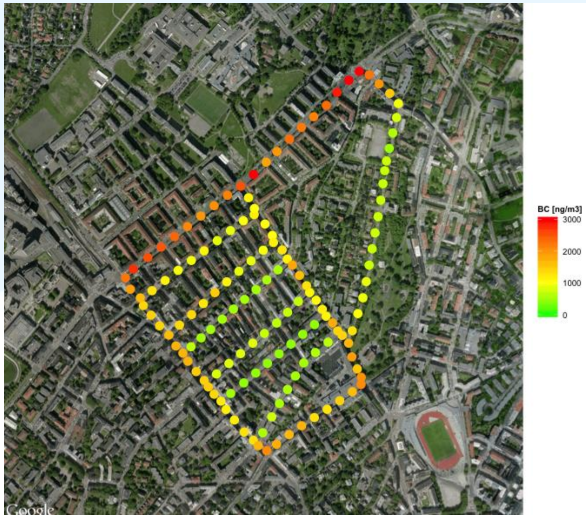
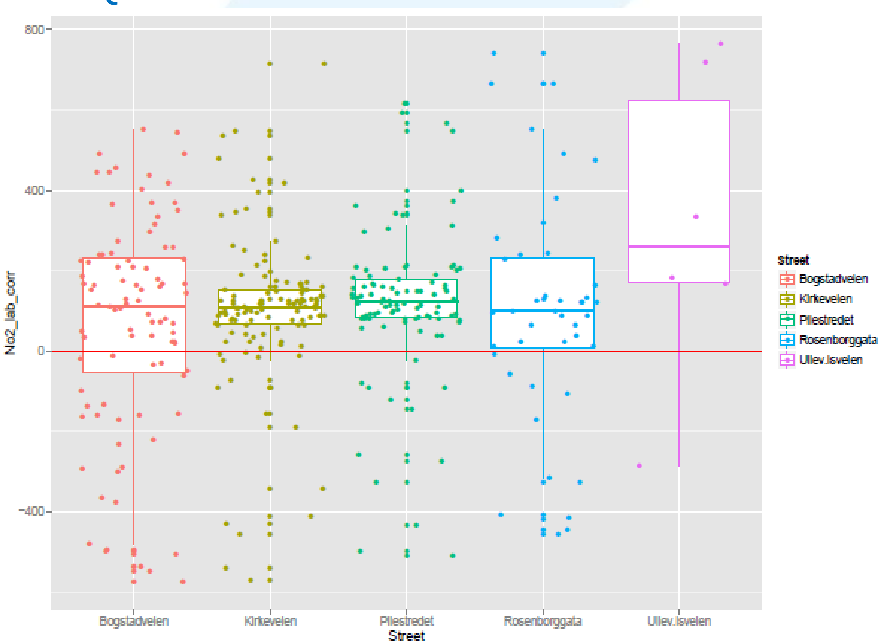
Applications: Mapping air pollution with mobile sensors



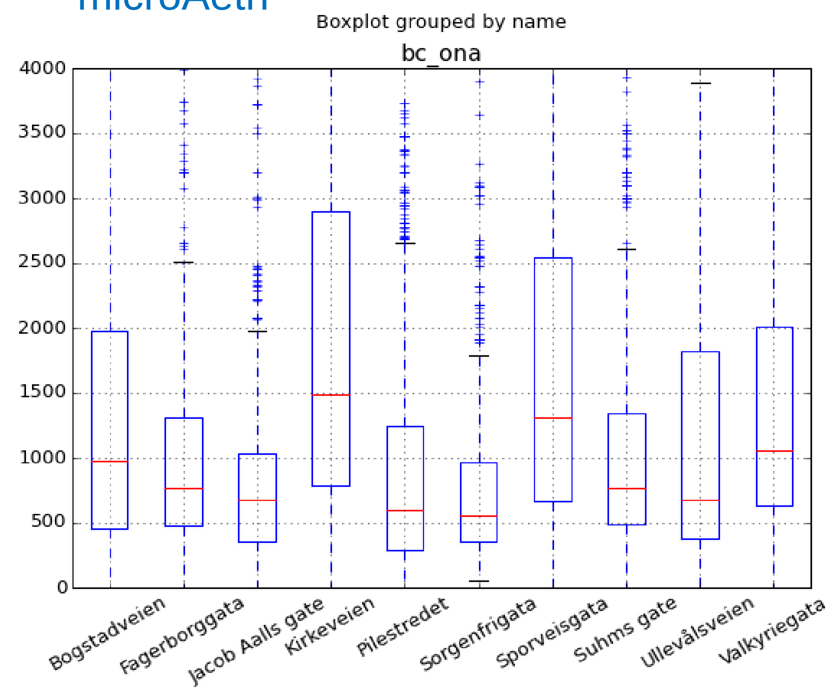




AQ e-bike: DunavNET



microAeth



Conclusions

1. The performance evaluation of the AQMesh platform (v 3.5) has included: analysis of 2 units in laboratory and co-location of 24 units in field for about 6 months.
2. The results in laboratory indicated a good correlation for all the gases (NO, NO_2, O_3 and CO). However the correlations are lower during the field co-location.
3. It is necessary to evaluate the **performance in field and not only in laboratory.**
4. The performance of the units depends on the environment: proximity to sources and meteorology
5. It is necessary to evaluate the **performance under different environmental conditions**.
6. It is necessary to apply a **field calibration**. The gradient and intercept obtained in field differs from the one obtained in the laboratory.
7. Because of variations with environmental conditions it is important to have **frequent field calibrations/evaluations**.
8. **Post-processing** the data to reduce interferences with temperature and relative humidity can improve the sensor performance.

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Can low-cost sensor data be used to support urban air quality assessments?

1. Low-cost sensors are a **promising technology**, with a rapid evolution in the market and performance of the sensors is improving.

2. **Data quality is a main concern**. For many sensor platforms (even commercial), the error characteristics, long-term performance, and performance under different environment conditions hasn't been tested.

3. The preliminary evaluation of the sensors' uncertainty assessing if they could reach the Data Quality Objectives (DQOs) defined by the European Air Quality Directive for indicative methods show **high uncertainty values that are exceeding the DQO**.

4. The **high variability in the performance sensor to sensor**, as well as the variability in the performance depending on weather conditions or changes in emission patterns, etc. makes them difficult to use for air quality compliance applications.

5. They are still in a research phase that **requires an exhaustive testing** and comprehension of the performance **of each individual sensor platform** before they can be deployed.

6. For these data to be used to supplement air quality monitoring networks and for scientific research, it needs to meet a high degree of quality and **the uncertainty should be assessed**.

7. The **use of low-cost sensors in combination with other sources of information** can help to reduce the uncertainty, providing more reliable results for air quality managers.

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Thank you for your attention

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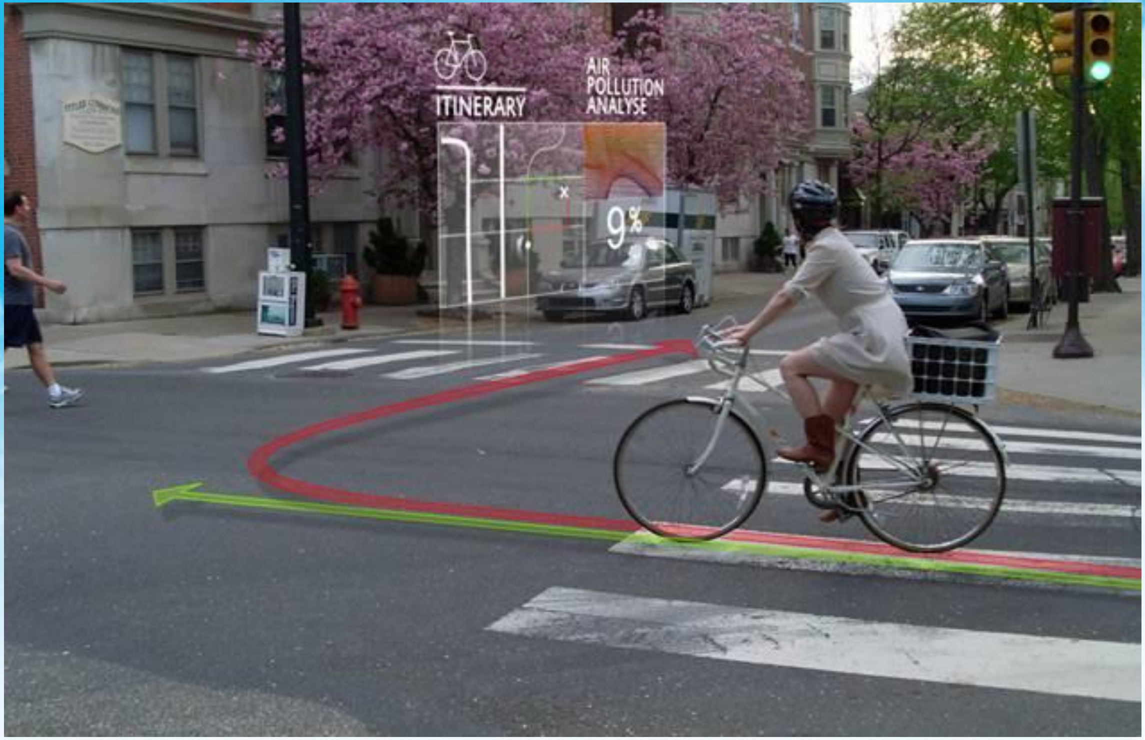


Norsk institutt for luftforskning

Ricardo Energy & Environment

Sensors – measurement and modelling – a discussion

Brian Stacey

AQUILA/FAIRMODE, 16th February 2016

Overview

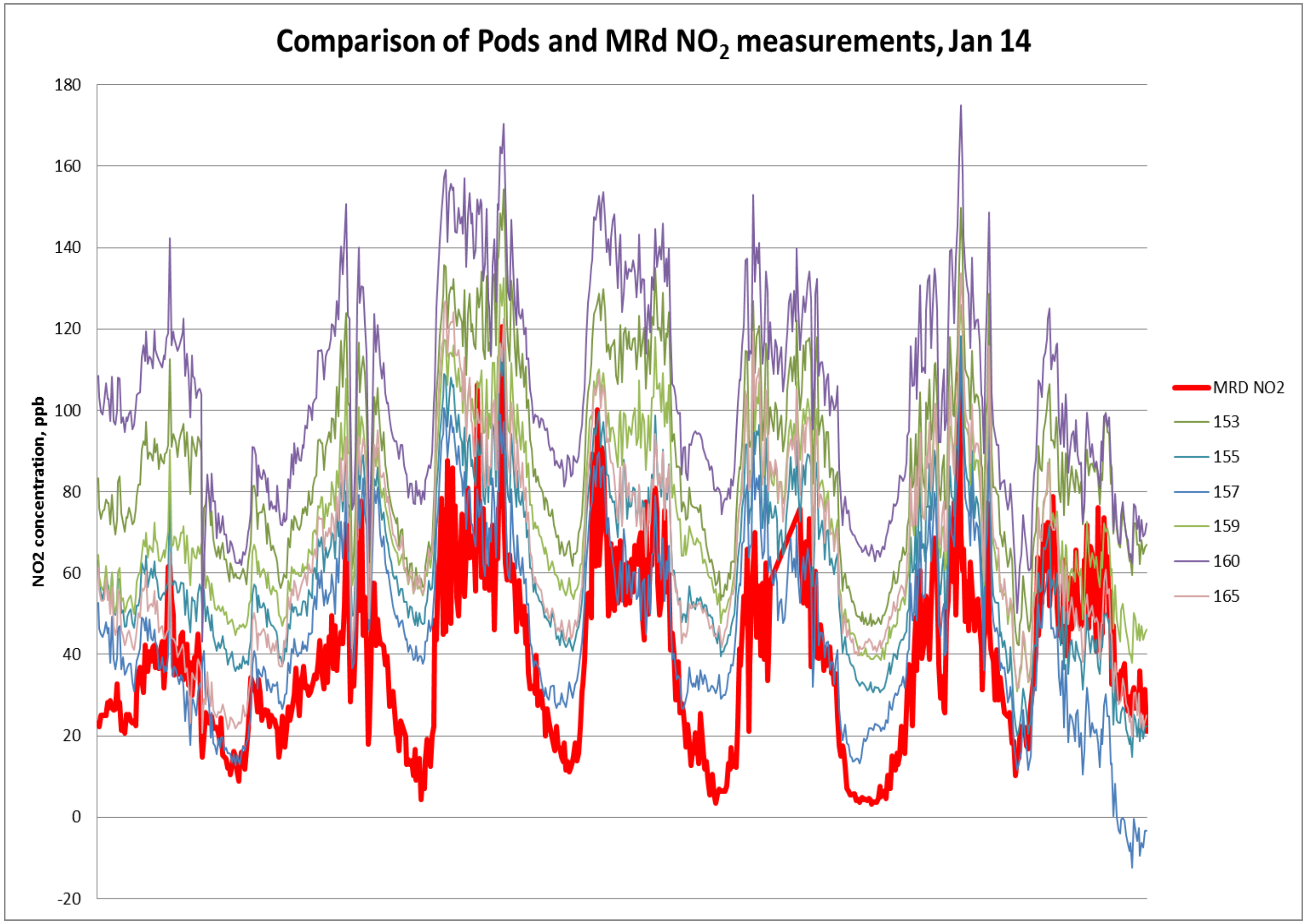
Encouraging new dawn for sensors:

- Offer cheap solution for high time resolution high density data
  - Dispersion analysis
  - Model validation
  - Hotspot identification
  - Personal exposure
  - “Healthiest” route planning

But: We aren’t there yet!

- Accuracy
- Precision
- Measurement uncertainty
- Ongoing QC

The journey so far

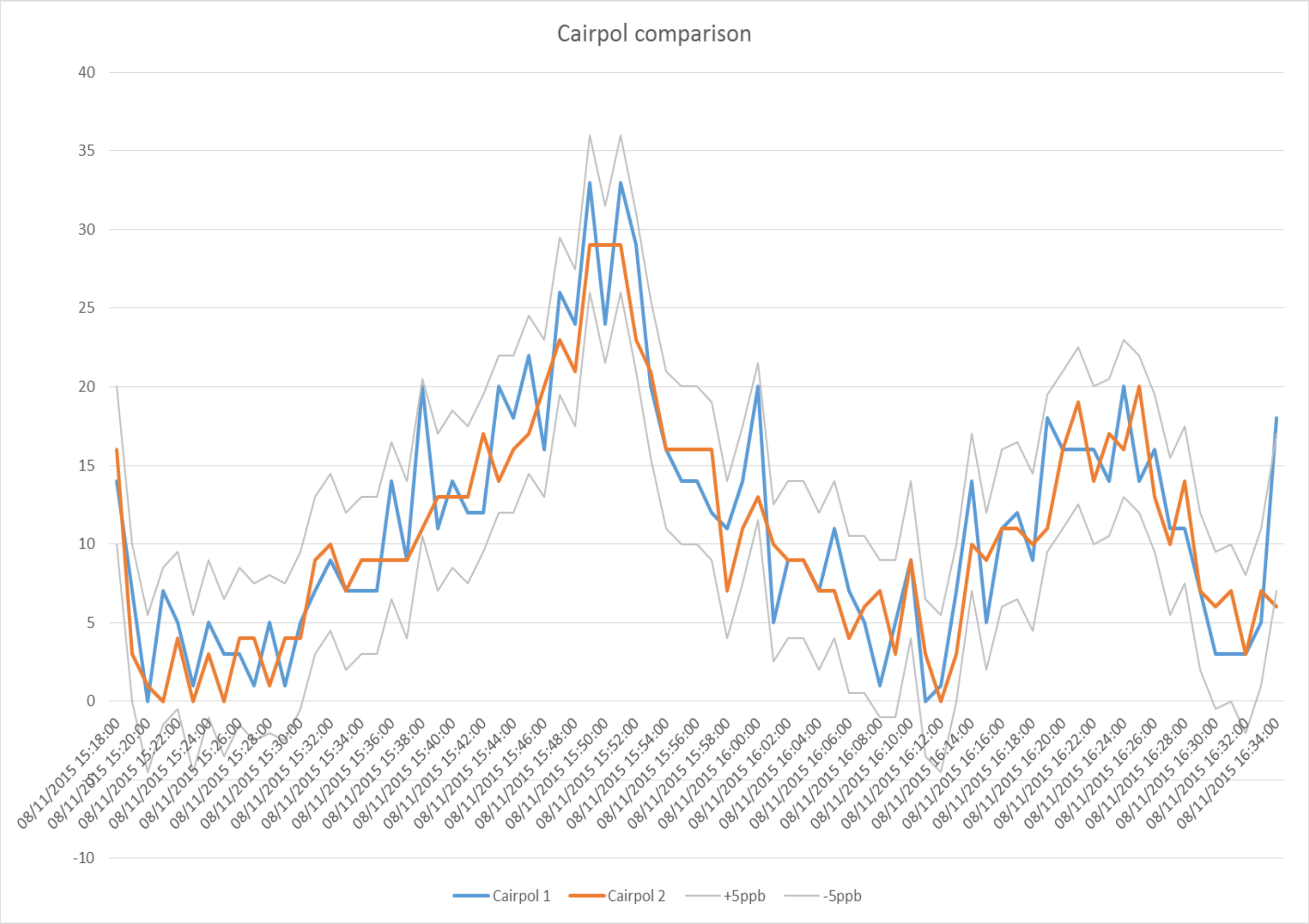


Red line represents "real" analyser. Other lines are nominally "identical" sensors, side by side next to the real analyser inlet.

Can't give this to modellers – it's pants!

Things have improved…

What's available now?



Straight out of the box, following many discussions about interferences and algorithm processing.

But:

Not all suppliers are this capable. The sensor supplier is not the same as the end providers. Ongoing QC is going to be critical if we are to use these devices

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