Developments and Applications of Sensor Technologies for Ambient Air Monitoring

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Workshop 'Current and Future Air Quality Monitoring', Barcelona, Spain

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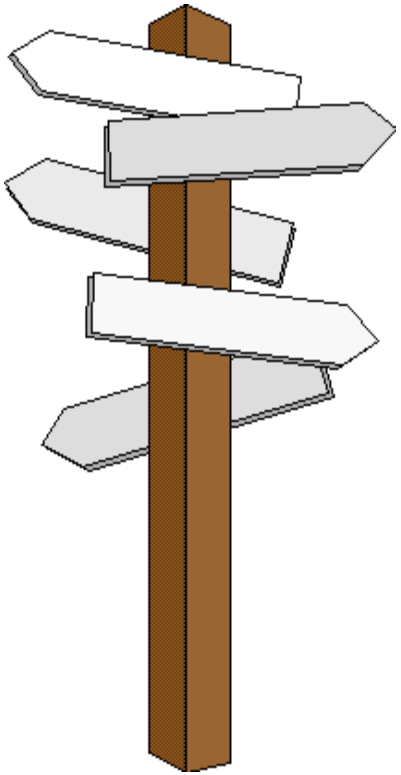
At Residència d'Investigadors, CSIC - Generalitat de Catalunya, C/ Hospital 64, Barcelona



Road map

- *Recent improvements of sensors for air pollution monitoring*
- *On-going projects and existing applications of sensor-based monitoring systems*
- *Strategies to make use of this technology?*
- *Some lessons learned - Which research is still needed?*

Micro-sensors: small sensors with physical dimensions in the sub-micrometer to millimeter range. They are used to convert gaseous compound concentration into an electrical signal.

- a semi-conductor whose resistance changes with the concentration of air pollutant

- miniaturized electrochemical that delivers a current varying with the pollutant of interest. This current is in general generated by an oxido-reduction reaction

Other sensor type: surface acoustic wave sensors, optical sensor (NDIR for CO, CO2)

Sensor improvement in recent years

- *New technologies*
- *Improvement of existing technologies*
- *New evaluation studies*

New technologies

- *Miniaturisation of MOX: huge number of publications on nano particles, nano-wire, carbon nanotubes: no commercial sensors yet*
- *Graphene sensors (material with low resistance able to enhance sensitivity) – no commercial sensors yet (see MACPoll)*
- *Chemical filter directly coated on the sensing layer to avoid cross-sensitivity (NO_2 and O_3)*
- *Sensors in integrated stations, light badge, (Unitec, Aeroqual, libellius …)*

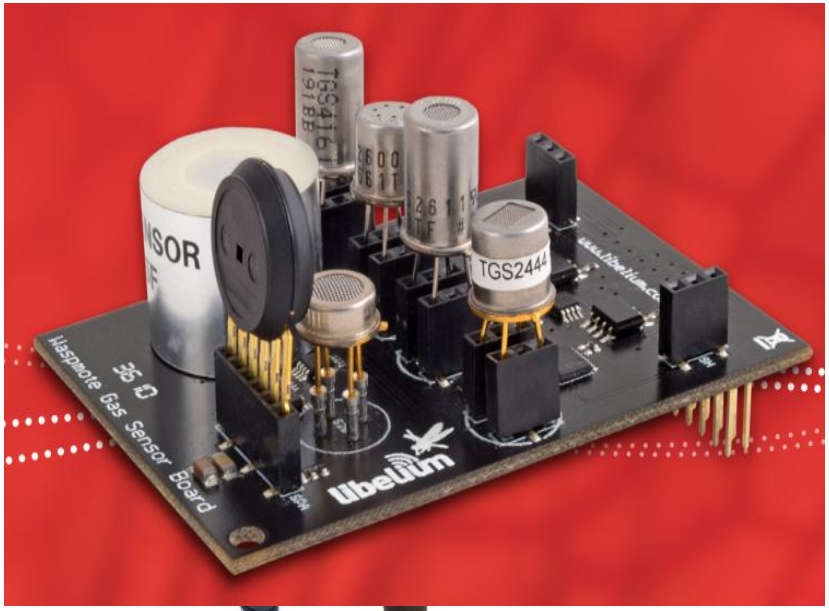
- UNITEC srl, ETL3000 MULTI-COMPONENT OUTDOOR AIR QUALITY MONITOR
- USING CO, NO_2, O_3 THICK FILM SENSORS Optional C_6H_6
- BUILT-IN DATA LOGGER (Flash memory)
- 15’ MINUTES OR HOURLY AVERAGES
- GSM MODEM FOR REMOTE DATA HANDLING

AEROQUAL, AQM 60 Air Quality Station
With 6 sensors including:

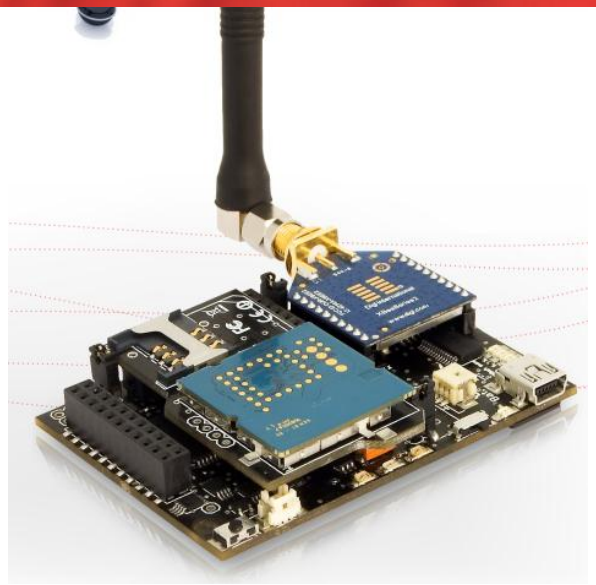
- ozone (O3),
- nitrogen dioxide (NO2),
- nitrogen oxides (NOx),
- carbon monoxide (CO),
- sulphur dioxide (SO2),
- volatile organic compounds (VOC),
- hydrogen sulphide (H2S),
- non-methane hydrocarbons (NMHC),
- carbon dioxide (CO2),
- particulate matter (PM10, PM2.5, PM1)

Libelium, WAsPMote with gas board
Include 7 sensors among which:

- Carbon Monoxide (CO) – TGS2442
- Carbon Dioxide (CO2) – TGS4161
- Nitrogen Dioxide (NO2) - MiC-2710
- Ammonia (NH3) – TGS2444
- Methane (CH4) – TGS2611
- Ozone (O3) (MiCS-2610)



For fixed measurements with wireless data transfer



Intel Berkeley Badge

- mobile phones/GPS
- NO2, Sensoric 3E50
- O3, Sensoric 3E1, e2v MiCS 2610
- CO, e2v MiCS 4514, Citytech MICROCeL

The mobile phones send the data and GPS positioning to a server.

Improvement of existing sensors

- *Pulsed-temperature mode (improve sensitivity/selectivity), not commercially available*
- *Cycles measurement-zero (e, g. AEROQUAL, R/R0)*
- *Electrochemical sensors with 4 electrodes (Alphasense B4 series, CityTech A3OZ and C3OZ) to subtract baseline drift to signals*
- *New corrections of temperature/humidity effects on sensor responses (Ingenieros Asesores)*

New evaluation studies

- *CO, NO_2, O_3 commercial sensors exist in the suitable range of concentrations**
- *Little validation studies are published, mainly some field and laboratory evaluations:*
  - *USEPA, Characterization of Low-Cost NO_2 Sensors (for Intel Berkeley and Aeroqual sensors), USEPA: Sensoric 3E50 possible NO2 sensor*

* http://www.airmontech.eu/fileadmin/airmontech/user/AAMG_2010-Presentations/MGerboles.pdf

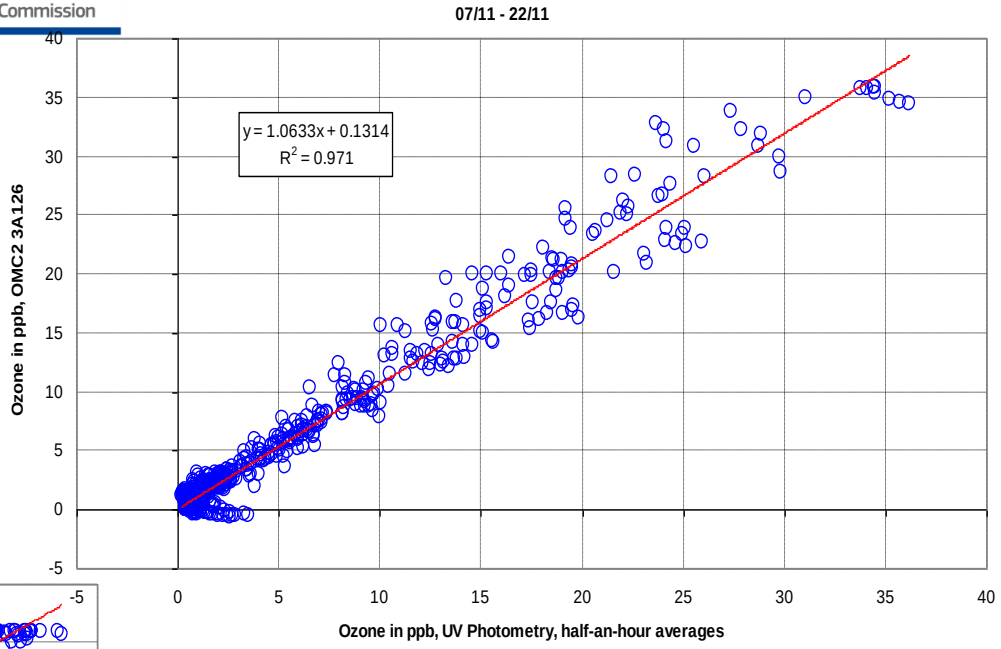
Test of ozone micro-sensors

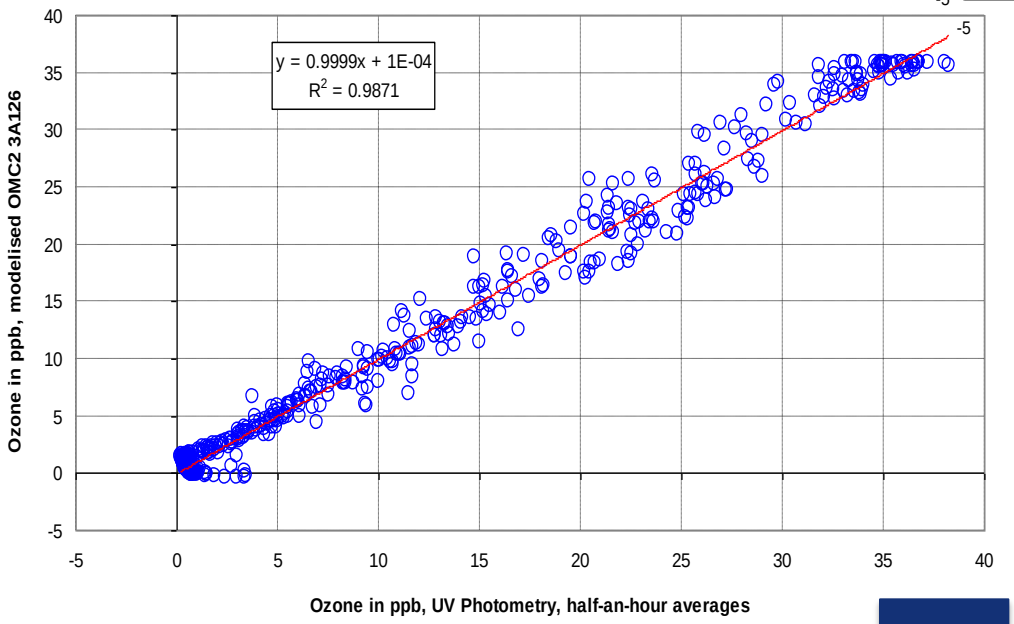
M. Gerboles, I. Fumagalli, F. Lagler and S. Yatkin, Field evaluation of NanoEnvi microsensors for O3 monitoring, EUR 25156 EN, ISBN 978-92-79-22682-3, ISSN 1831-9424, doi:10.2788/44968, 2011.

M. Gerboles and D. Buzica, Evaluation of Micro-Sensors to monitor Ozone in Ambient Air, EUR 23676 EN, ISBN 978-92-79-11104-4, ISSN 1018-5593, DOI 10.2788/5978, 2009.

Two-week field calibration, MICS 2610 sensors

$$O_3 = \sum_{n=0}^{3} x_n \left(R e^{KT} \right)^n$$





Subsequent 2-week implementation of the calibration function

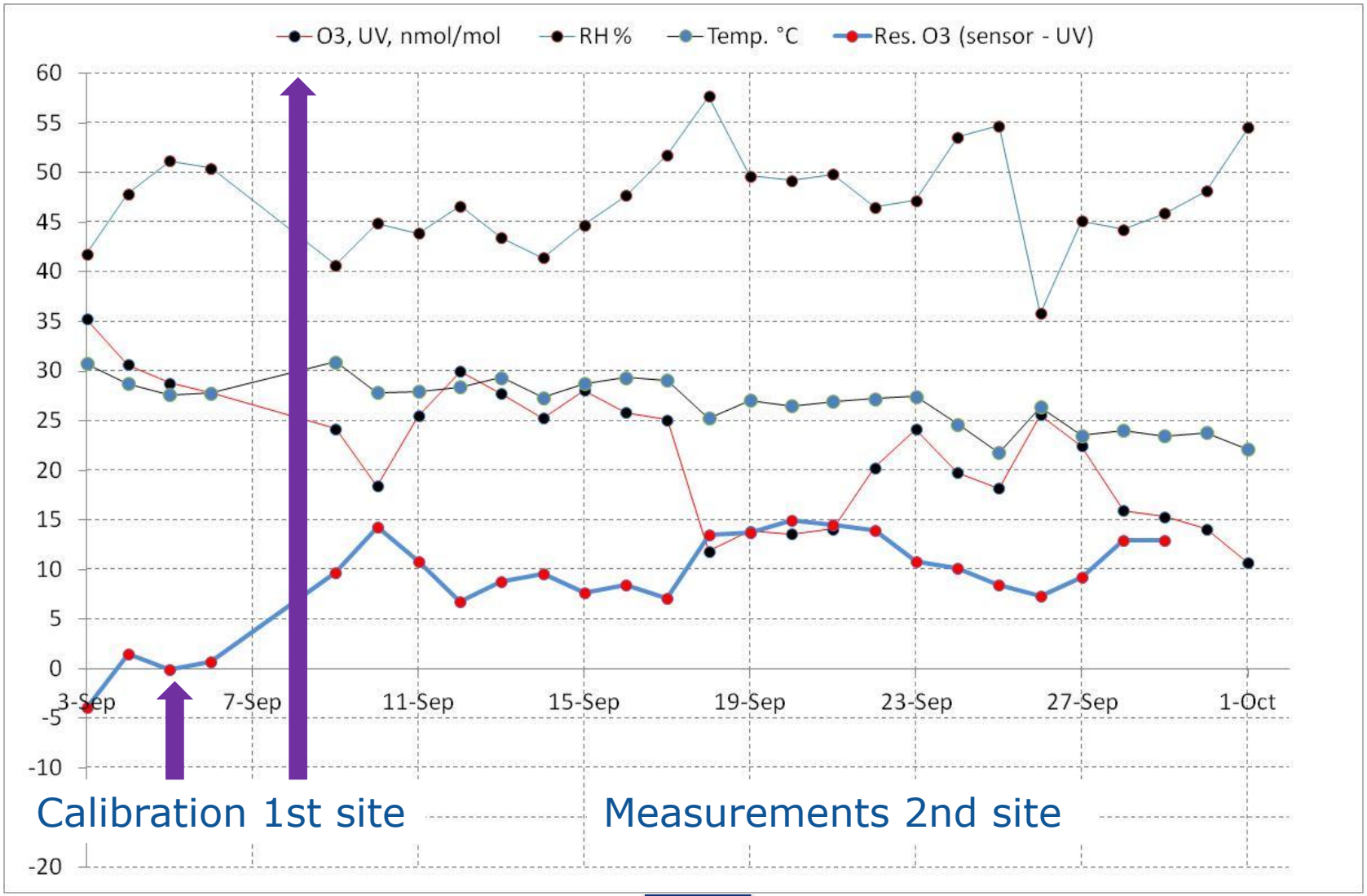
At O_3 = 30 ppb

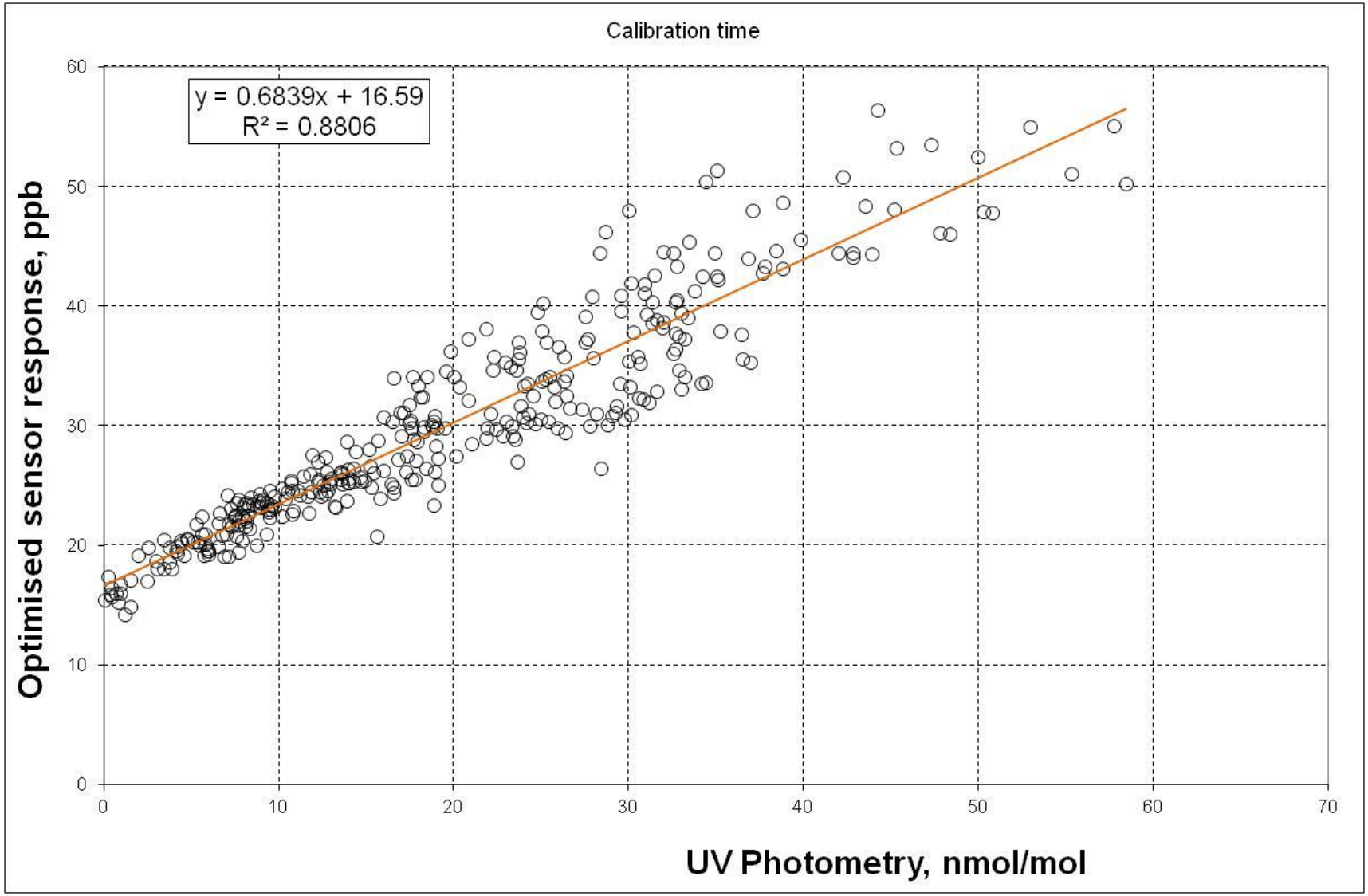
$Ur = 2 (s^2_{lof} + s_r^2 + s^2_{bias})$

= 15 %

For hourly values

NanoEnvi Sensor – UV photometry (nmol/mol)




Calibration time
y = 0.6839x + 16.59
R² = 0.8806
Optimised sensor response, ppb
UV Photometry, nmol/mol
0
10
20
30
40
50
60
70

JRP ENV01 MACPoll

Jun 2011 – Jun 2014

EMRP
European Metrology Research Programme
Programme of EURAMET

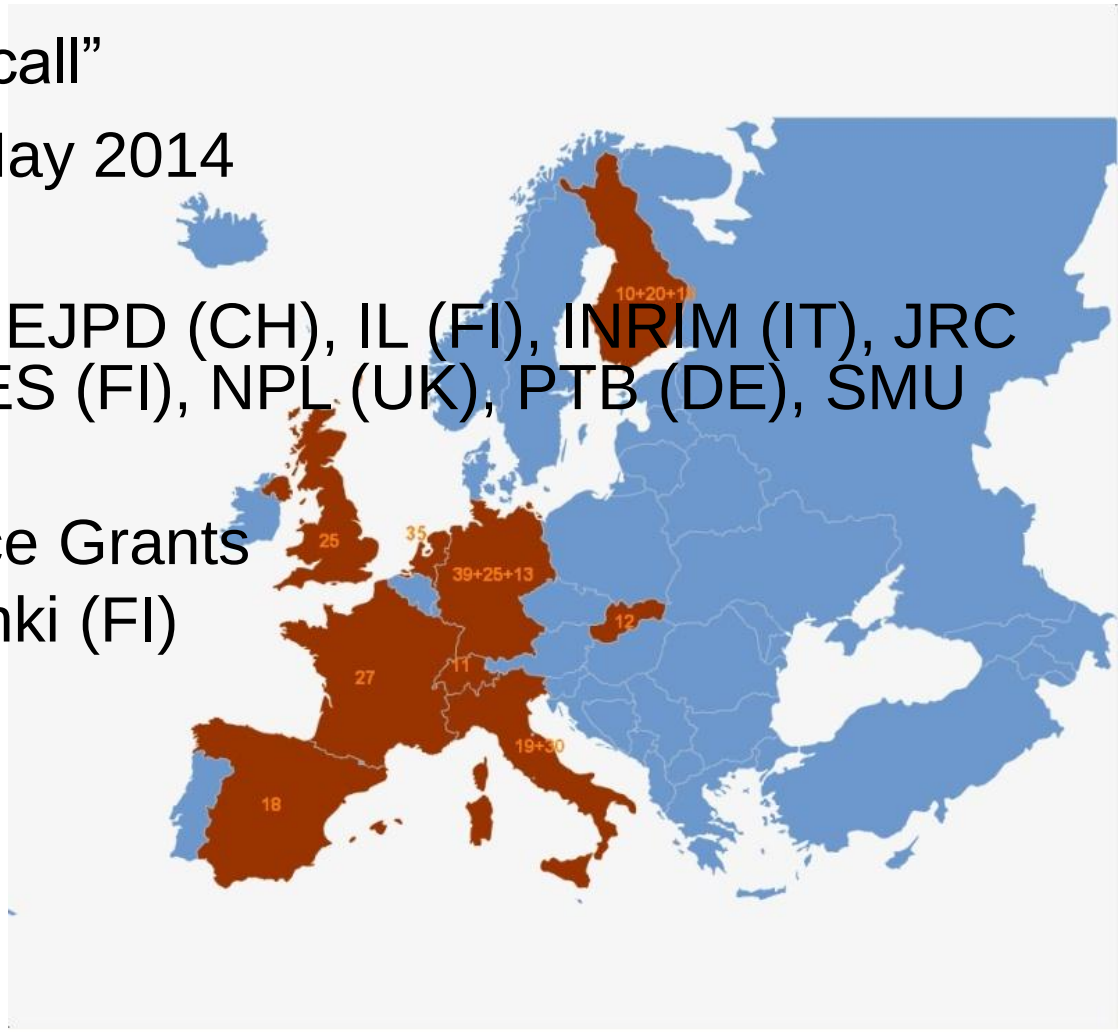
The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

Metrology for Chemical Pollutants in Air

- EMRP “Environment call”
- Period June 2011 – May 2014
- 12 Partners

  VSL (NL), BAM (DE), EJPD (CH), IL (FI), INRIM (IT), JRC (EC), LNE (FR), MIKES (FI), NPL (UK), PTB (DE), SMU (SK), UBA (DE)
- 2 Research Excellence Grants

  CSIC (ES), Un. Helsinki (FI)



www.macpoll.eu

Sensors WP4

EMRP
European Metrology Research Programme
Programme of EURAMET
The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

- Focus on gaseous pollutants regulated by the Air Quality Directive (2008/50/EC) – suitability of sensors as indicative methods (U<25% for NO_2, U<30% for O_3…)
- NO_2: development and validation of new graphene sensors + validation of available NO_2 commercial sensors with laboratory and field tests
- O_3: validation of available commercial sensors with laboratory and field tests

Sensors WP4

EMRP
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- 3rd year of project: field tests of a cluster system including sensors for NO/NOx/ NO_2, SO_2, CO, O_3 and benzene
- Other deliverables:
  - Protocol to validate the performance of sensors
  - Procedure for calibration of sensors
  - Measurement uncertainty for NO_2, O_3 and the cluster of sensors
  - Limited tests in indoor air

O_3 Sensors

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Manufacturer	Model	Type
Unitec s.r.l – IT	O_3 Sens 3000	Resistive
Ingenieros Assessores – SP	NanoENvi mote and MicroSAD datalogger, with Oz-47 sensor	Resistive
αSense - UK	O_3 sensors (B4 series)	4 electrodes
Citytech – G	Sensoric 4-20 mA Transmitter Board with O3E1 sensor	3 electrodes
Citytech – G	Sensoric 4-20 mA Transmitter Board with O3E1F sensor	3 electrodes
Citytech – UK	A3OZ EnviroceL -	4 electrodes
e2V – CH	MiCS-2610 sensor and OMC2 datalogger,	Resistive
e2V – CH	MiCS Oz-47 sensor and OMC3 datalogger	Resistive
IMN2P – FR	Prototype WO3 sensor with MICS-EK1 Sensor Evaluation Kit	Resistive
FIS - J	SP-61 sensor and evaluation test board	Resistive

NO_2 Sensors

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Manufacturer	Model
Unitec s.r.l – IT	Sens 3000
Ingenieros Assessores – SP	NanoENvi mote and MicroSAD datalogger, unidentified sensor probably e2v-MICS sensor
αSense – UK	NO_2 sensors (B4 series)
Citytech – G	Sensoric 4-20 mA Transmitter Board with 3E50 sensor
Citytech – UK	A3OZ EnviroceL (NO2 and O3)
MIKES – FI	Prototype graphene sensors
InRim – IT	Prototype graphene sensors

The limiting factor in using sensing systems based on low cost gas sensors is the reliability of the sensing layer of the gas sensors rather then the performance of sophisticated IT application.

Improvement of sensitivity, stability, selectivity and reducing the power consumption are the main tasks addressed by the research groups.

RECENT OR ON-GOING PROJECTS / APPLICATIONS

Monitoring of ship's emissions

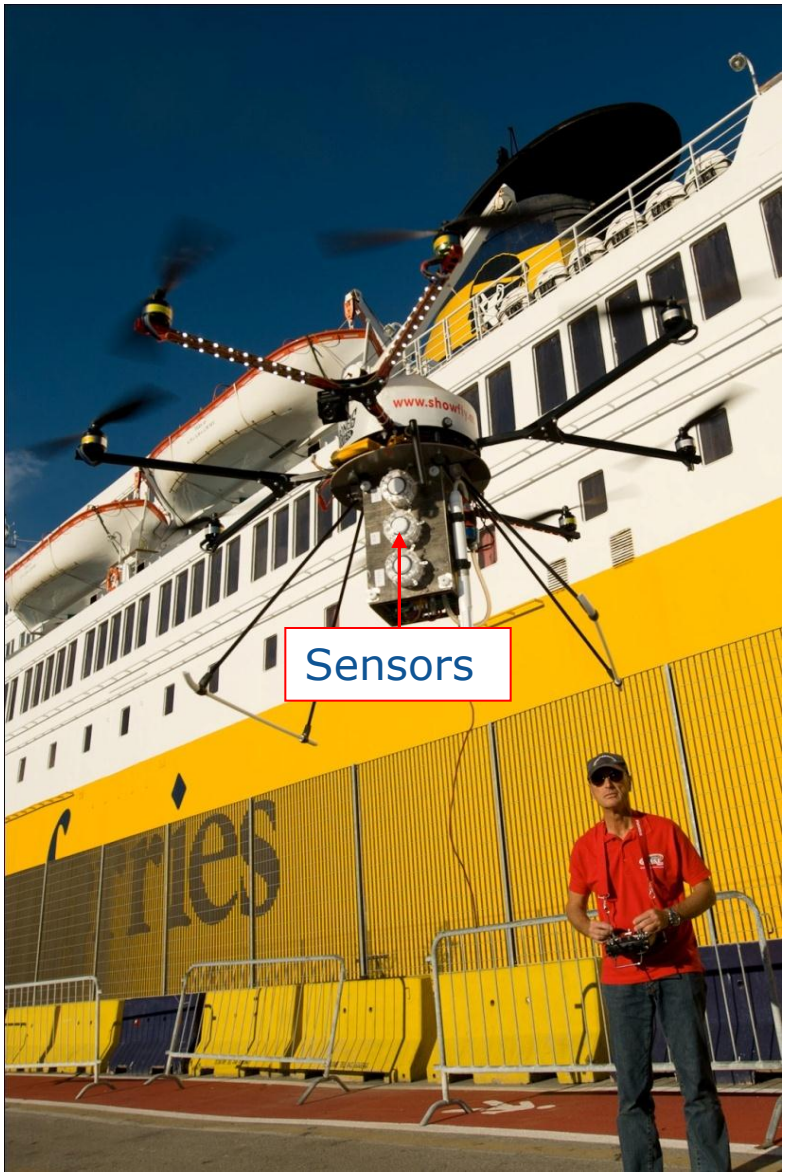
Sensors at high levels of concentrations

FINAL REPORT ON SIRENAS project: Remote Sensing of Ship's Emissions of Sulphur Dioxide, B. Alfoldy, J. Balzani, F. Lagler, J. Hjorth and A. Borowiak, 21.06.2011

Recent project (JRC):

Monitoring of ship emissions with high levels of CO, NO, NO_2 and SO_2 using an unmanned Aerial Vehicle (UAV) (i)

The payload (up to 1.5 kg) is carried with a remotely controlled Oktokopter (autonomy: 7 minutes), the measurement signals are sent directly to the ground. A live videocamera was installed to allow better positioning.



Exhaust plume measurement from unmanned flying platform (ppm concentration range):

CONFIGURATION 1:

- Real time measurements by electrochemical sensors:

  -NDIR CO_2 GASCARD (0-3000 ppm),

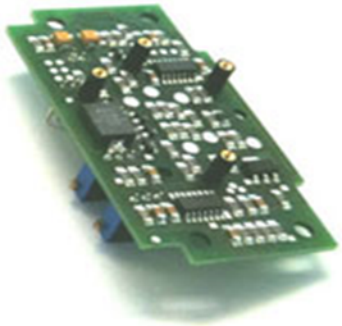
  -NO, NO_2, SO_2 membrapor electrochemical sensors (0-100,0-20,0-20 ppm),

- Temperature.

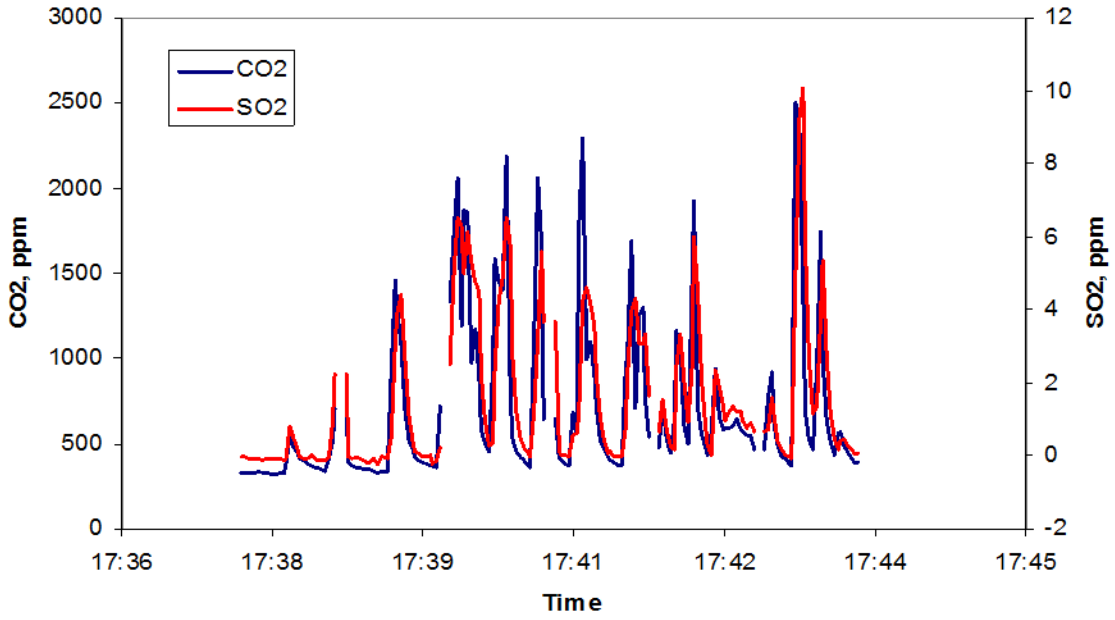
CONFIGURATION 2

- Sampling by under-pressurized canister with a remotely controlled valve,
- Measurement in laboratory by traditional gas analyzers.

Sensor unit



Transmitter unit



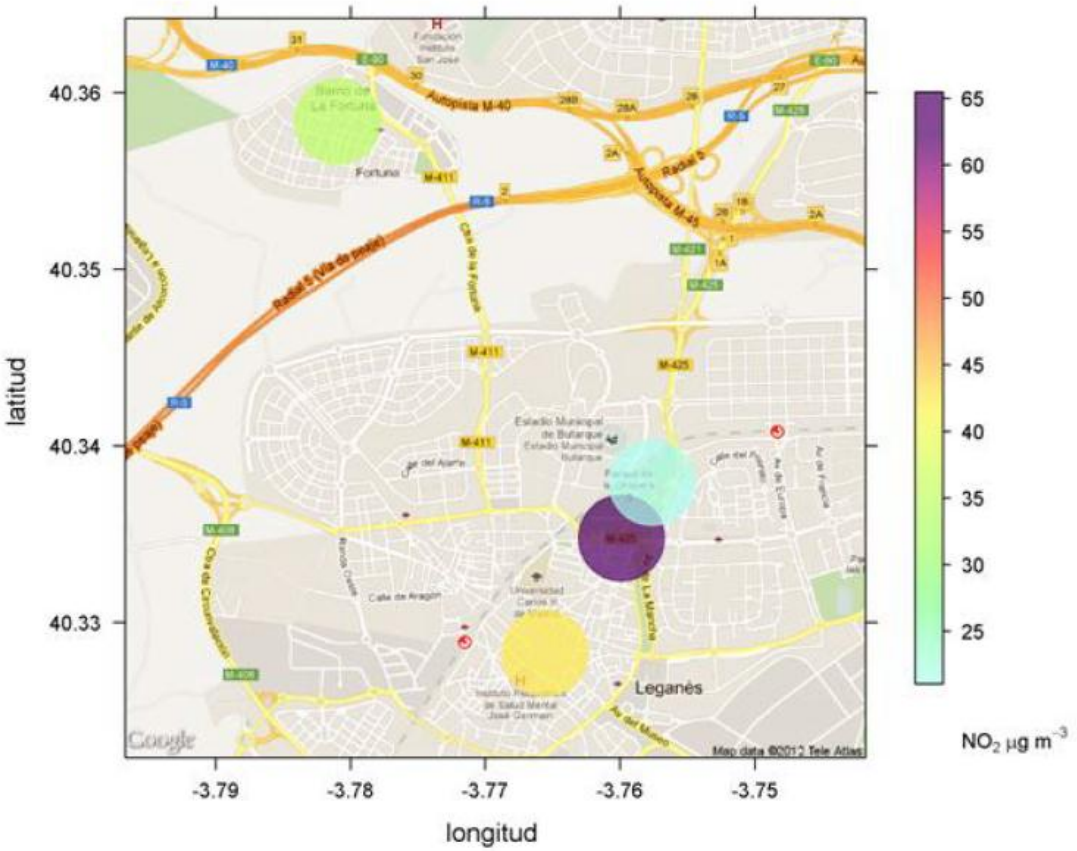
Simultaneous SO_2, CO_2 concentration plots

- SO_2/CO_2 ratio: 4.13 ppb/ppm,
- Measurement of canister sample by gas analyzers gives: 3.84 ppb/ppm,
- Difference < 8%.

Monitoring of urban air quality

Sensors at low levels of concentrations

Determination of ozone gradient over short distances (1 km) using NanoEnvi Analyst of Ingenieros Asesores (ES)



LEGANES, ES

2011 Ingenieros Asesores S.A. Nanotechnology Area ingenierosasesores.com CAMPAÑA DE MEDIDAS COMPLEMENTARIAS DE CALIDAD DEL AIRE EN LEGANÉS. INFORME FINAL. 2012

NETWORK OF SENSORS FIXED POSITION

Life Rescatame – EC DG Env.

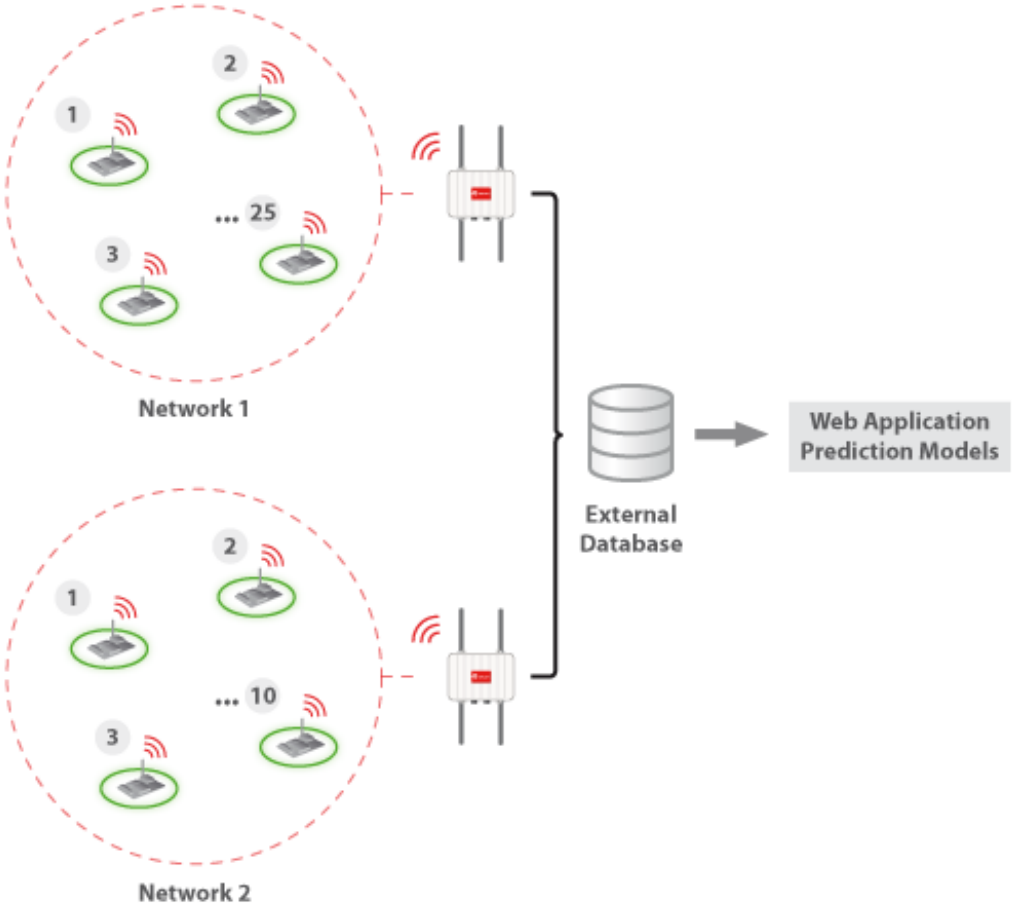
http://www.rescatame.eu

- Prevention of high urban pollution from traffic
- Promote the sustainable management of urban traffic using air-quality sensors + prediction models.

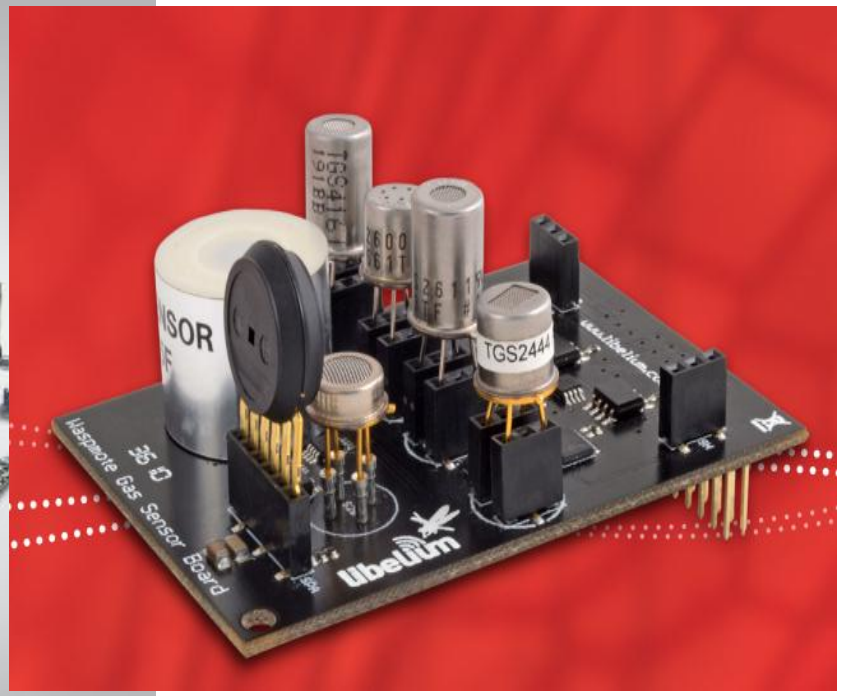
  *The Spanish city of **Salamanca** will be the scenario for this project although the proposed model can easily be implemented in other locations.*

35 Waspmotes were deployed in two different locations; measuring 7 parameters:

Temperature
Relative humidity
Carbon monoxide (CO)
Nitrogen Dioxide (NO2)
Ozone (O3)
Noise
Particle



European Commission

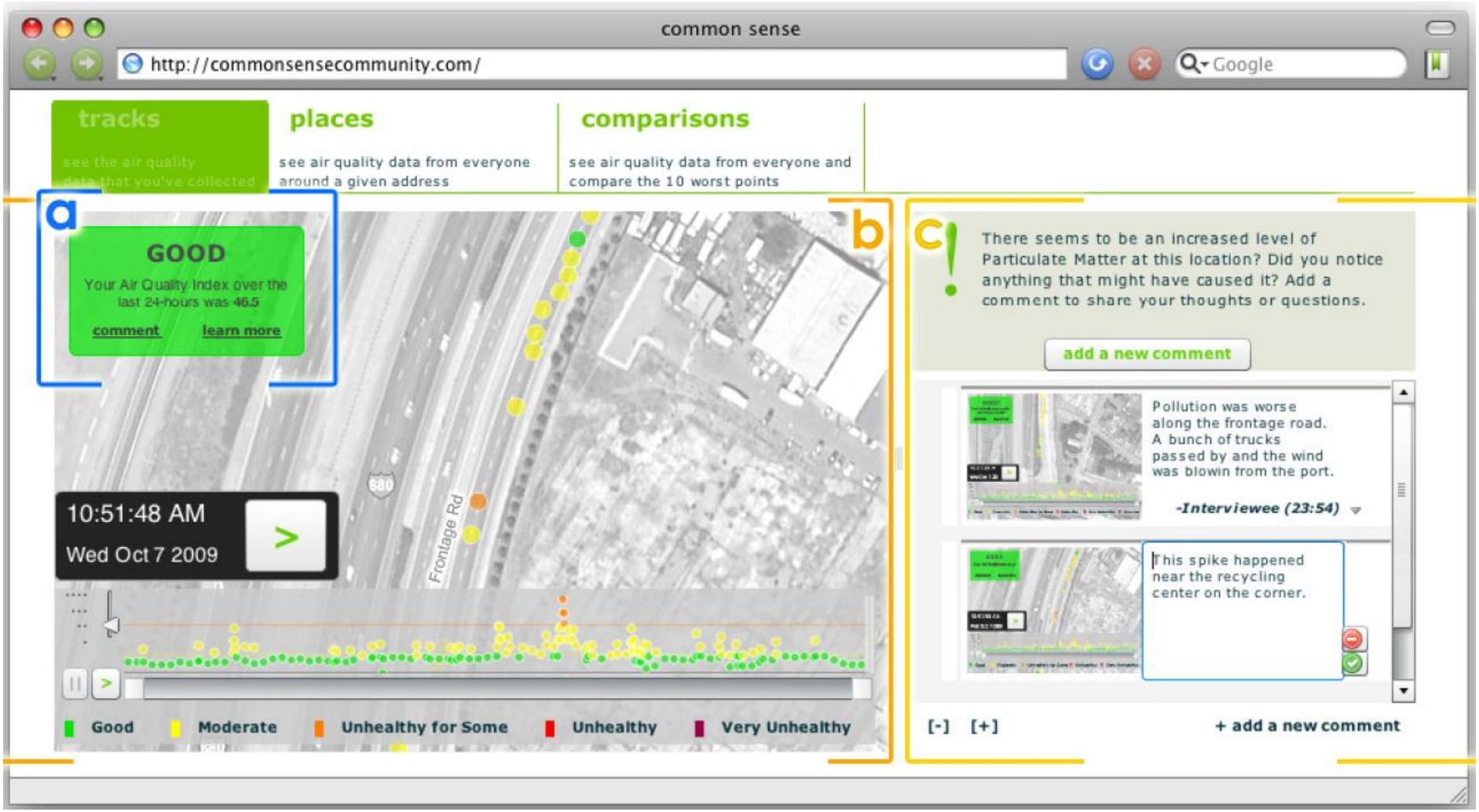


NETWORK OF MOBILE SENSORS

Common sense, INTEL Lab Berkley - USA

- Web-based and mobile applications
- provide live and historical data
- visualization tools
- online community features to allow people to explore and discuss the data and develop strategies for practical action.

European Commission



Sensor units components

Satellite navigation

Mobile phone

Gas sensors

Simple operation!

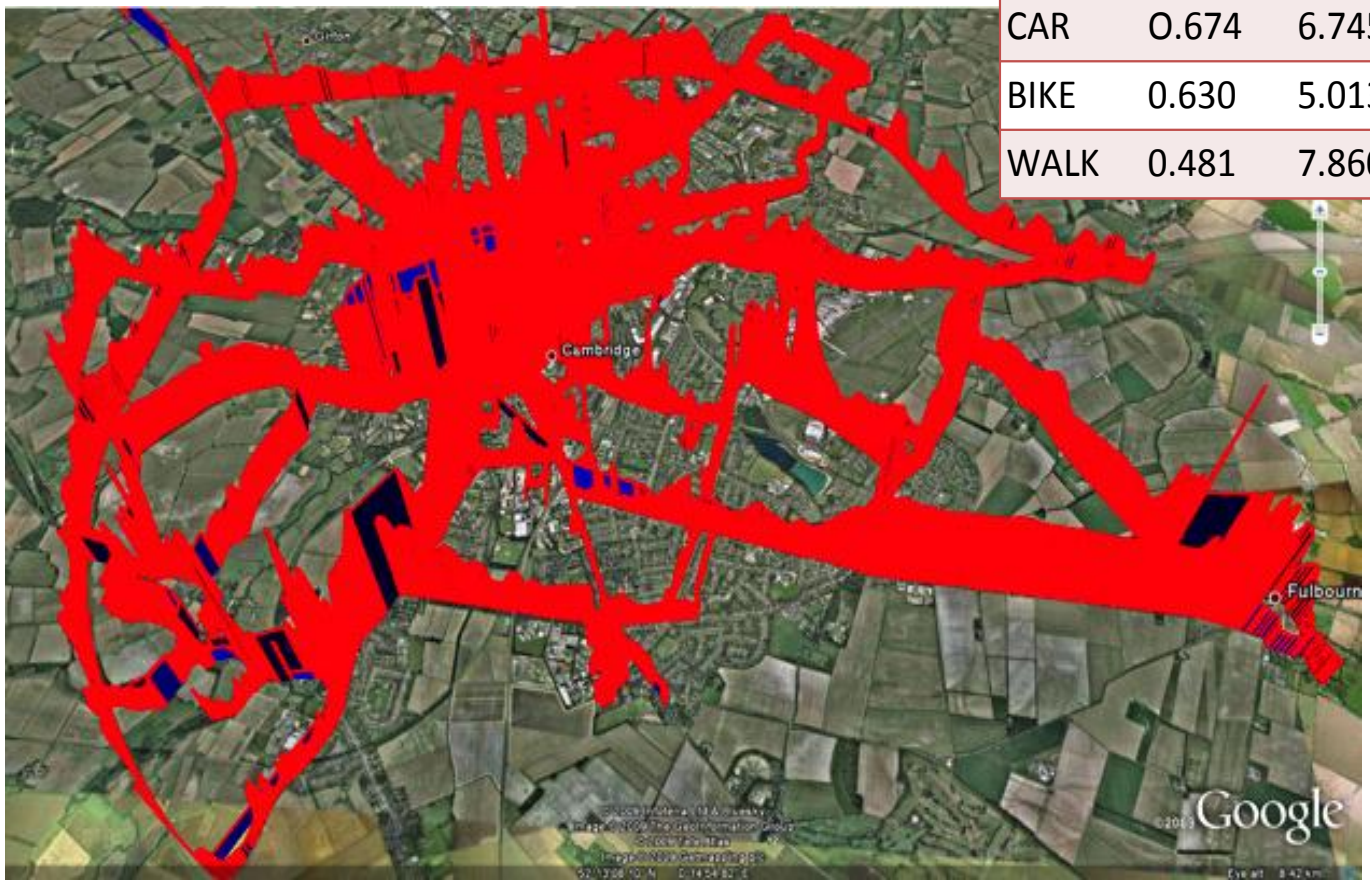
400 gm (incl. batteries)

Rod Jones

rlj1001@cam.ac.uk

Statistical evaluation CO

CO	MEAN	MAX
CAR	O.674	6.745
BIKE	0.630	5.013
WALK	0.481	7.860



European Policy

According to the European Directive 2008/50/EC, methods of measurements are classified as:

- Reference/Equivalent methods, mainly U<15 %

- or as Indicative methods, provided that Member States can demonstrate that U<25% (NO_2) , 30% (O_3) ... the Data Quality Objectives

The European Directive allows reducing the number of fixed monitoring sites by up to 50 % in zones and agglomerations where indicative measurements are used

European Policy

Micro-sensors:

- for now: not mentioned, not foreseen in European legislation for regulatory purposes

- European Members States shall demonstrate that Data Quality Objectives for Indicative Methods are met

For now, the European Commission mainly observes the results of some Research projects related to micro-sensors: MACPoll, AIRMONTEC, FP7-ENV.2012.6.5-1 (air quality monitoring in a "Smart City" context with community involvment)

Some lessons learned – what is needed

- *Sophisticated applications that combine sensors with WEB based system, GPS and GPRS system are now available. However, we miss validated sensors for monitoring at ambient air levels (ppb)*
- *Many lab. and field comparisons of sensors with reference methods are carried out. However, results are hardly repeatable. We need model equations that better describe the sensing processes to hope to reach the DQO of indicative*
- *We have to better demonstrate the validity of the spatial distributions determined using sensors even for the sole informative applications*

Some lessons learned – what is needed

- *Better fixed than mobile sensors for data quality and the time response of sensors*
- *Develop methods:*
  - *for correcting of cross-sensitivities and temperature/humidity effect*
  - *For calibration (lab, field) linked with aging and baseline / span drift of sensors*