EGU 2014 - Atmospheric and Meteorological Instrumentation

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OPEN HARDWARE, LOW COST, AIR QUALITY STATIONS FOR MONITORING OZONE IN COASTAL AREA

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Outline

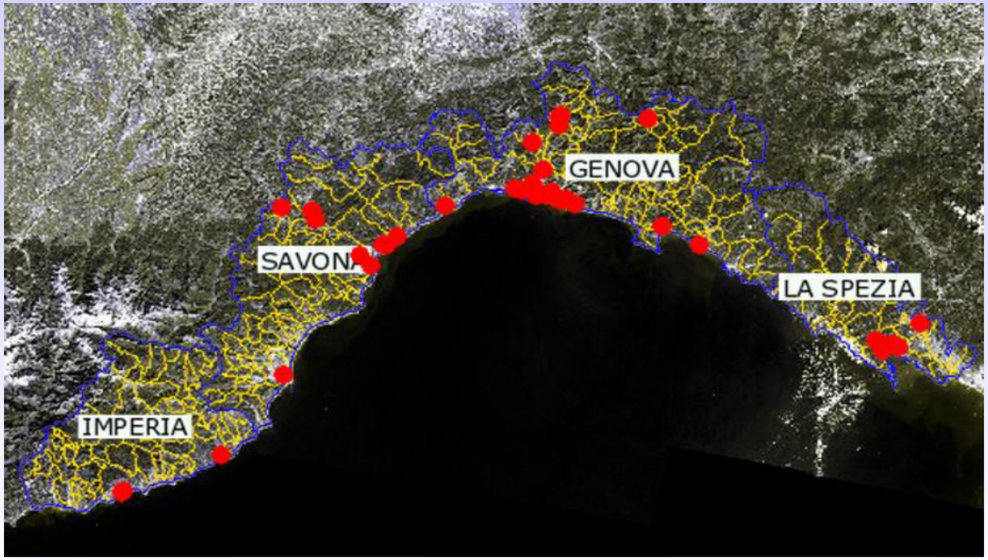
- Official monitoring networks
- Why Ozone
- Air Quality assessment in the digital era
- Low Cost Gas sensors: Electrochemical and metal oxide technologies
- ACRONET paradigm:
  - Infrastructure
  - Sensor board prototype
- Data Analysis and Field calibration
- Temperature error correction
- Forward calibration test
- Conclusion and future trends

Air Quality Monitoring Networks

Air pollution is monitored by **networks of high reliability, static measurement stations** referring both to standard air quality monitoring techniques, recommended by EU Commission and U.S. Environmental protection Agency, or to other equivalent measuring methods.

These monitoring stations are bulky shelters with **very high costs**, both. in terms of purchasing and maintenance.

All this led governments to the implementation of low density monitoring networks.



Why Ozone

- It is a good test-bench
  - It has low spatial variability
  - There are a lot of official monitoring stations measuring O3
- O3 level is one of the parameters that should be monitored in AQ assessment scenarios

*Ground-level ozone is a **toxic gas** linked to lung diseases and is formed by reactions of precursor gases, such as carbon monoxide. While emissions of precursors fell by between 15 and 32%, during 2002-2011, ozone concentrations decreased only slightly, and between 14 and 65% (this range partly reflects variations caused by atmospheric conditions which differ between years) of Europe's **urban population were exposed to levels above EU targets**. The researchers also note that ozone is causing widespread **damage to natural ecosystems** and **reductions in crop yields**.*

EEA (2013). Air quality in Europe. EEA Report No. 9/2013: 1-112.

- It affects other gas measurements

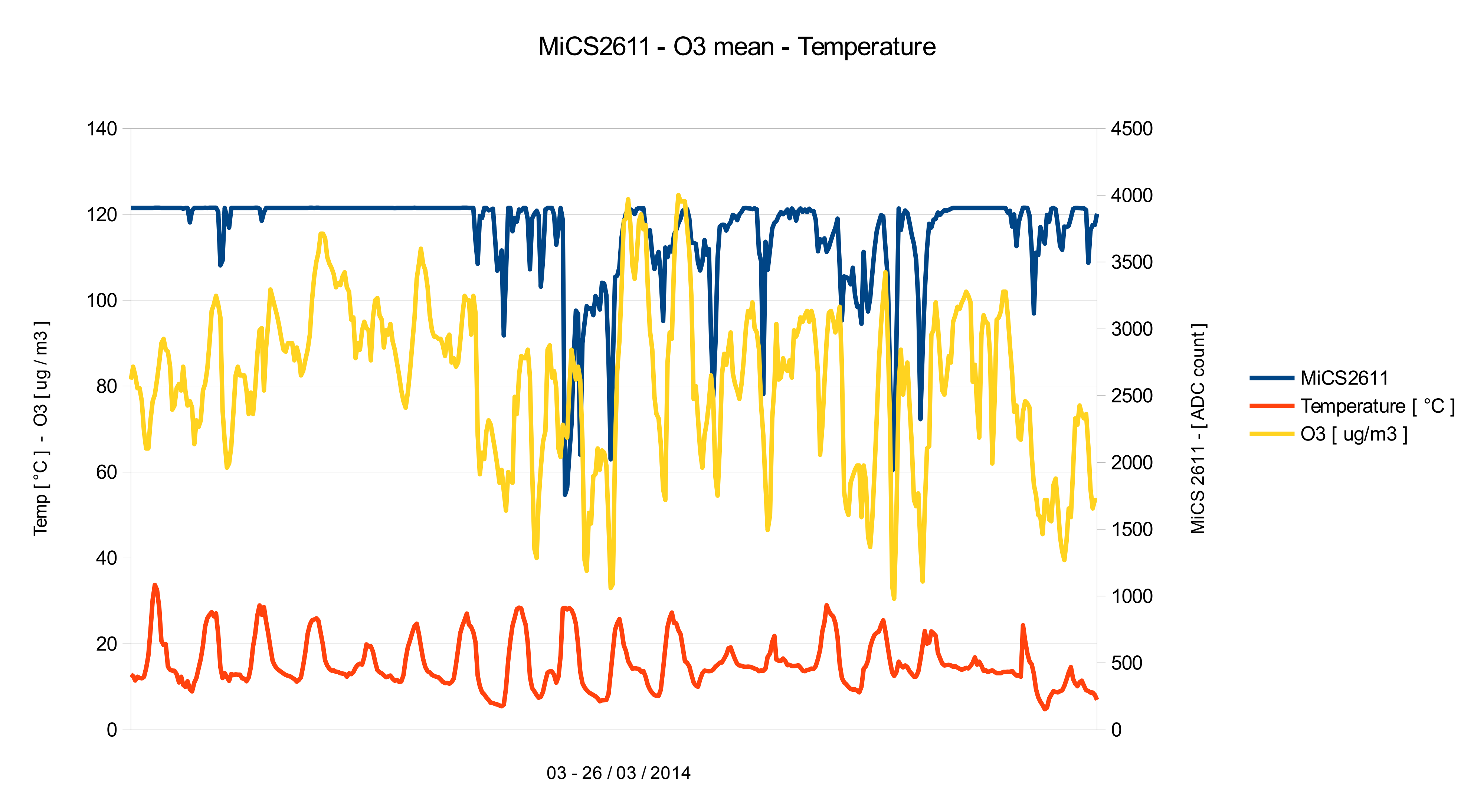
Sensor market analysis

	Principle of operation	Certified Range	Error Estimation	Sensitivity to other Gas or T° or HU	Documentation of the sensor characteristic	cost	availability	Calibration available
Alphasense NO	4-electrode sensors	0-20 ppm	<5 ppb	H_2S, NO_2, Cl_2, SO_2, H_2, CO, NH_3, CO_2, **O_3**, Halothane	Y	77 €	Y	Performance data available
Alphasense O_3	4-electrode sensors	>2 ppm	<3 ppb	H_2S, NO_2, Cl_2, NO, SO_2, H_2, CO, NH_3, CO_2,	Y	84 €	Y	Performance data available
Alphasense NO_2	4-electrode sensors	0-20 ppm	<3 ppb	H_2S, NO, Cl_2, SO_2, C_2H_4, CO, NH_3, CO_2, **O_3**, Halothane	Y	77 €	Y	Performance data available
Alphasense CO	4-electrode sensors	0-50 ppm	<10ppb	H_2S, NO_2, Cl_2, NO, SO_2, H_2, NH_3, C_2H_4	Y	85 €	Y	Performance data available
SGX EC4-2000-NO	Electrochemical	0-2000 ppm	0.5 ppm	TBA	Y	95 $	Not in stock	-
SGX EC4-250-NO	Electrochemical	0-250 ppm	0.5 ppm	SO_2, NO_2, CO, H_2	Y	93 $	4	-
SGX MICS 2614 O3	Metal Oxide Semiconductors	10 – 1000 ppb			Y	7 $	110	Y
SGX EC4-20-NO_2	Electrochemical	0-20 ppm	0.1 ppm	H_2S, NO, Cl_2, SO_2, CO	Y	95 $	Not in stock	-
SGX MICS 2714 NO_2	Metal Oxide Semiconductors	0,05-10 ppm			Y	7 $	110	Y
SGX MICS 4514 CO	Dual Metal Oxide Semiconductors	1-1000 ppm			Y	6 $	747	Y
SGX MICS 5524 CO	Metal Oxide Semiconductors	1-1000 ppm			Y	5 $	Not in stock	Y
Shinyei Model PPD42NS Particle Sensor	Optical	>1μm			Y	40 €	Y	Y (not sufficient)
Qbit PM_{10} station	laser	1-1000 μg/m³			Y	3500 €	Y	Y (?)

Low Cost AQ Sensors: Metal Oxide vs Electrochemical

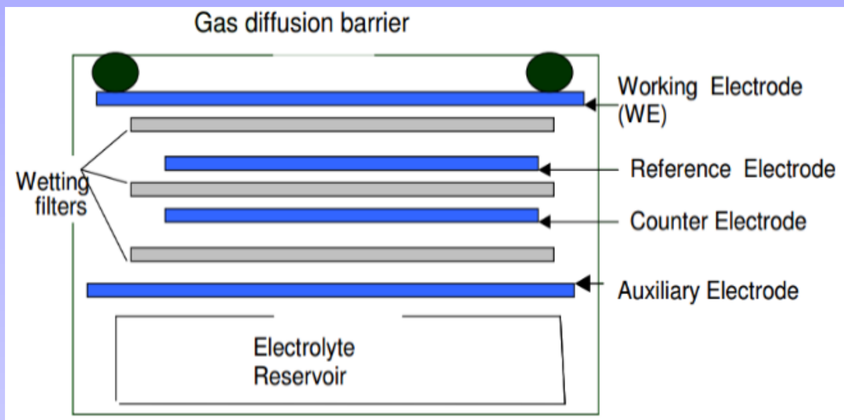
	METAL OXIDE	ELECTROCHEMICAL
Electronics	Heating circuit	• Potentiostat • Transimpedence amplifier
Power usage	Low	Very low
Stabilization time	1h	1h to 1day
Sensitivity to wind exposure	Yes (may cause cooling effect)	No
Sensitivity to sun exposure	Yes	Yes
Weather proof	Yes	Yes
Temporal resolution	Fine enough	Fine enough
Sensitivity to T and RH	Yes	Yes

MiCS-2611 Raw Data

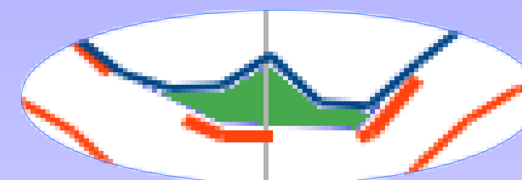


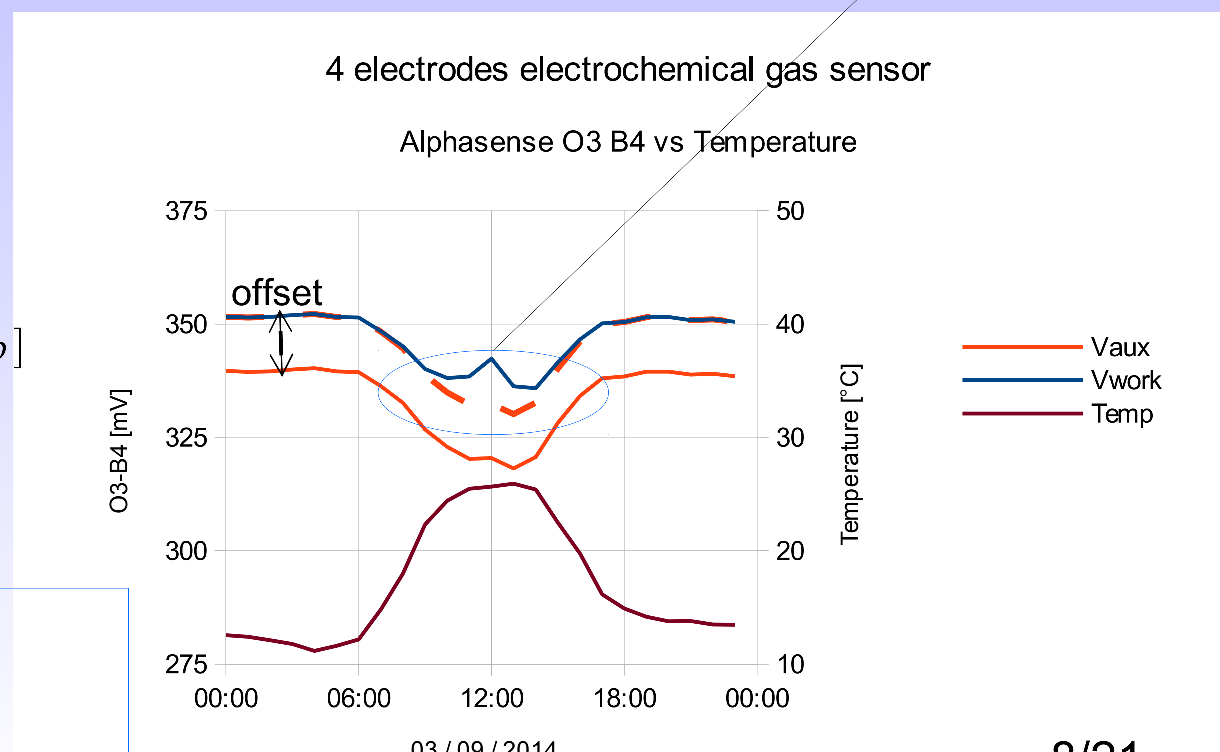
No calibration curve provided → ADC output analysis

Low Cost AQ Sensors: Electrochemical



- Low Power
- Robust
- Low Cost





$$C_{O3} = \frac{(V_{work} - V_{workZero}) - (V_{aux} - V_{auxZero})}{S} [ppb]$$

V_{work} : voltage on working electrode

V_{aux} : voltage on auxiliary electrode

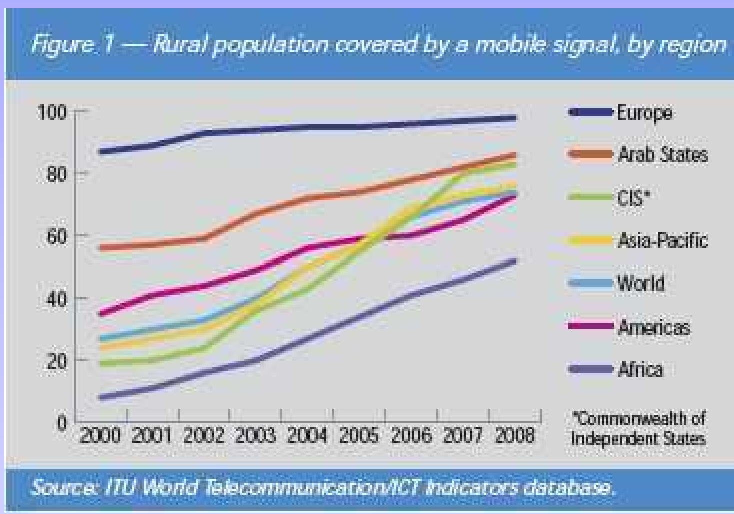
$V_{workZero}$: V_{work} at 0 ppb ozone concentration

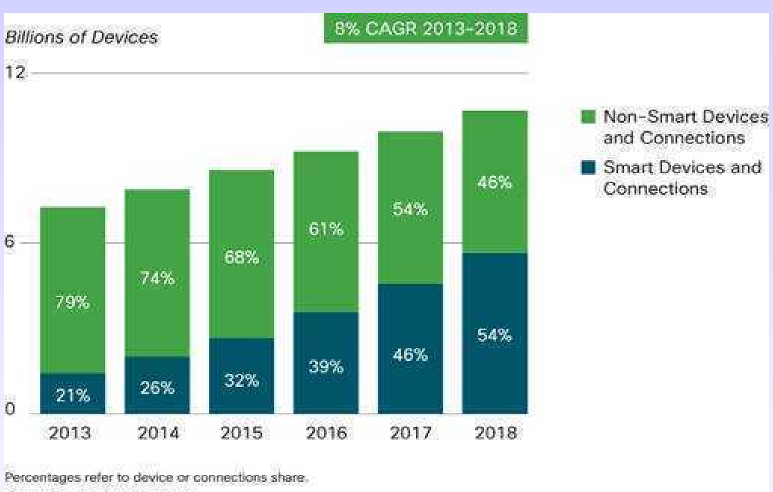
$V_{zuxZero}$: V_{aux} at 0 ppb ozone concentration

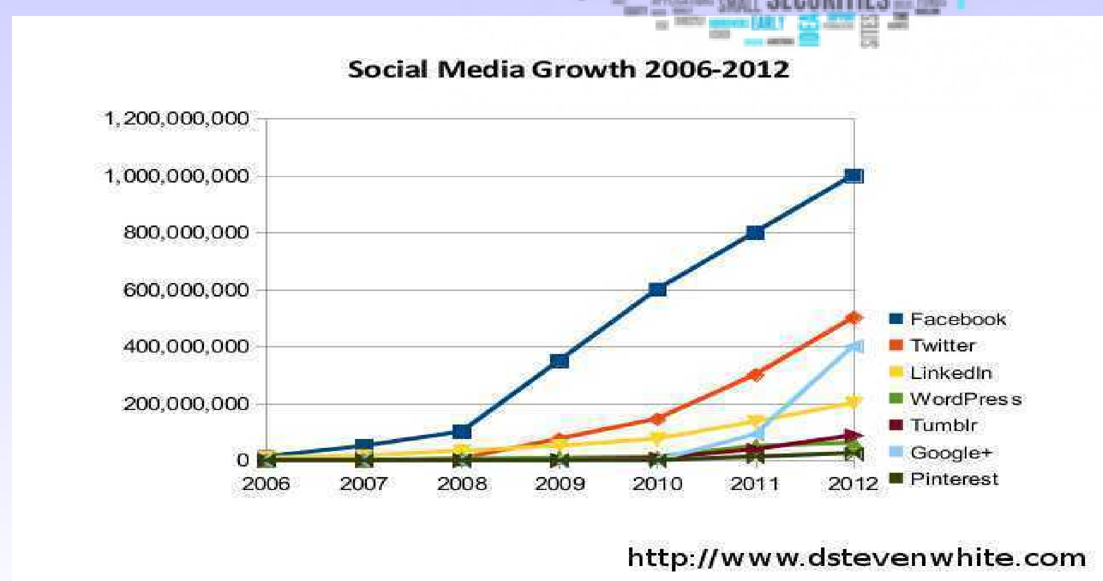
S : sensitivity

Alphasense O3-B4

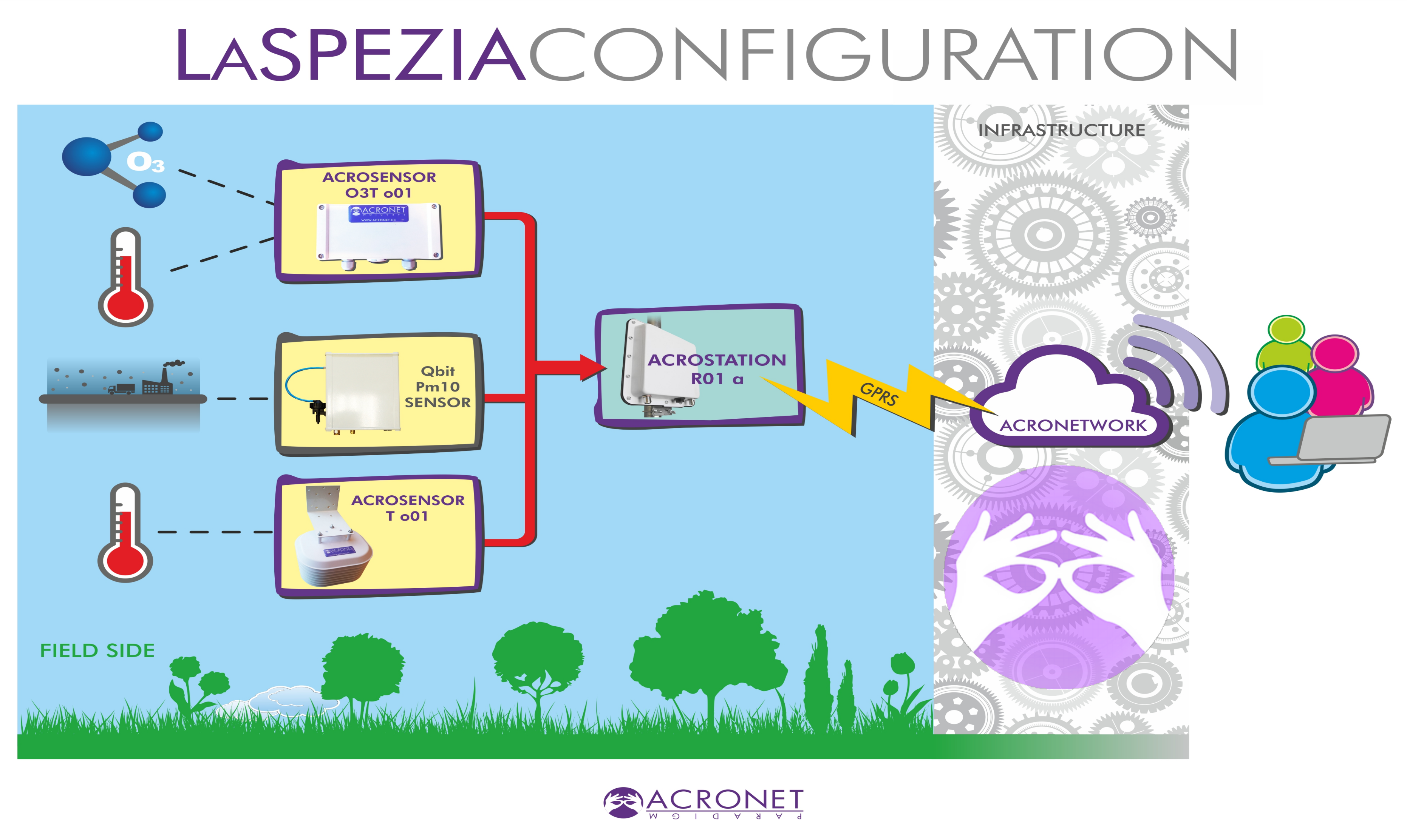
Air Quality assessment in the digital era







The ACRONET Paradigm: The infrastructure

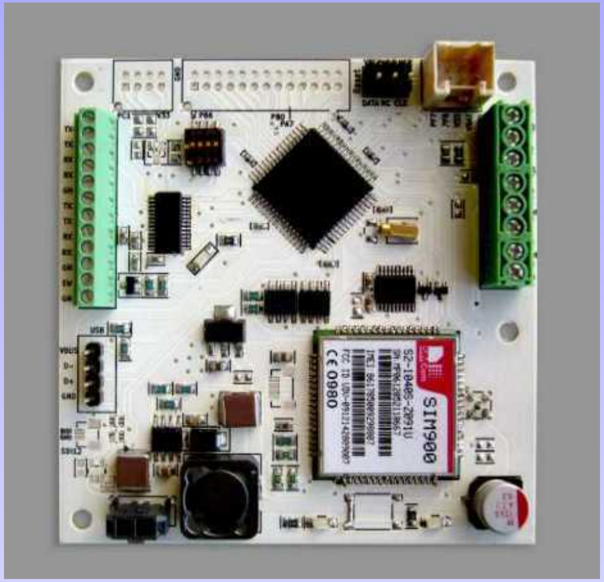


The ACRONET Paradigm: AQ sensor board

ACROSTATION r01a

- Acroboard Station V01 r08a
- Solar Panel – Lead Acid Battery – Acroboard Power V01 r04a
- Antenna
- Enclosure

TOTAL ~ 300€



SENSOR BOARD

- Sensors:
  - Alphasense O3-B4 (O3)
  - SGX MiCS-2611 (O3)
  - Sensirion SHT25 (T and RH)
- Enclosure

TOTAL ~ 300€

Sensor Network
Field calibration

Idea:

Real time estimation of parameters for linear calibration.

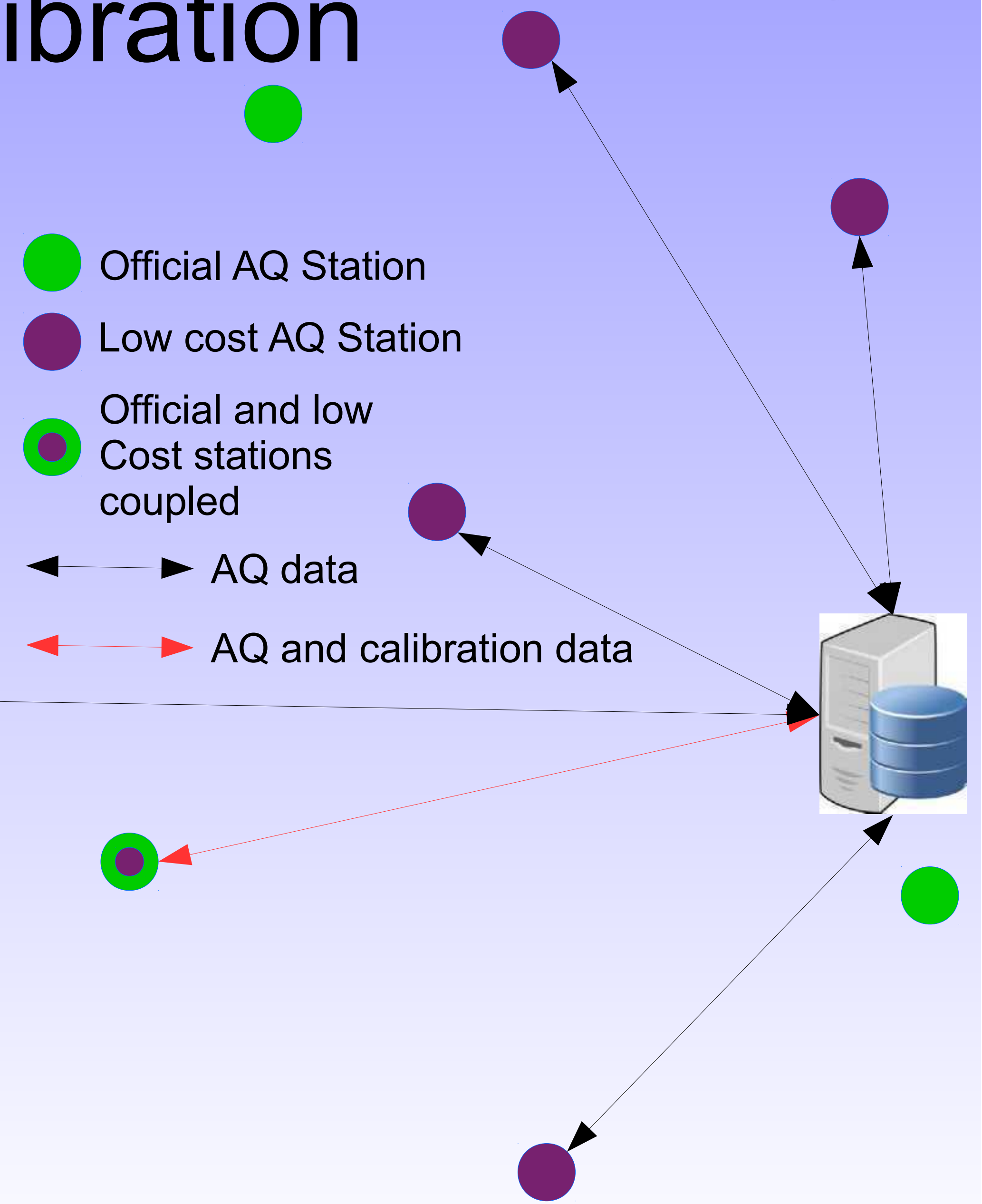
INTEGRATION WITH OFFICIAL MONITORING NETWORKS

Why?

- Simple and Low cost
- Follows seasonality
- Compensates sensor degradation

But ...

- How frequently?
- What is the maximum distance



Test Description and Data processing

Experimental measurement test:

- **Date:** 2014/03/04 – 2014/03/26
- **Measures:**
  - O3 (x2)
  - Temperature
  - Relative Humidity

Official AQ monitoring:

- Photometric technology
- **Sample rate:** 2 min
- **Aggregation rate:** 1 h
- Human data post-validation (24h)

Raw electric data →

ADC
Average on 20 sequential measures
f = 800 kHz
[2 min]

↓

Send data to server

[10 min]

↓

Moving average
1 hour

→ Calibration → Estimated O3 concentration

O3-B4 Linear Calibration 1/2

$$C_{O3} = \frac{(V_{work} - V_{workZero}) - (V_{aux} - V_{auxZero})}{S} [ppb]$$

$$\bar{O}3 = \Delta V \cdot \alpha_S + \beta_O$$

$\bar{O}3$: *estimated O3 concentration*

$\Delta V : V_{work} - V_{aux}$

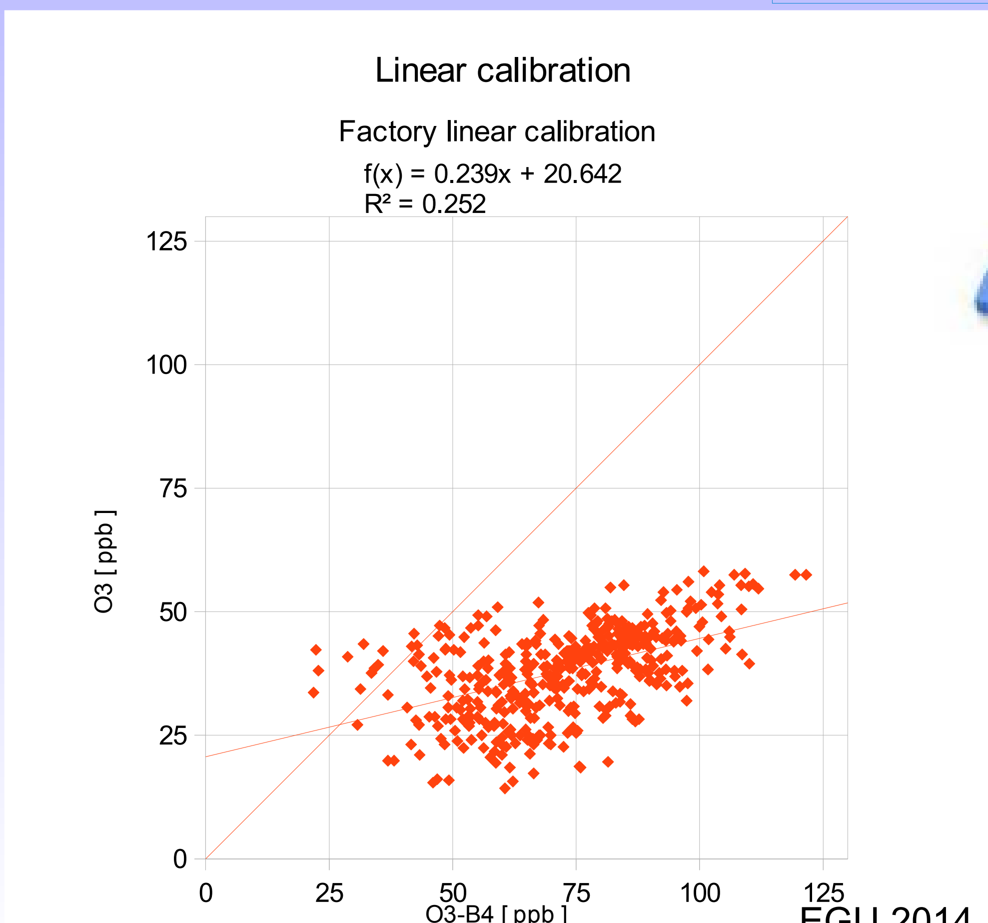
$\alpha_S : (O3 - B4\ sensitivity)^{-1}$

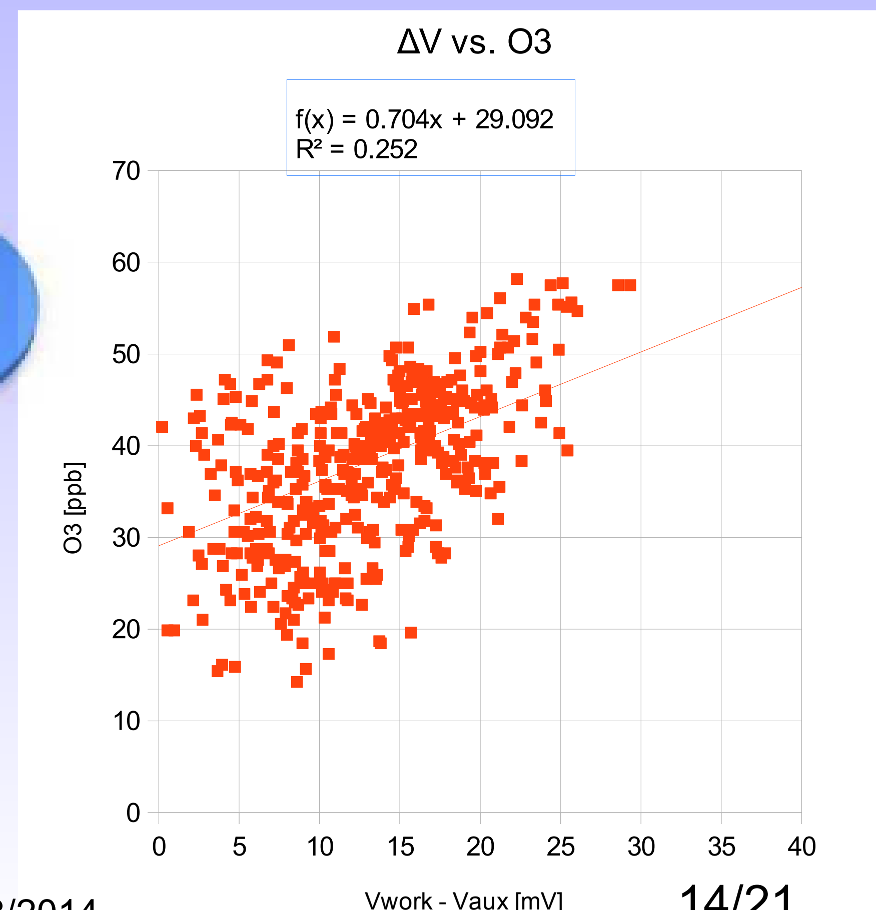
$\beta_O : O3 - B4\ offset$

Factory Calibration:

α_s = 2.941 [ppb / mV]

β_o = 35.29 [ppb]





O3-B4 Linear Calibration 2/2

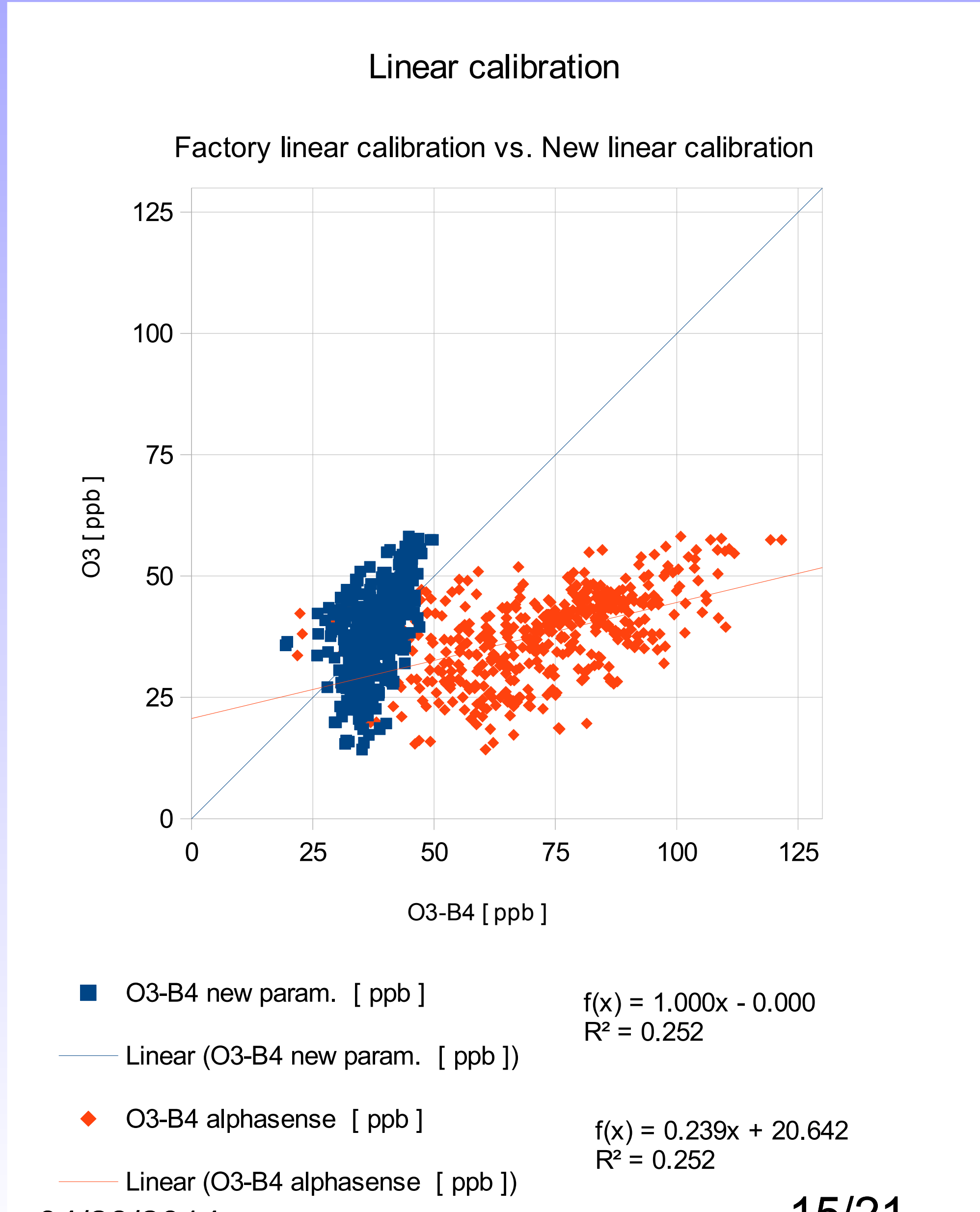
C_{O3} **vs. ΔV trend line:**

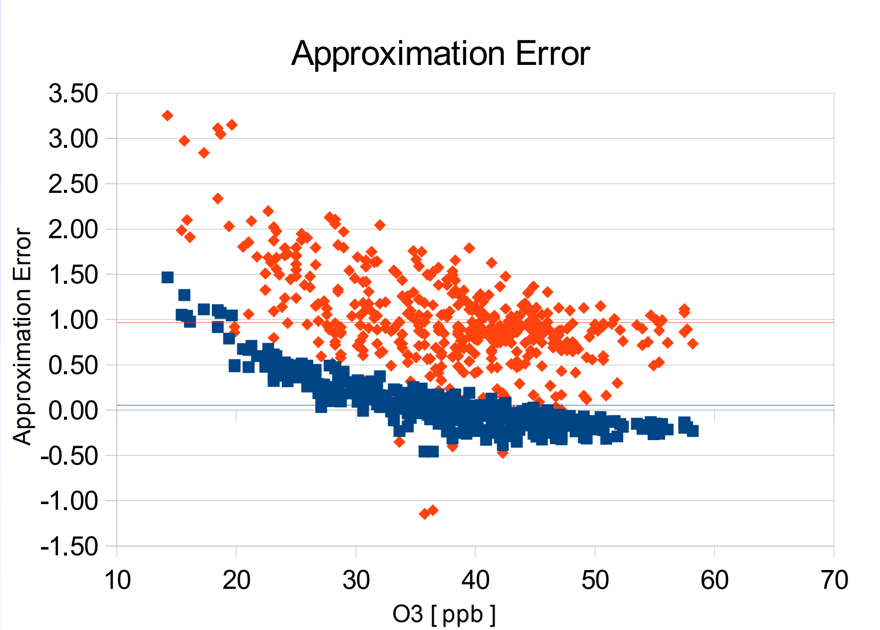
f(x) = 0.704x + 29.092
R^2 = 0.252

New Linear Calibration:

α_S = 0.709 [ppb / mV]

β_O = 29.092 [ppb]





O3-B4 Temperature correction

O3 B4 is a reducing sensor for which the ISB (I*ndividual Sensor Board*) is reversing the output, thus with positive temperature changes you are seeing negative value changes.

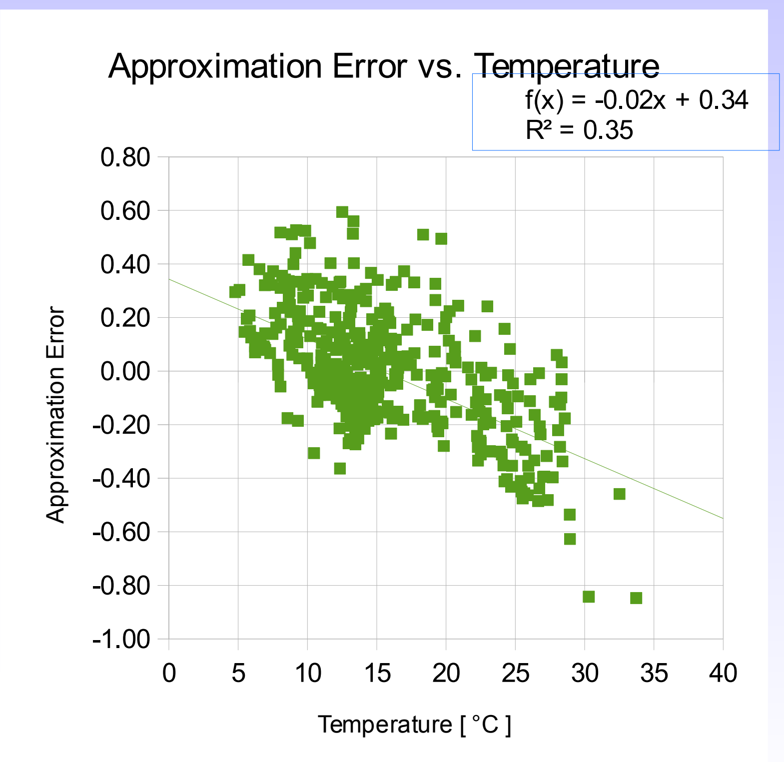
Linear Calibration
(new parameters)

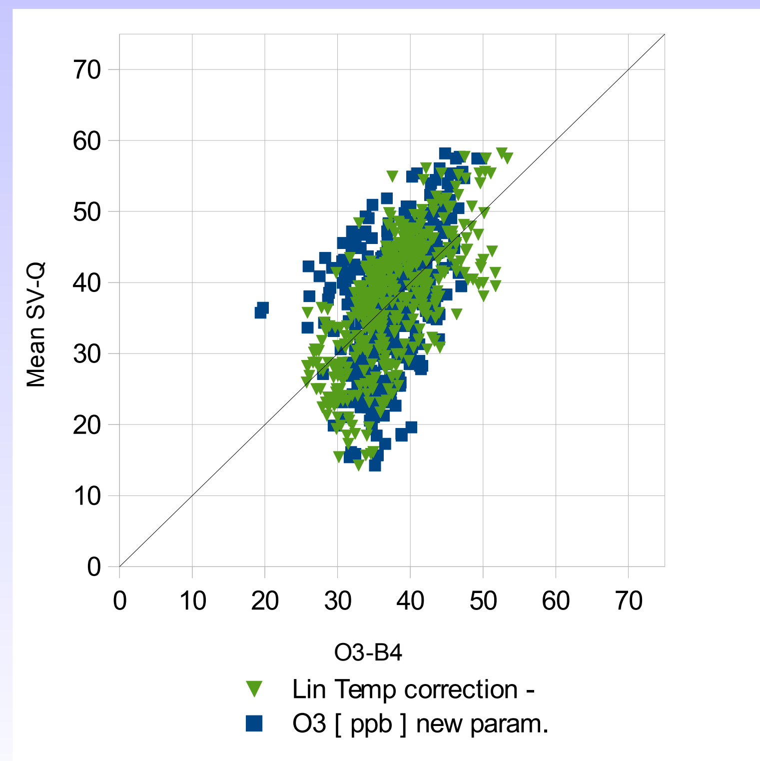
$R^2 = 0.252$

Linear Temperature Correction

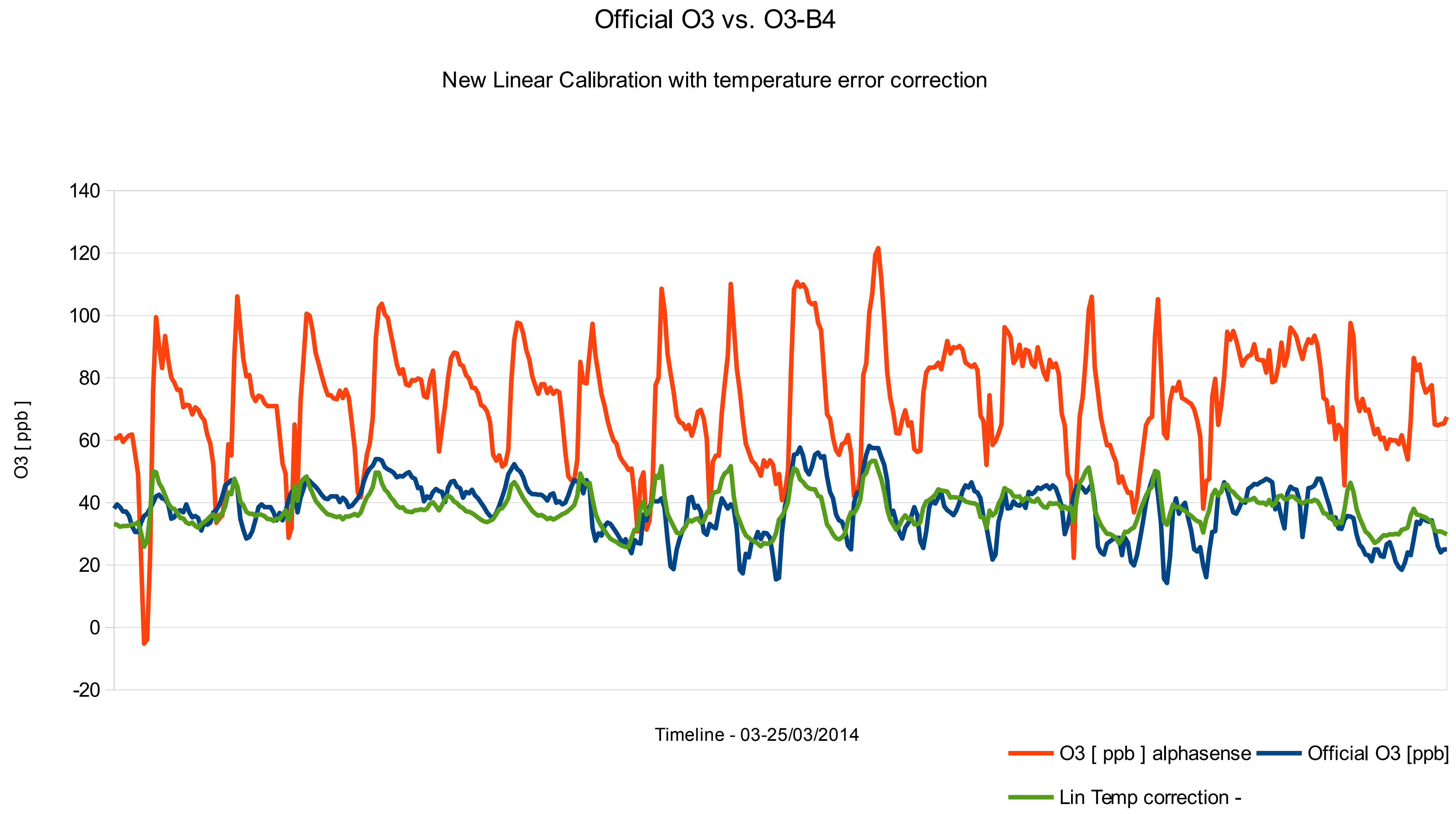
Linear temperature correction

$R^2 = 0.466$





Calibration Results



Forward Calibration test

DATASET

- Training Set: 03-14/03/2014
- Test Set: 14-25/03/2014

Official O3 Data

Training Set Raw Data (O3 + T)

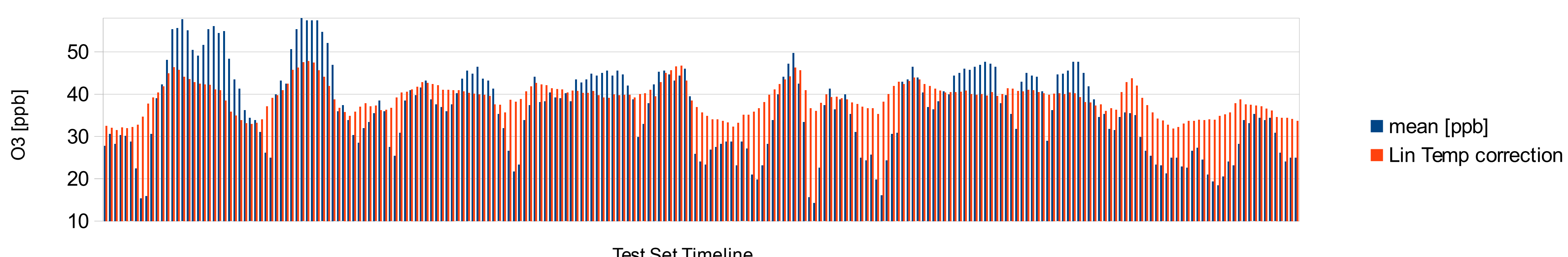
Calibration line with temperature correction

Test Set Raw Data (O3 + T)

Calibration line with temperature correction

Estimated O3

R^2
0.515



AQ Research Project

CIMA Research Foundation & La Spezia Port Authority started a new experimental campaign near a trusted AQ station (~ 5m):

Objectives of the research are the implementation and evaluation of a "lower cost" AQ sensor node.

Sensors:

- Alphasense O3-B4 (Ozone)
- QbitPM10 (PM10)
- DS18B20 (Temperature) x2

Conclusions and future trends

CONCLUSIONS

- Two O3 low cost sensors were tested
- New **field linear calibration** with linear temperature error correction were implemented

FUTURE TRENDS

- Test experimental field calibration for a longer period
- Test also nonlinear calibration
- Look for peaks and low level different calibration curve
- Test other lower cost Air Quality sensors (NOx, CO, PM10, PM2.5)

Thanks for your attention

Working on
the Shoulders
of Giants

...

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