European Network on New Sensing Technologies for Air Pollution Control and Environmental Sustainability - *EuNetAir*

COST Action TD1105

INTERNATIONAL WG1-WG4 MEETING on

New Sensing Technologies and Modelling for Air-Pollution Monitoring

University of Aveiro, Institute for Environment and Development - IDAD

Aveiro, Portugal, 14 - 15 October 2014

Action Start date: 01/07/2012 - Action End date: 30/06/2016 - Year 3: 2014-15 (*Ongoing Action*)

Sensor-Box for Air Quality Control Measurements

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

EuNetAir
European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

Michele Penza and Domenico Suriano

Function in the Action: Action Chair & WG Member

ENEA - Brindisi, Italy

ENEA
AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

OUTLINE

- **STATE-OF-ART ON AQ SENSING TECHNOLOGIES:**
  - **Data Quality Objectives (DQO) of AQ DIRECTIVE (2008/50/EC) on Ambient Air Quality and Cleaner Air for Europe (CAFE)**
- **VALIDATED AQ MONITORING by ENEA NASUS SENSORS:**
  - **CO Monitoring in collaboration with ARPA-Puglia, Brindisi, IT**
  - **NO_2, PM_{10} Monitoring in collaboration with JRC-IES, Ispra, IT**
- **CURRENT CHALLENGES:**
  - **AQ Sensors Applications in City of Bari: IT PON *RES-NOVAE***
  - **IAQ Sensors Applications in Schools: IT PON *BAITAH***
  - **AQ Sensors Applications on Buses (L'Aquila): IT *Smart Ring***
- **CONCLUDING REMARKS:**
  - **IAQ and AQ Sensors Applications in European Cities**
  - **Air Quality Index (AQI)**

CURRENT STATUS in AIR QUALITY SENSORS

European Commission

Michel Gerboles, JRC-Ispra, IES

Fixed measurements: definition

'fixed measurements' means measurements taken at fixed sites to determine the levels in accordance with the relevant *Data Quality Objectives* (DQO);

Fixed measurements are mandatory in zones and agglomerations where the upper assessment thresholds are exceeded.

AQD: European DIRECTIVE 2008/50/EC on ambient air quality and cleaner air for Europe, art. 2

CURRENT STATUS in AIR QUALITY SENSORS

European Commission

Michel Gerboles, JRC-Ispra, IES

AQD: Data Quality Objectives (DQO)

	SO_2, NO_2/NOx, CO	Benzene	O_3
Uncertainty for **fixed measurements**	15 %	25 %	15 %
	Fluoresc., chemil., NDIR	automatic GC or pumped sampling	UV photometry
	demonstration of equivalence would be mandatory to use micro-sensors		

CURRENT STATUS in AIR QUALITY SENSORS

European Commission

Indicative methods: definition

'indicative measurements' means measurements which meet *data quality objectives* that are less strict than those required for *fixed measurements*;

AQD: European Directive 2008/50/EC on ambient air quality and cleaner air for Europe, art. 2

Michel Gerboles, JRC-Ispra, IES

CURRENT STATUS in AIR QUALITY SENSORS

European Commission

AQD: Data Quality Objectives (DQO)

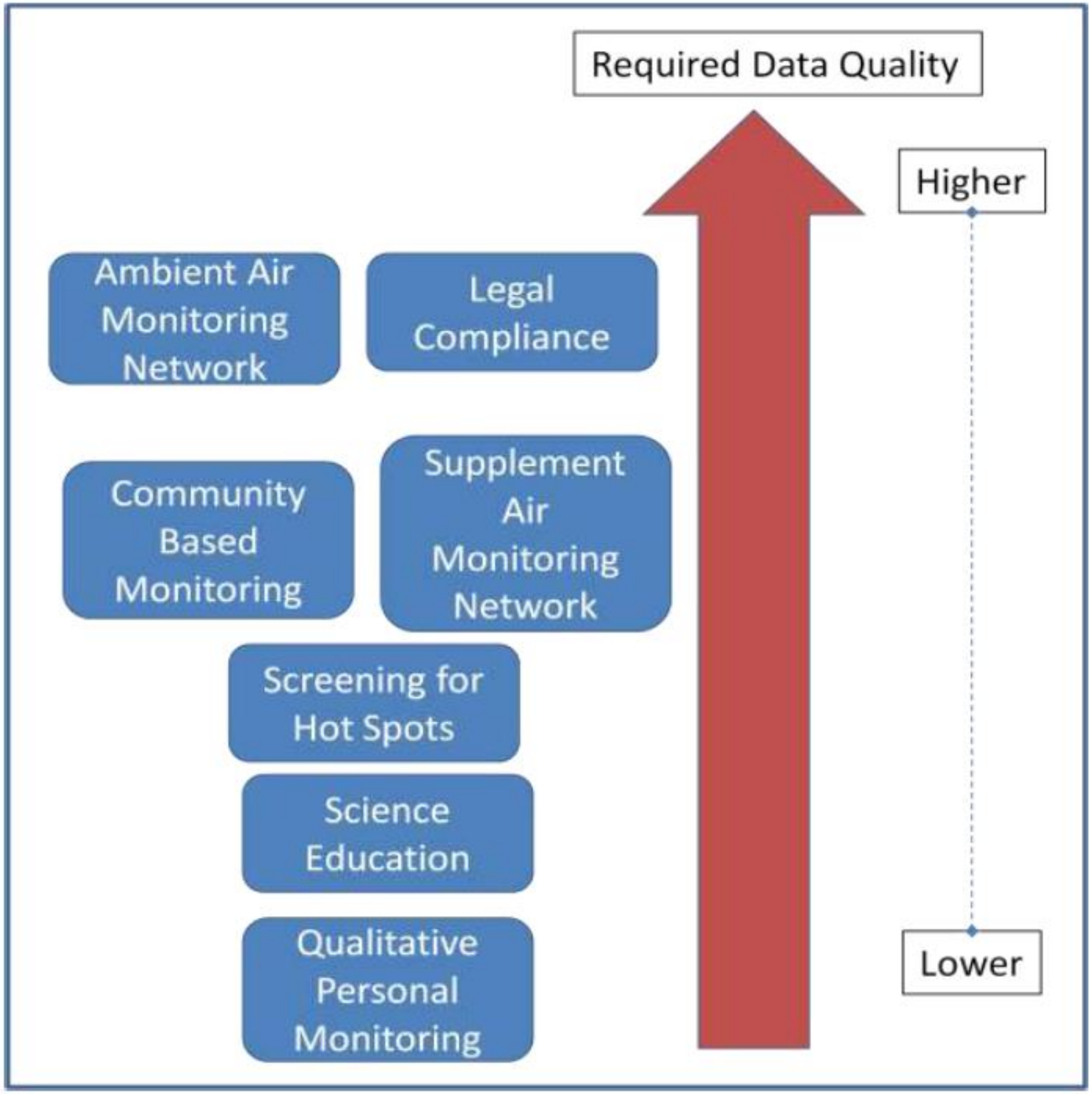
	SO_2, NO_2/NO /NOx, CO	Benzene	O_3
Uncertainty for **fixed measurements**	15 %	25 %	15 %
Uncertainty for **indicative measurements**	**25 %**	**30 %**	**30 %**
	diffusive samplers, ***micro-sensors***		

Michel Gerboles, JRC-Ispra, IES

Roadmap for Next Generation Air Monitoring

U.S. Environmental Protection Agency

Data Quality Requirements for the range of NGAM applications



US EPA, March 2013:

Tim Watkins, US EPA
Watkins.Tim@epa.gov

Viens Matthew, US EPA
Viens.Matthew@epa.gov

http://epa.gov/research/airscience/docs/roadmap-20130308.pdf

PORTABLE AQ SENSOR-SYSTEM: ENEA NASUS

- **TECHNICAL DATASHEET**

- ***AQ SENSORS***: **CO, NO_2, O_3, SO_2, H_2S, PM_{10}**
- ***METEOROLOGICAL SENSORS***: **RH, T**

AGENZIA NAZIONALE
PER LE NUOVE TECNOLOGIE, L'ENERGIA
E LO SVILUPPO ECONOMICO SOSTENIBILE

SENSOR TECHNOLOGIES: *Proofs-of-Concept*

NASUS GAS SENSOR BOX

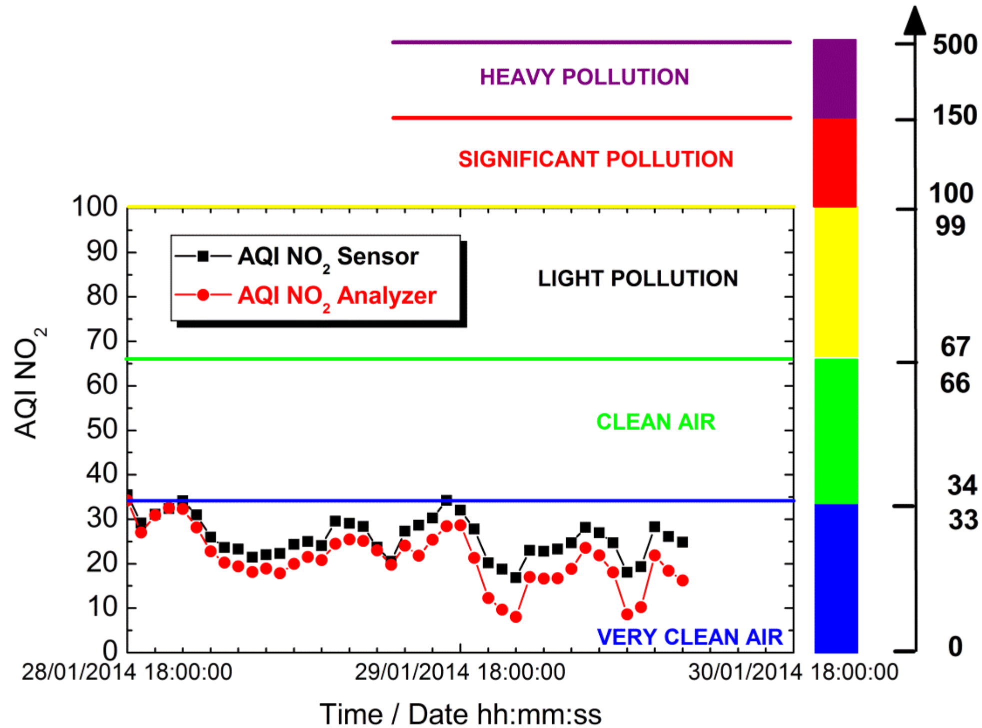
M. Penza et al., COST Brescia Meeting at EUROSENSORS 2014, 7-10 September 2014

Courtesy from ENEA

Real Measurements in collaboration with JRC-IES, Ispra, Italy

- **COCX_A3_Alphasense**
- **NO2A1_A3_Alphasense**
- **SO2AF_A3_Alphasense**
- **H2SA1_A3_Alphasense**

4 sensors (Electrochemical) to detect air-pollutants (e.g., CO, NO_2, SO_2) H_2S, T and RH



Air Quality Index (AQI) by NO_2 Sensor And NO_x Chemiluminescence Analyzer

AIR-SENSOR BOX: *Proof-of-Concept by ENEA*

MicroSensors for Urban Air Quality Monitoring

Wireless Sensor-Node Network for Air Quality Monitoring

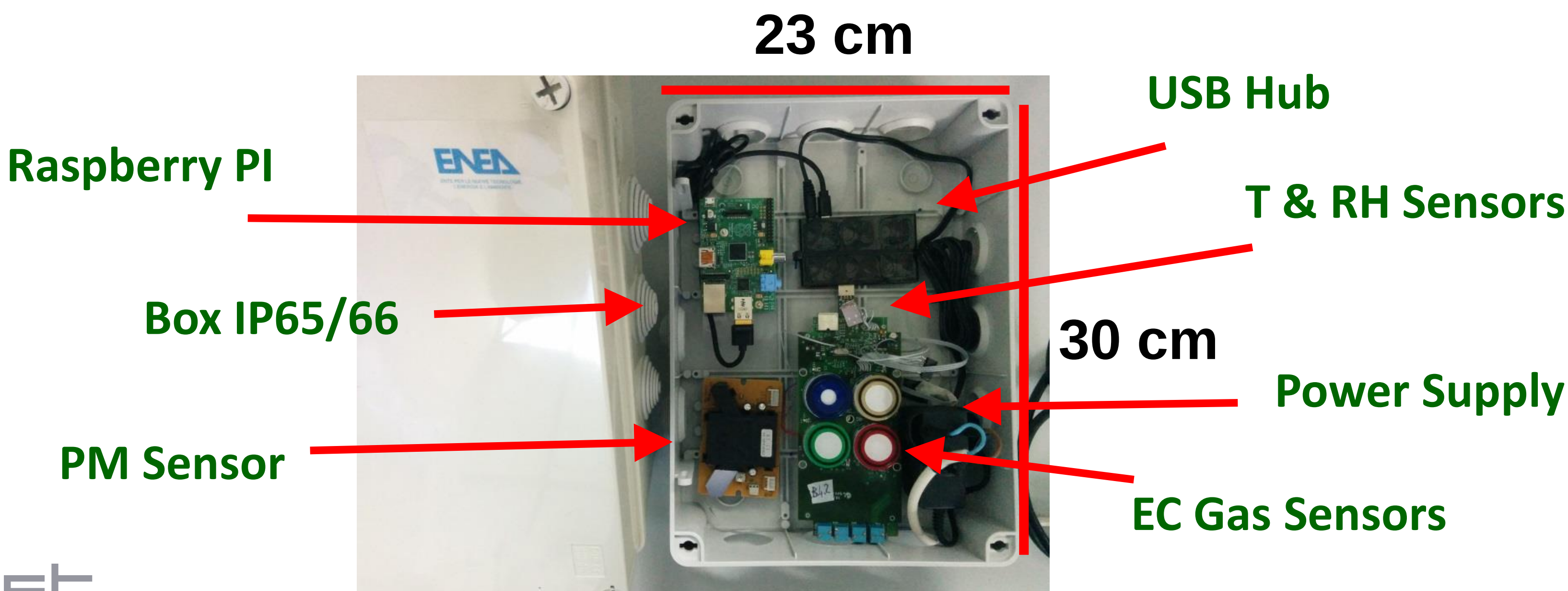
- ***Hardware***:

  A. AQ Multiparametric Sensor Node: NO_2, O_3, CO, SO_2, PM_{10}, T, RH

  B. Electronics: Raspberry PI, Modem GSM, SIM Card, Wi-Fi

  C. Database: saving data in real-time on a server (***IBM Italia collaboration***)

ENEA
AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE



AIR-SENSOR BOX: *Proof-of-Concept by ENEA*

MicroSensors for Urban Air Quality Monitoring

CO-B4	Alphasense, UK
NO2-B4	Alphasense, UK
O3-B4	Alphasense, UK
SO2-B4	Alphasense, UK
PPD20V	Shinyei, JP
TC1047A	Microchip
HIH5031	Honeywell

- **4 Electrochemical Sensors**: NO_2, O3, CO, SO_2
- **1 PM Sensor/Counter**: PM (1 - 5 µm)
- **Environmental Sensors**: T & RH

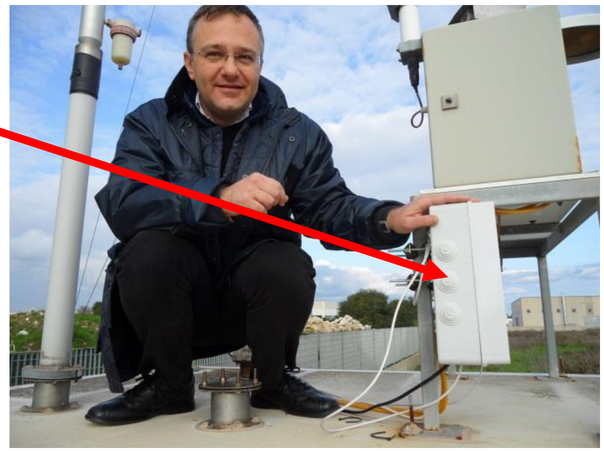
VALIDATED AQ MONITORING
by ENEA NASUS SENSORS:

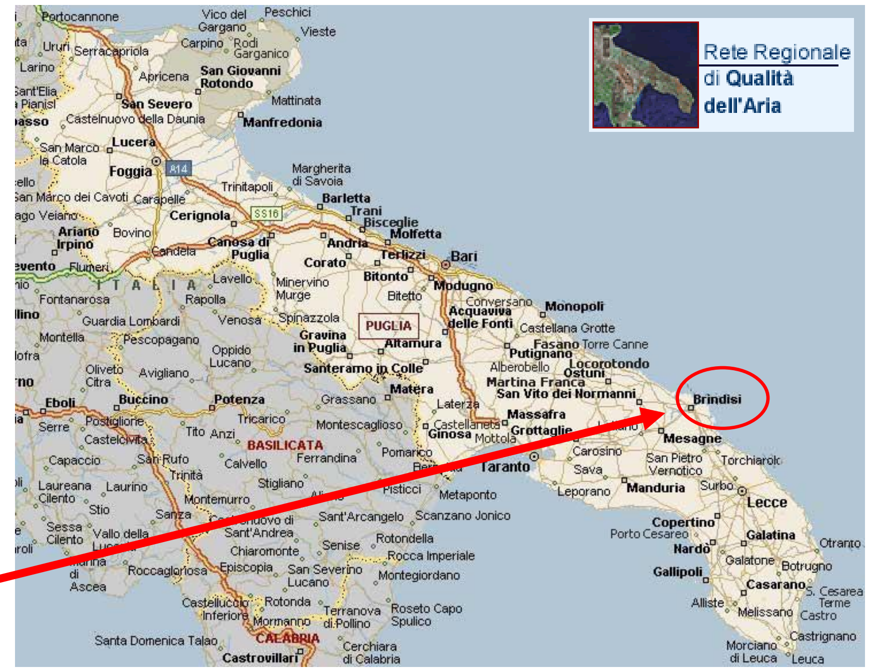
- CO Monitoring in collaboration with ARPA-Puglia, Brindisi, IT
- NO_2, PM_{10} Monitoring in collaboration with JRC-IES, Ispra, IT

NASUS 4: VALIDATION in Collaboration with ARPA-Puglia (1/4)

VALIDATION OF *NASUS 4* IN AN OFFICIAL LOCAL-NODE OF THE NETWORK ARPA-PUGLIA, *Regional Agency for Environmental Protection*

NASUS 4 on ARPA PUGLIA *fixed station* roof





ARPA-PUGLIA fixed stations locations: Industrial area at Brindisi (Italy)

NASUS 4: VALIDATION in Collaboration with ARPA-Puglia (2/4)

Validation Time-Domain Measurements Method:

NASUS 4 Sensors *versus* Standard Chemical Analyzers

Standard Chemical Analyzers

VS

NASUS 4 Sensors by ENEA Brindisi

NASUS 4: CO Validation in Collaboration with ARPA-Puglia (3/4)

$E(t) = |C_N(t) - C_A(t)|$

Mean $E(t)$ = 28.6 ppb

Max $E(t)$ = 339.5 ppb

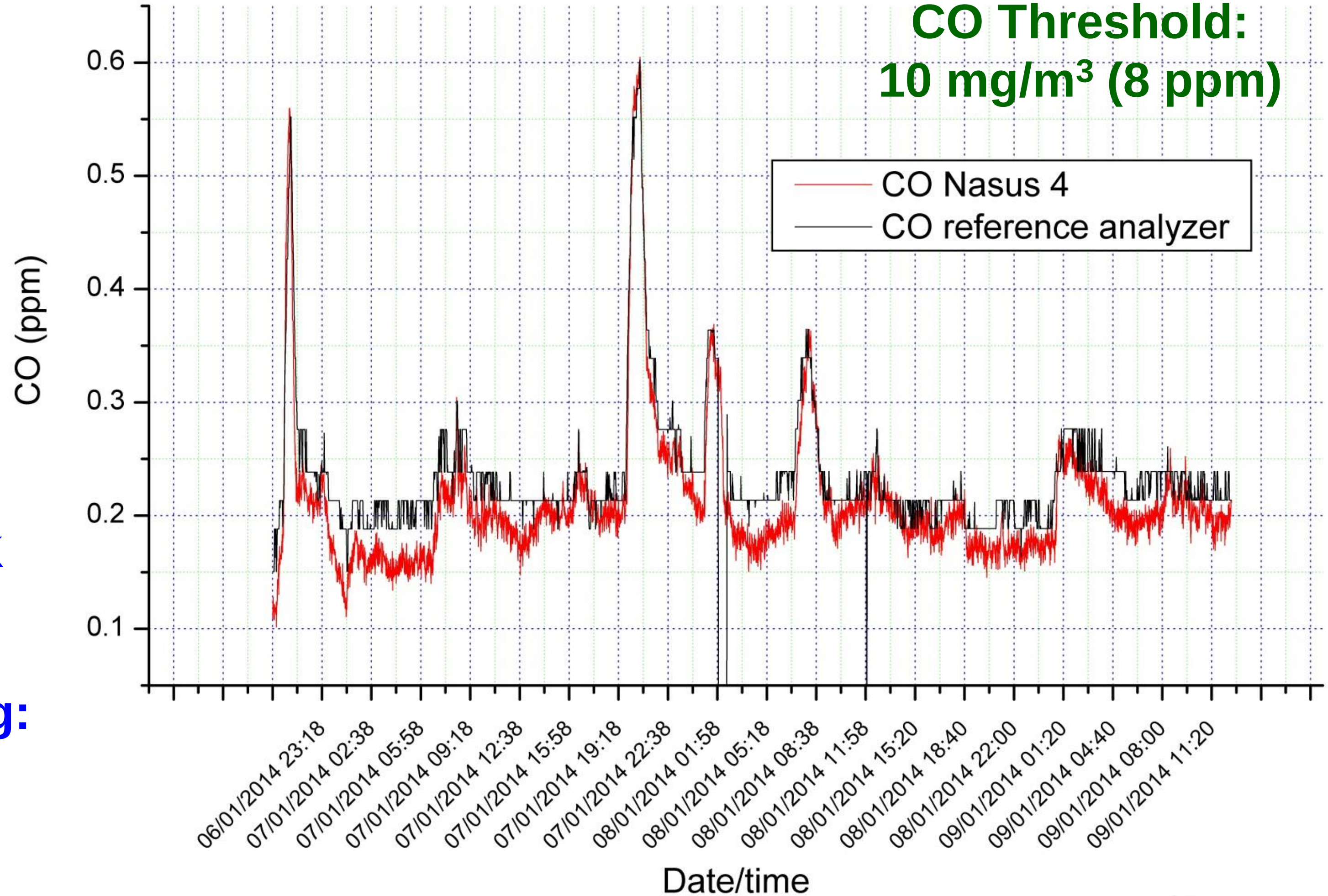
Very Good Accuracy !

E(t) = Error

$C_N(t)$: Nasus 4 CO sensor concentration

$C_A(t)$: CO reference analyzer concentration

CO Threshold:
10 mg/m^3 (8 ppm)



CO EC Sensor COCX by Alphasense Ltd, UK

Measurement Timing: 6 - 9 January 2014

COST EUROPEAN COOPE

NASUS 4: CO Validation in Collaboration with ARPA-Puglia (4/4)

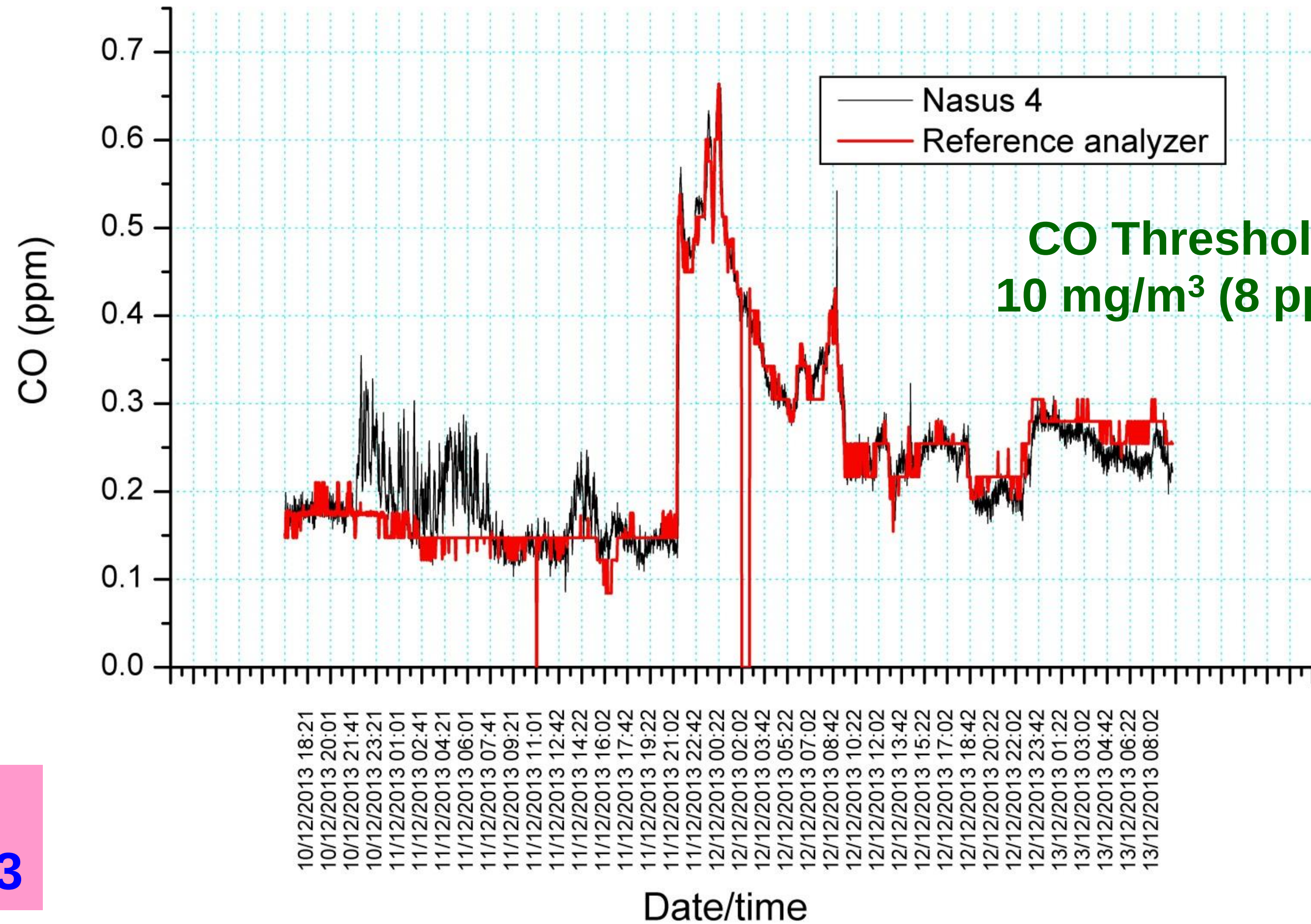
E(t) = Error
$C_N(t)$: Nasus 4 CO sensor concentration
$C_A(t)$: CO reference analyzer concentration

$E(t) = |C_N(t) - C_A(t)|$

Mean E(t) = 29.05 ppb

Max E(t) = 427.6 ppb

Very Good Accuracy !



CO Threshold: 10 mg/m^3 (8 ppm)

CO EC Sensor COCX by Alphasense Ltd, UK

Measurement Timing: 10 - 13 December 2013

VALIDATION OF *NASUS 4* IN A REAL SCENARIO BY MEANS OF JRC AQ MOBILE LAB

NASUS 4 on JRC AQ Mobile Laboratory

NASUS 4: Validation in Collaboration with JRC-IES, Ispra (2/7)

Validation Time-Domain Measurements Method:

NASUS 4 Sensors *versus* Standard Chemical Analyzers

Standard Chemical Analyzers

VS

NASUS 4 Sensors by ENEA Brindisi

NASUS 4: NO_2 Validation in Collaboration with JRC-IES, Ispra (3/7)

$E(t) = |C_N(t) - C_A(t)|$

Mean E(t) = 5 ppb

Max E(t) = 12.7 ppb

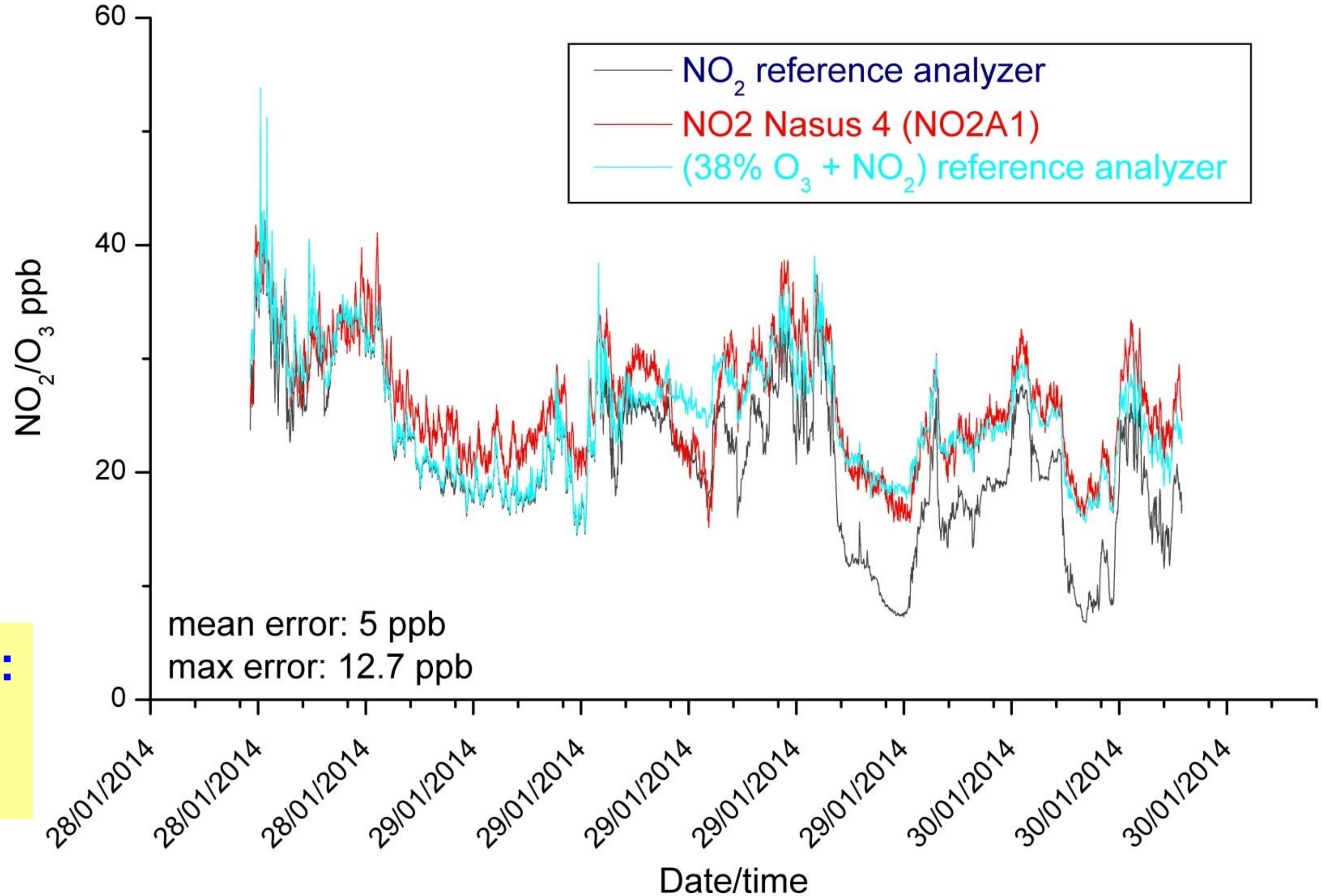
Good Accuracy !

NO_2 Thresholds:
200 μg/m³ (100 ppb)
400 μg/m³ (200 ppb)

NO_2 EC Sensor NO2A1 by Alphasense Ltd, UK

Measurement Timing:
28 - 30 January 2014
WINTER: 2 DAYS

E(t) = Error
$C_N(t)$: NO_2 sensor concentration
$C_A(t)$: NO_2 reference analyzer concentration



NASUS 4: NO_2 Validation in Collaboration with JRC-IES, Ispra (4/7)

$E(t) = |C_N(t) - C_A(t)|$

Mean E(t) = 3.36 ppb

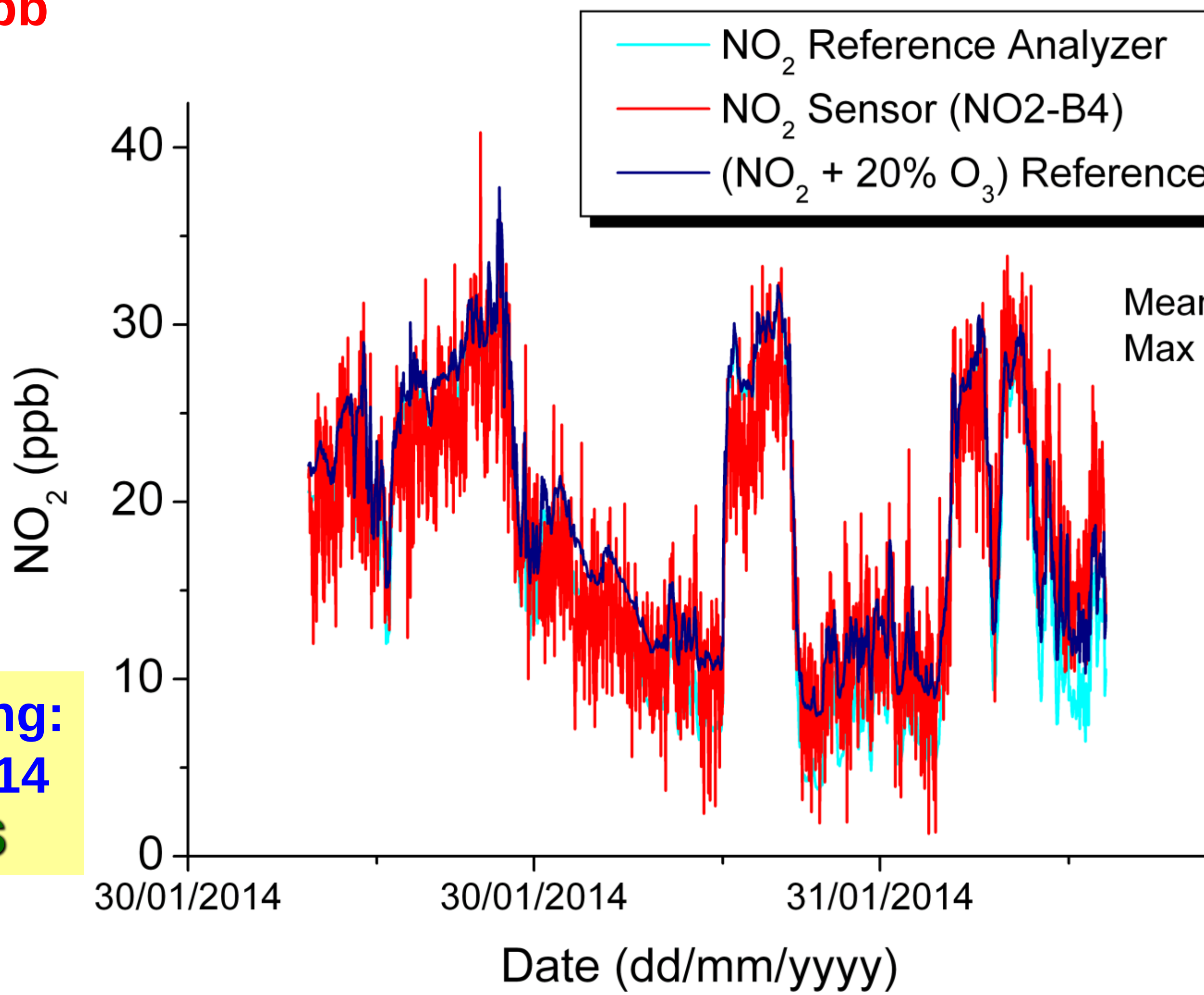
Max E(t) = 14.83 ppb

E(t) = Error
$C_N(t)$: NO_2 sensor concentration
$C_A(t)$: NO_2 reference concentration

Very Good Accuracy !

NO_2 Thresholds:
200 μg/m³ (100 ppb)
400 μg/m³ (200 ppb)

EC Sensor NO2B4
Alphasense Ltd



Measurement Timing:
30 - 31 January 2014
WINTER: 2 DAYS

NASUS 4: NO_2 Validation in Collaboration with JRC-IES, Ispra (5/7)

E(t) = |C_N(t) - C_A(t)|

Mean E(t) = 12.75 ppb

Max E(t) = 193 ppb

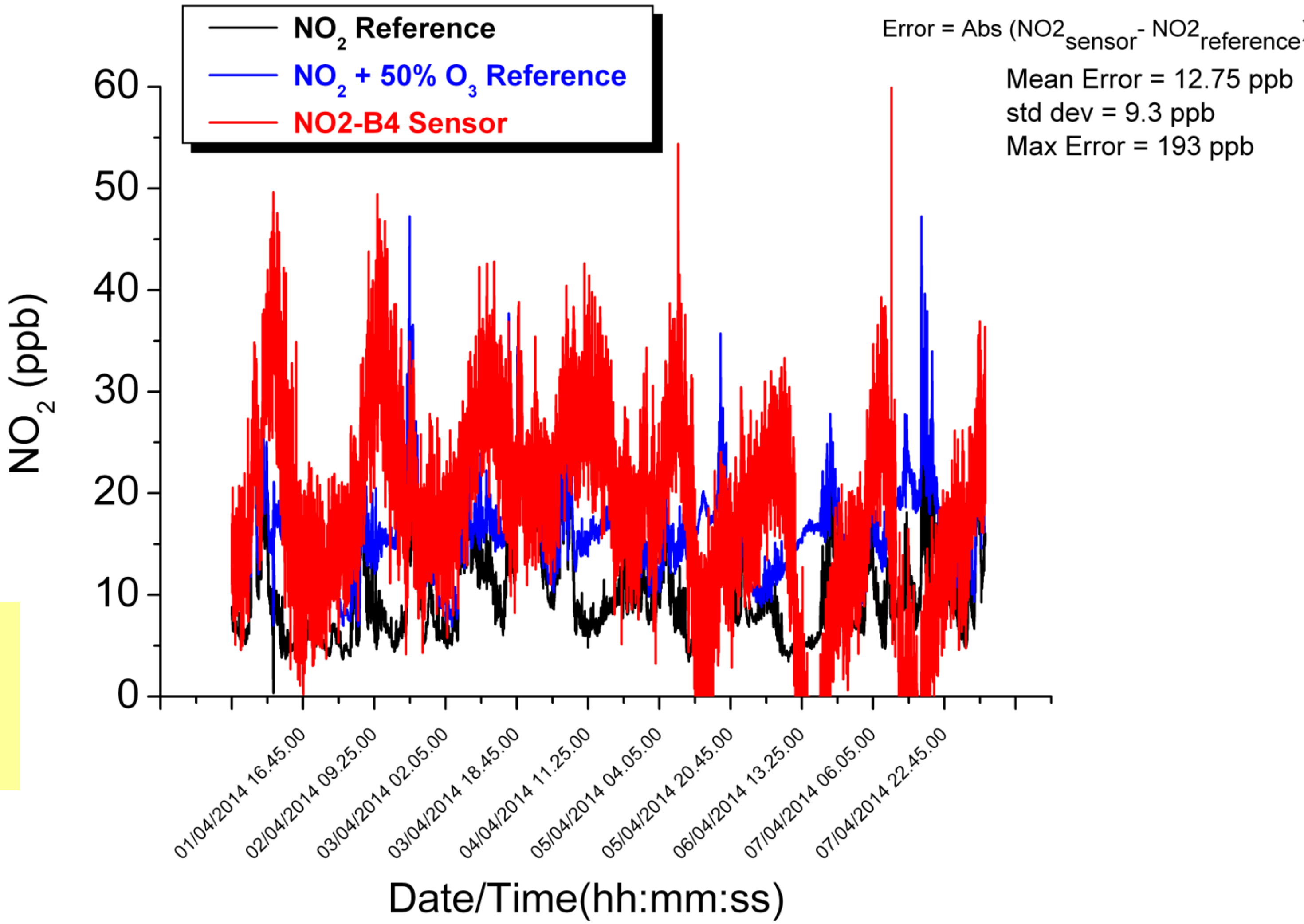
Moderate Accuracy !!

NO_2 Thresholds:
200 μg/m³ (100 ppb)
400 μg/m³ (200 ppb)

NO_2 EC Sensor NO2B4 by Alphasense Ltd, UK

Measurement Timing:
1 Apr - 8 May 2014
SPRING: 38 DAYS

E(t) = Error
C_N(t): Nasus 4 NO_2 sensor concentration
C_A(t): NO_2 reference analyzer concentration

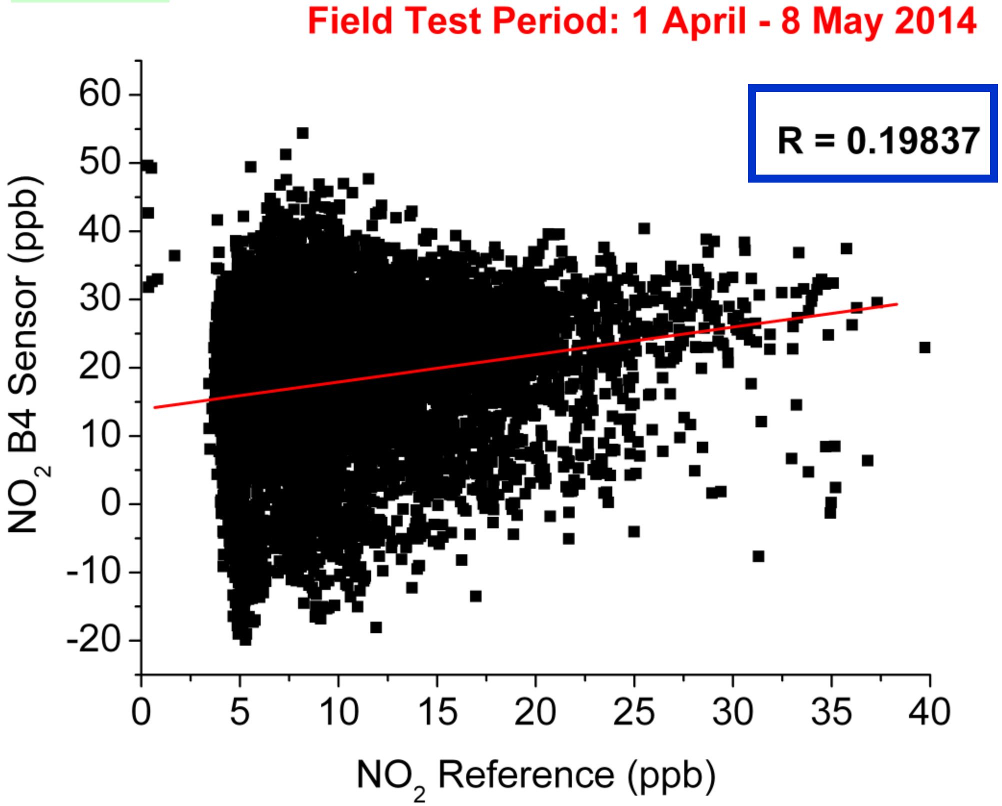


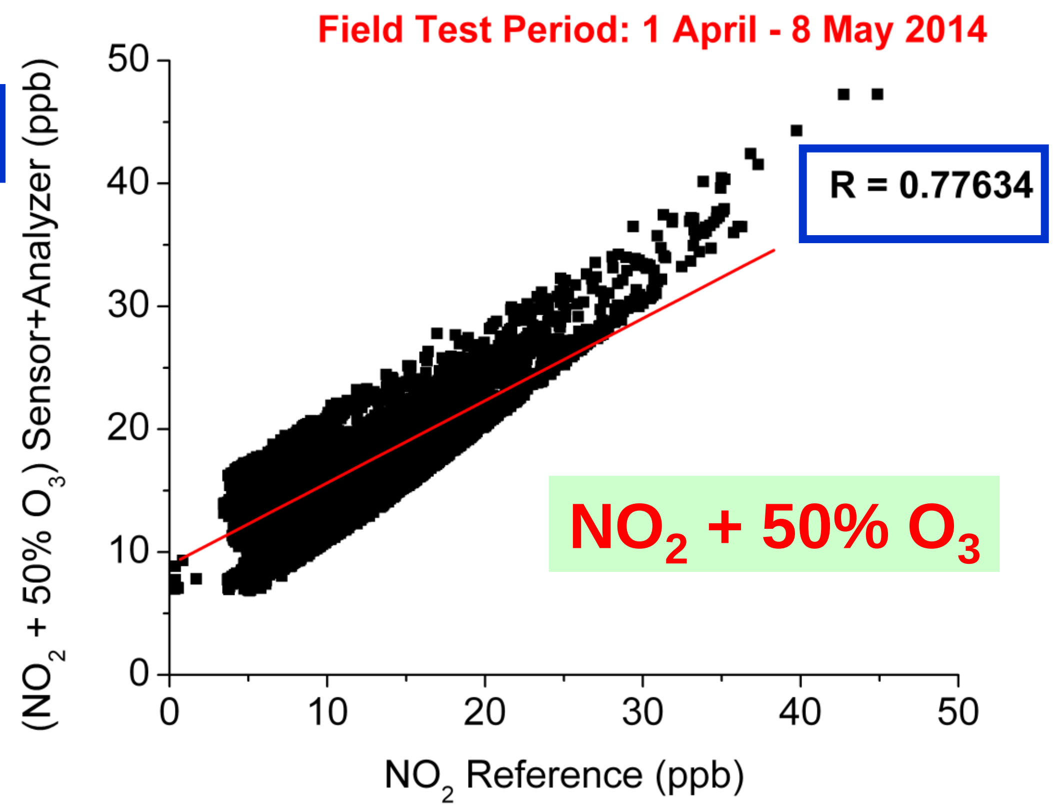
EUROPEAN COOPERA

Cross-sensitivity of O_3 to NO_2 Sensor
Validation in Collaboration with JRC-IES, Ispra (6/7)

NO_2 EC Sensor NO2B4, by Alphasense Ltd, UK

NO_2





Measurement Timing: 1 Apr - 8 May 2014 - 38 DAYS

NASUS 4: CO Validation in Collaboration with JRC-IES, Ispra (7/7)

$E(t) = |C_N(t) - C_A(t)|$

Mean E(t) = **0.17 ppm**

Max E(t) = **0.69 ppm**

Good Accuracy !!

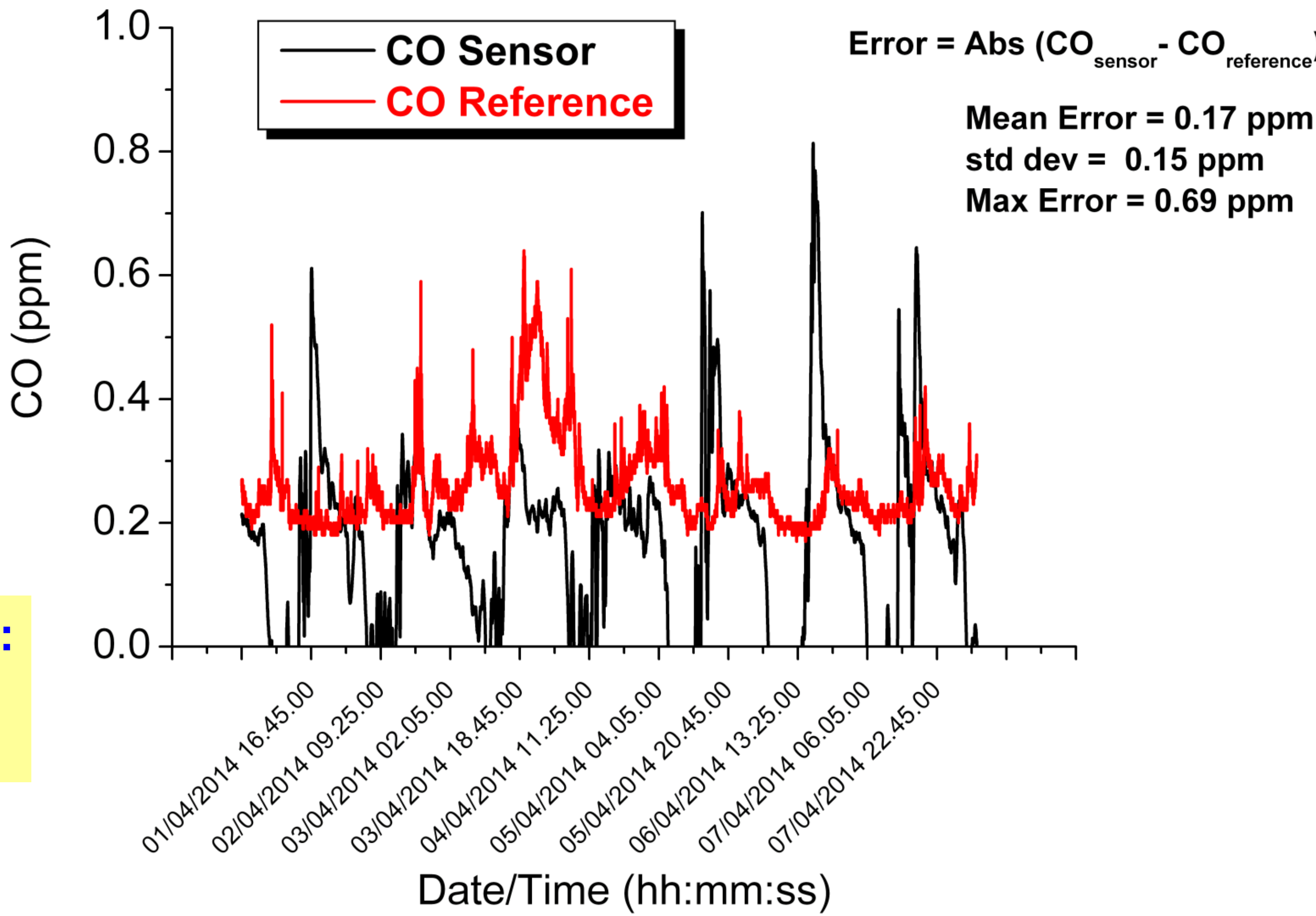
CO Threshold: 10 mg/m^3 (8 ppm)

EC Sensor CO-CX_A3 by Alphasense Ltd, UK

Measurement Timing:
1 Apr - 8 May 2014
SPRING: 38 DAYS

EUROPEAN COOPER/

$E(t)$ = Error
$C_N(t)$: CO sensor concentration
$C_A(t)$: CO reference analyzer concentration

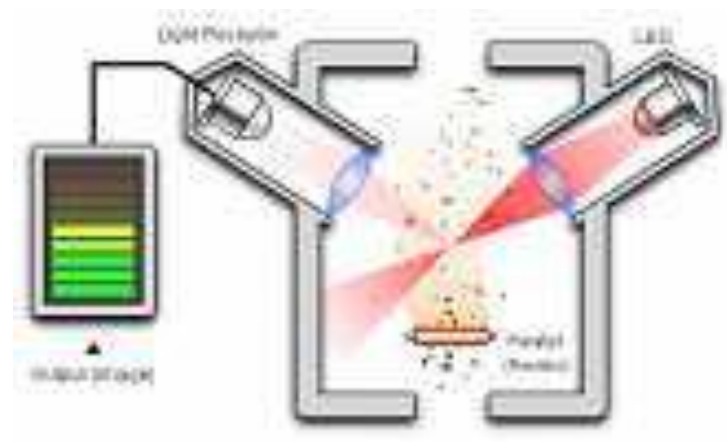


NASUS 4: PM Validation in Collaboration with JRC-IES, Ispra (1/4)

PPD20V Particle Sensor
by Shinyei Ltd, Japan

Detectable Particle Size: 1 - 5 μm

$$C(t) = A_0 + S \times V(t)$$



C(t) = PM Concentration [μg/m³]

A_0 = Bias Constant (3.2795 μg/m³)

S = Sensor Sensitivity (46.85 (μg/m³)/V)

V(t) = Sensor Output Voltage [V]

NASUS 4: PM Validation in Collaboration with JRC-IES, Ispra (2/4)

$E(t) = |C_N(t) - C_A(t)|$

Mean E(t) = 8.98 μg/m³

Max E(t) = 41.76 μg/m³

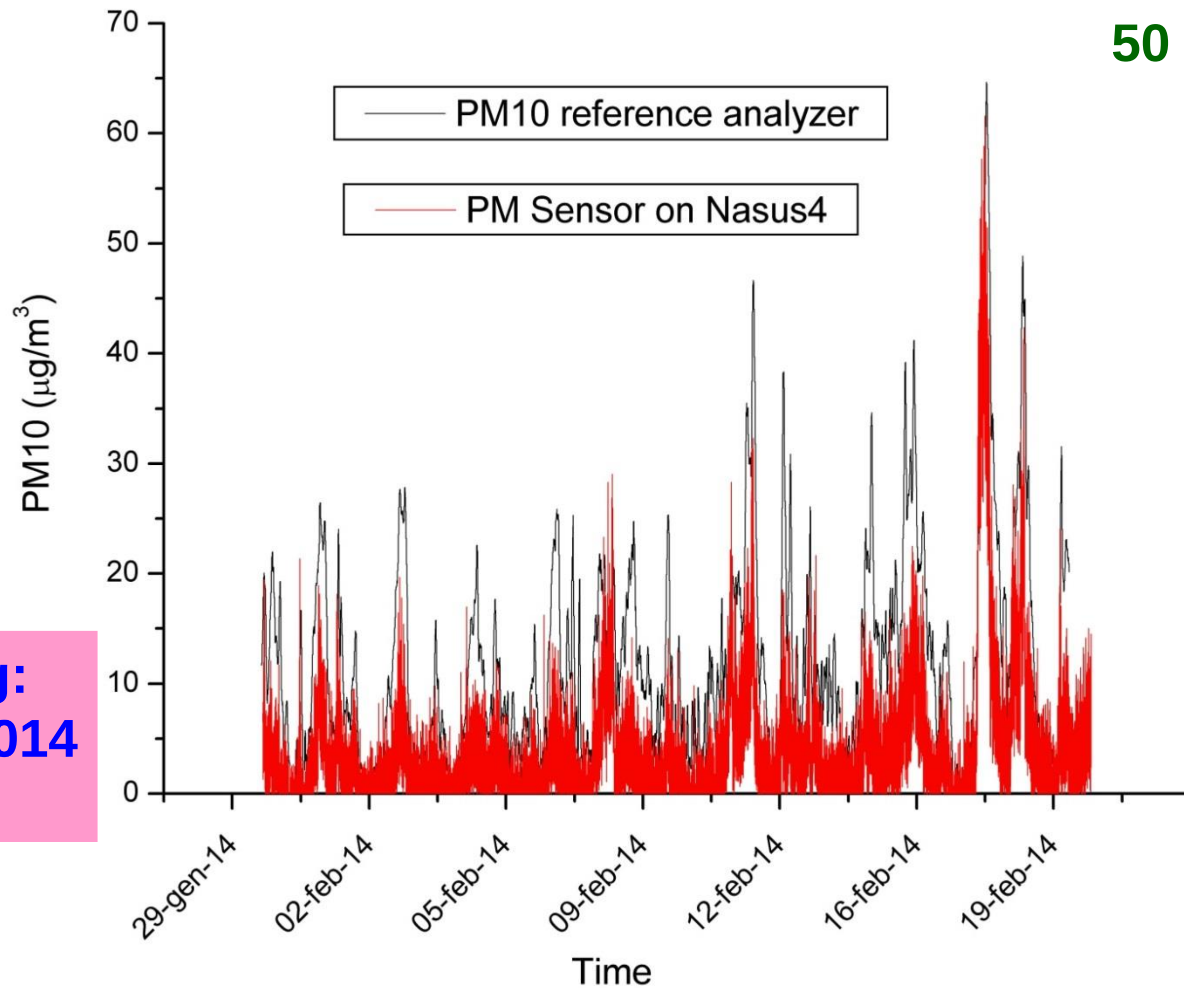
E(t) = Error

$C_N(t)$: PM sensor concentration

$C_A(t)$: PM10 reference analyzer concentration

Very Good Accuracy !

PM10 Threshold: 50 μg/m³



Optical Particle Sensor PPD20V by Shinyei Ltd, Japan

Measurement Timing:
29 Jan 2014 - 19 Feb 2014
WINTER: 21 DAYS

cost EUROPEAN CO

NASUS 4: PM Validation in Collaboration with JRC-IES, Ispra (3/4)

PM_{10} Threshold: 50 μg/m³

$E(t) = |C_N(t)-C_A(t)|$

Mean E(t) = 4.79 μg/m³

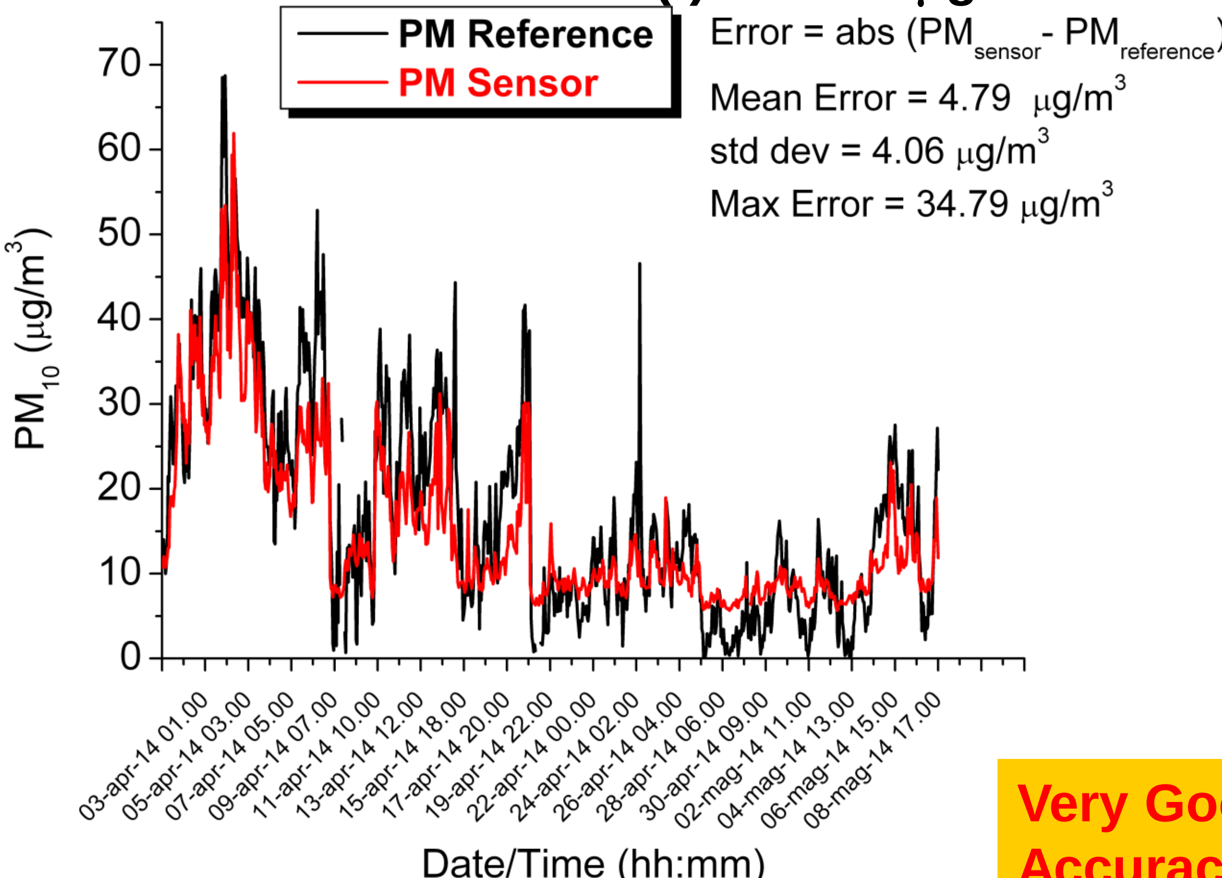
Max E(t) = 34.79 μg/m³

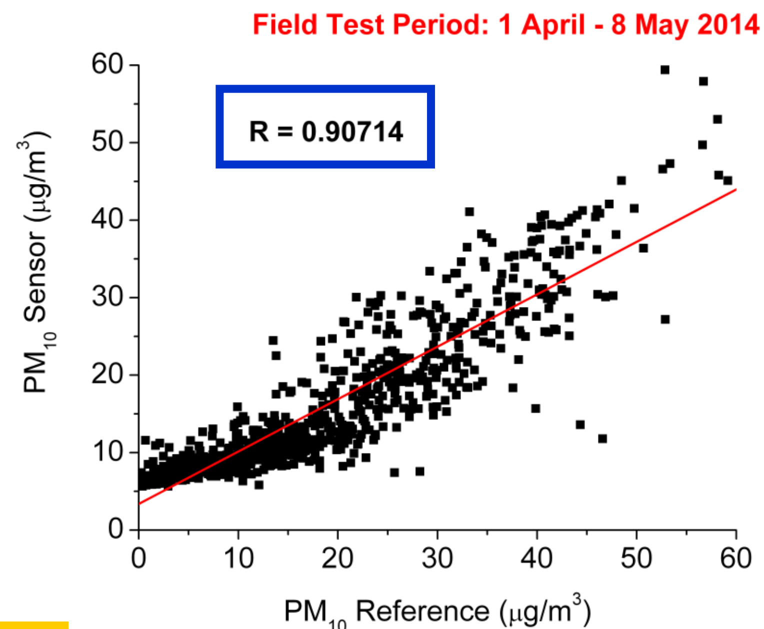
E(t) = Error

$C_N(t)$: PM sensor concentration

$C_A(t)$: PM10 analyzer concentration

Optical Particle Sensor PPD20V by Shinyei Ltd, Japan





Very Good Accuracy !

Measurement Timing: 1 Apr 2014 - 8 May 2014

SPRING: 38 DAYS

NASUS 4: PM Validation in Collaboration with JRC-IES, Ispra (4/4)

PM_{10} Threshold: 50 μg/m³

$$E(t) = |C_N(t) - C_A(t)|$$

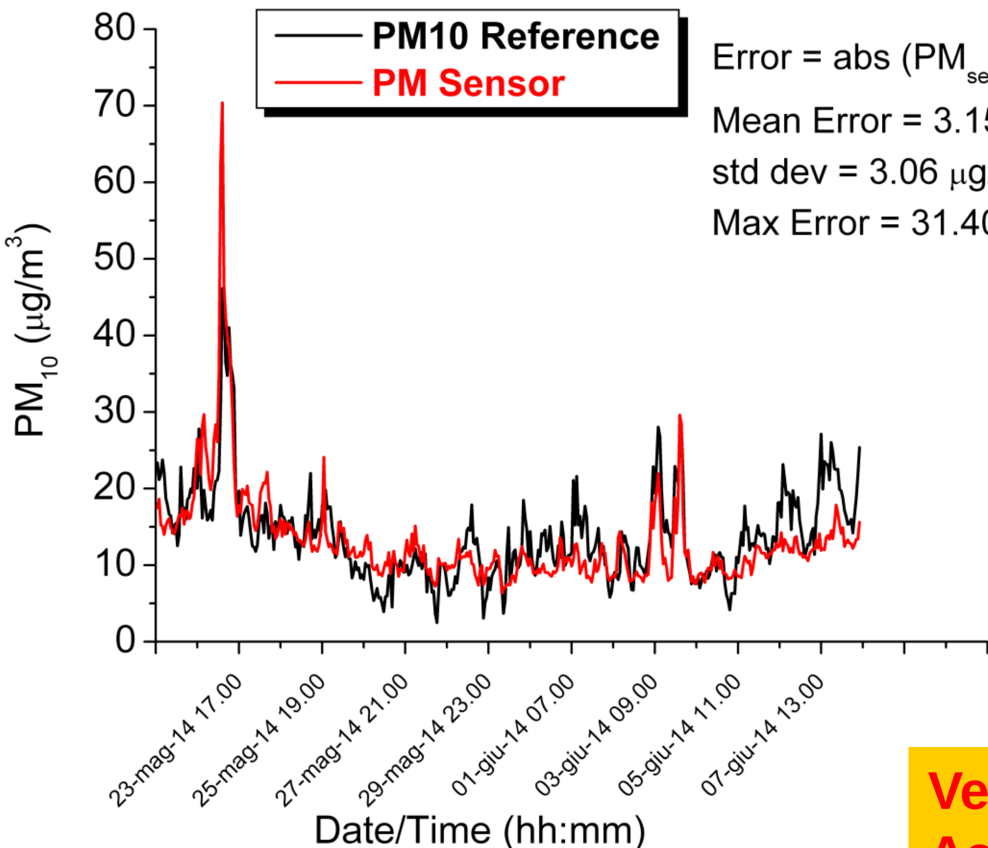
Mean E(t) = 3.15 μg/m³

Max E(t) = 31.40 μg/m³

E(t) = Error

$C_N(t)$: PM sensor concentration

$C_A(t)$: PM10 analyzer concentration



Error = abs (PM_{sensor} - $PM_{reference}$)

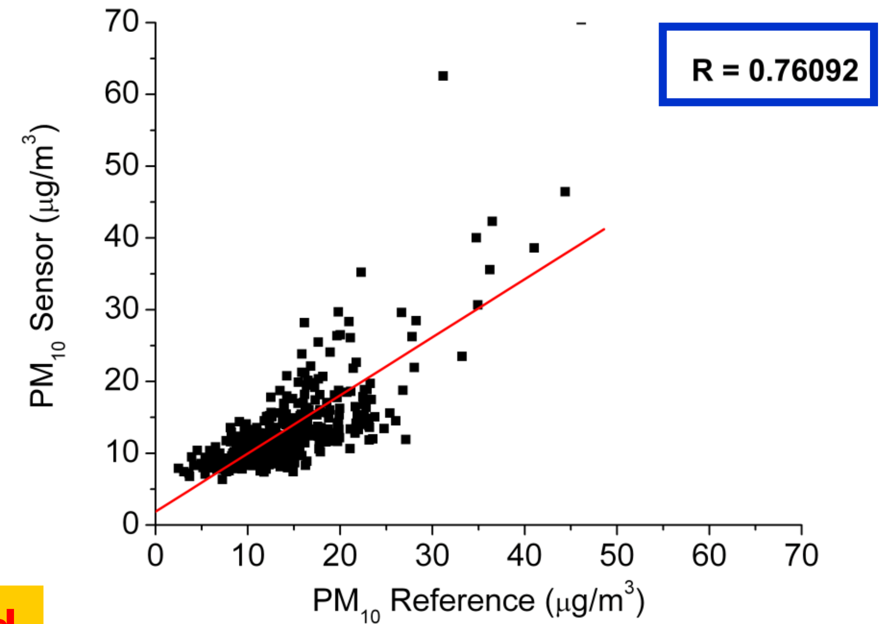
Mean Error = 3.15 μg/m³

std dev = 3.06 μg/m³

Max Error = 31.40 μg/m³

Optical Particle Sensor PPD20V by Shinyei Ltd, Japan

Field Test Period: 21 May - 8 June 2014

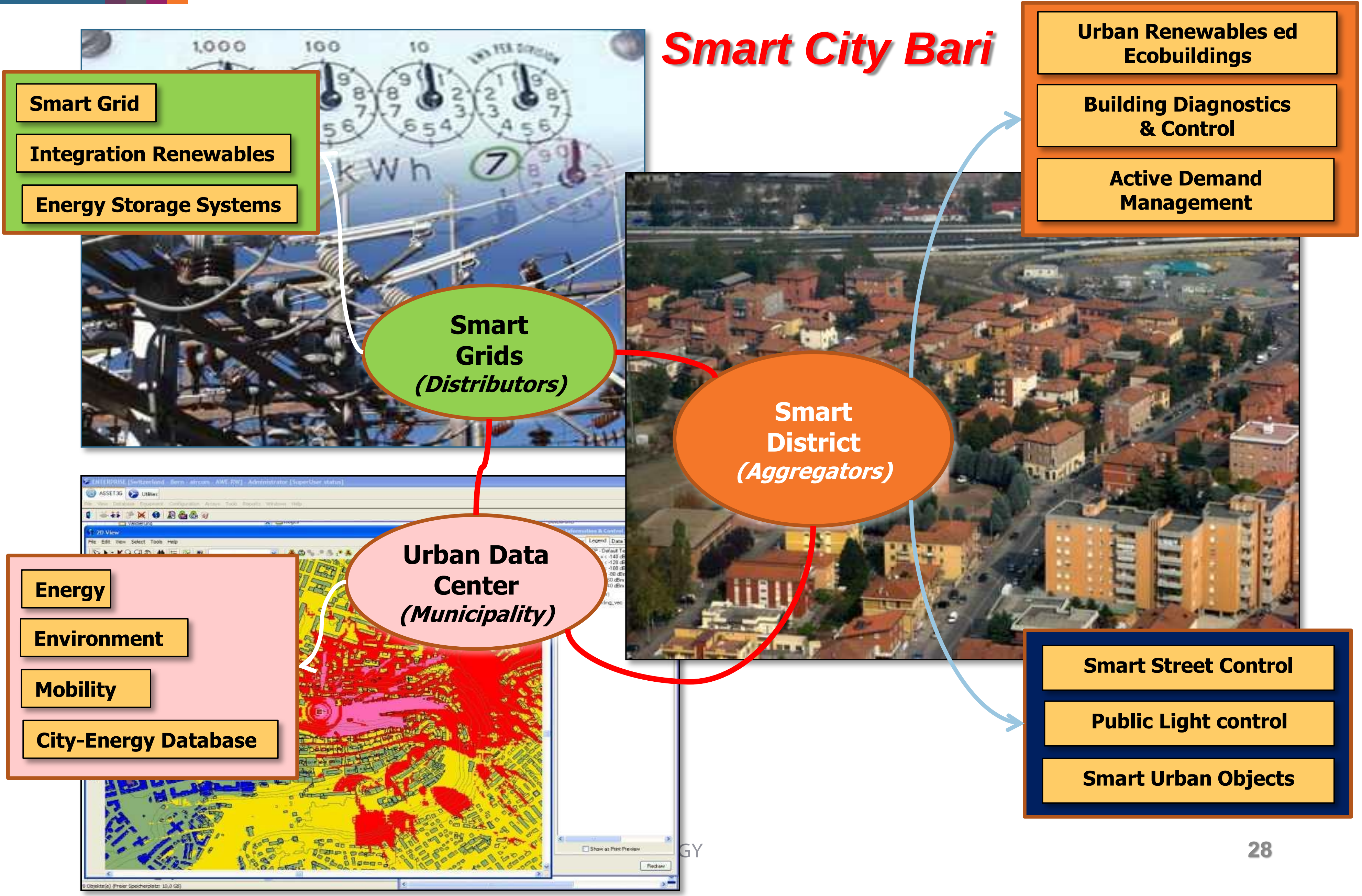


Very Good Accuracy !

Measurement Timing: 21 May 2014 - 8 Jun 2014

SPRING: 18 DAYS

IT NATIONAL PROJECT *RES-NOVAE*: APPLICATIONS SCENARIO



IT NATIONAL PROJECT *RES-NOVAE*: INDOOR APPLICATIONS

Smart City Bari

ENEA AQ Sensor Node

11 cm

19 cm

Real-Word Scenario for Sensor Technology Demonstration:

Schools, Public Offices, Buildings

IT NATIONAL PROJECT *RES-NOVAE*: OUTDOOR APPLICATIONS

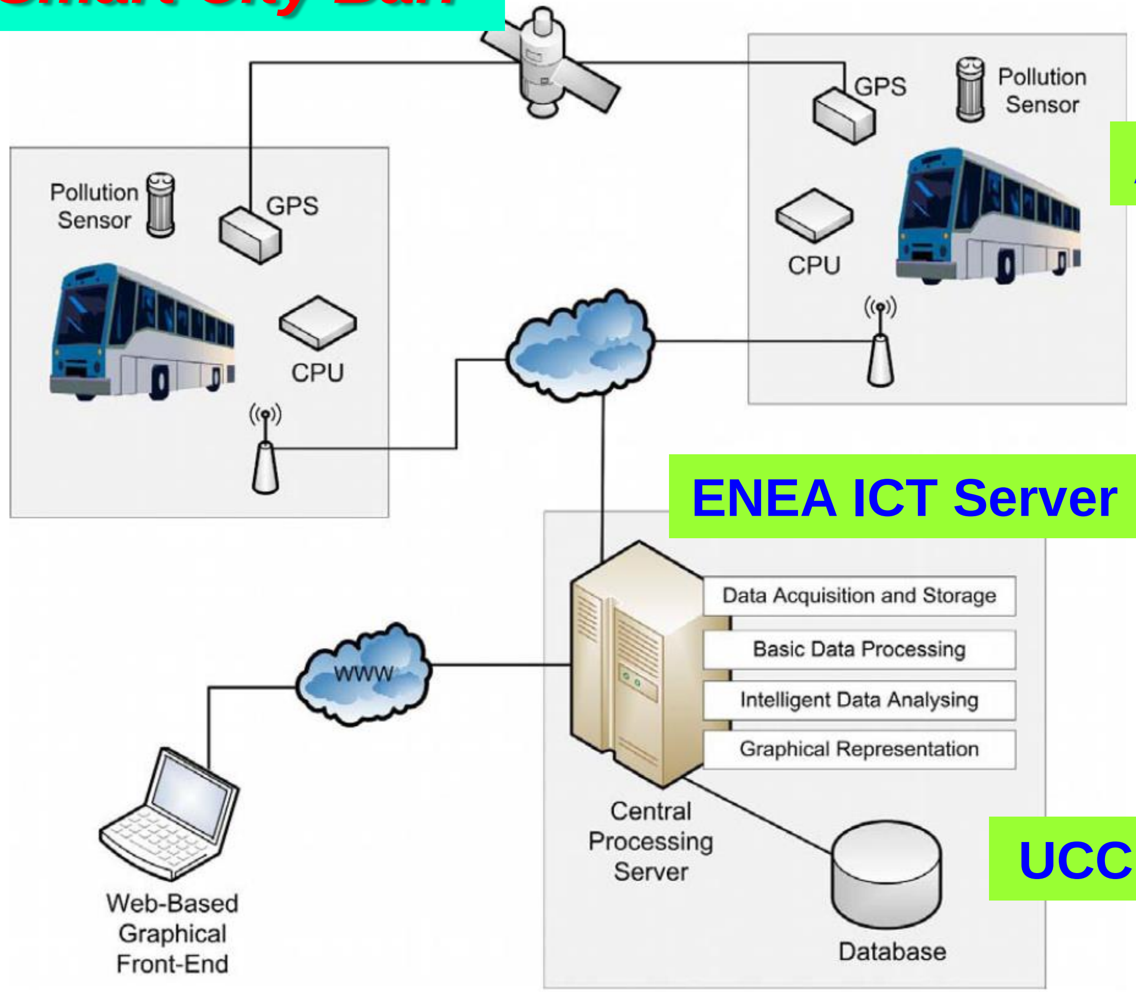
Real-Word Scenario for Sensor Technology Demonstration:
AQ ENEA Sensors Mobile Node mounted on public bus (AMTAB) in Bari (Italy).
Urban Control Center (UCC) collects ENV/ENE/OTH data from City.

Smart City Bari

AMTAB Public Buses

ENEA Mobile Sensor Node for Air Quality Monitoring: CO, NO_x, O_3, SO_2, CO_2, PM10, T, RH

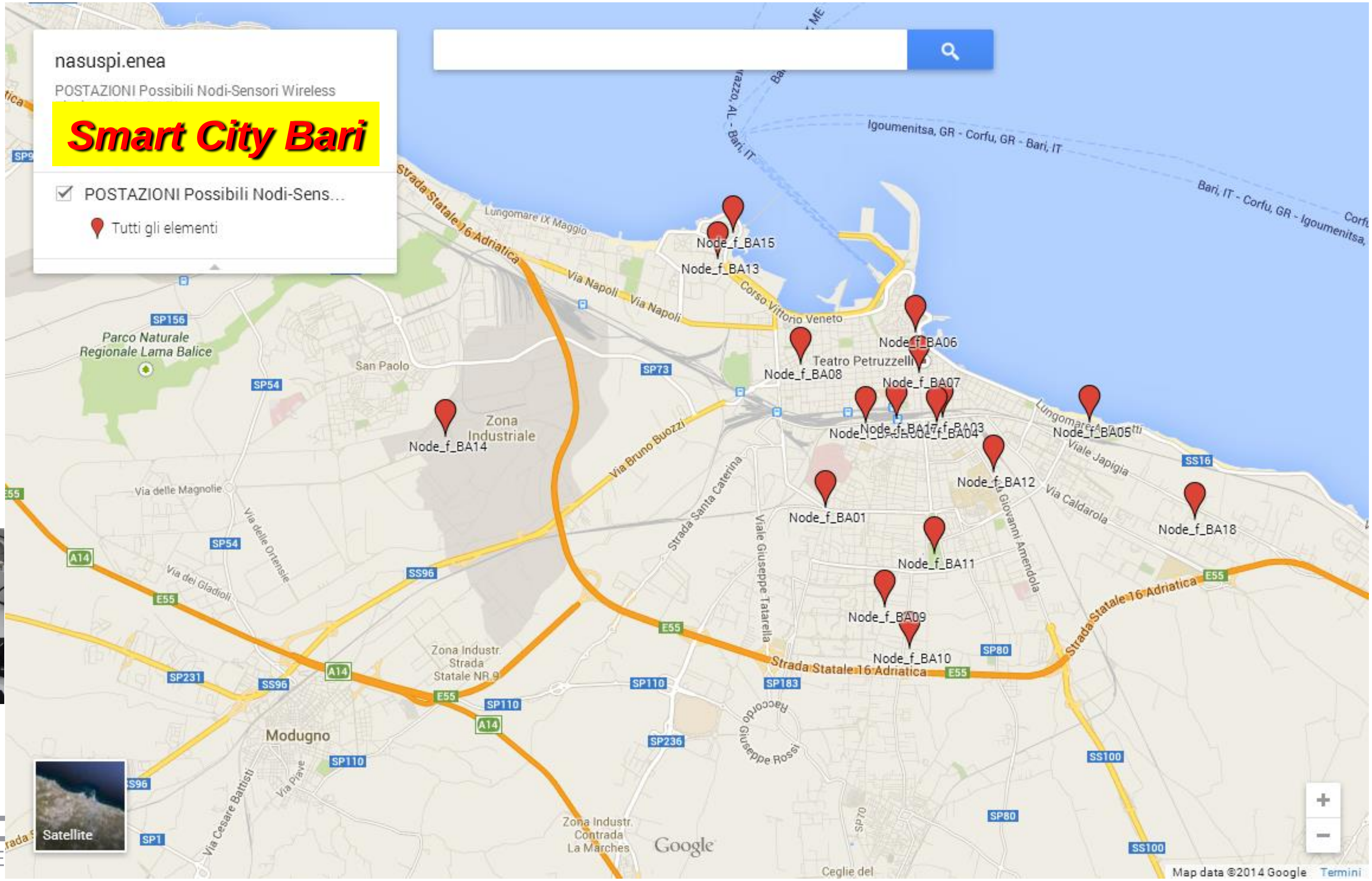
ENEA ICT Server



UCC by IBM Italia

IT NATIONAL PROJECT *RES-NOVAE*: OUTDOOR APPLICATIONS

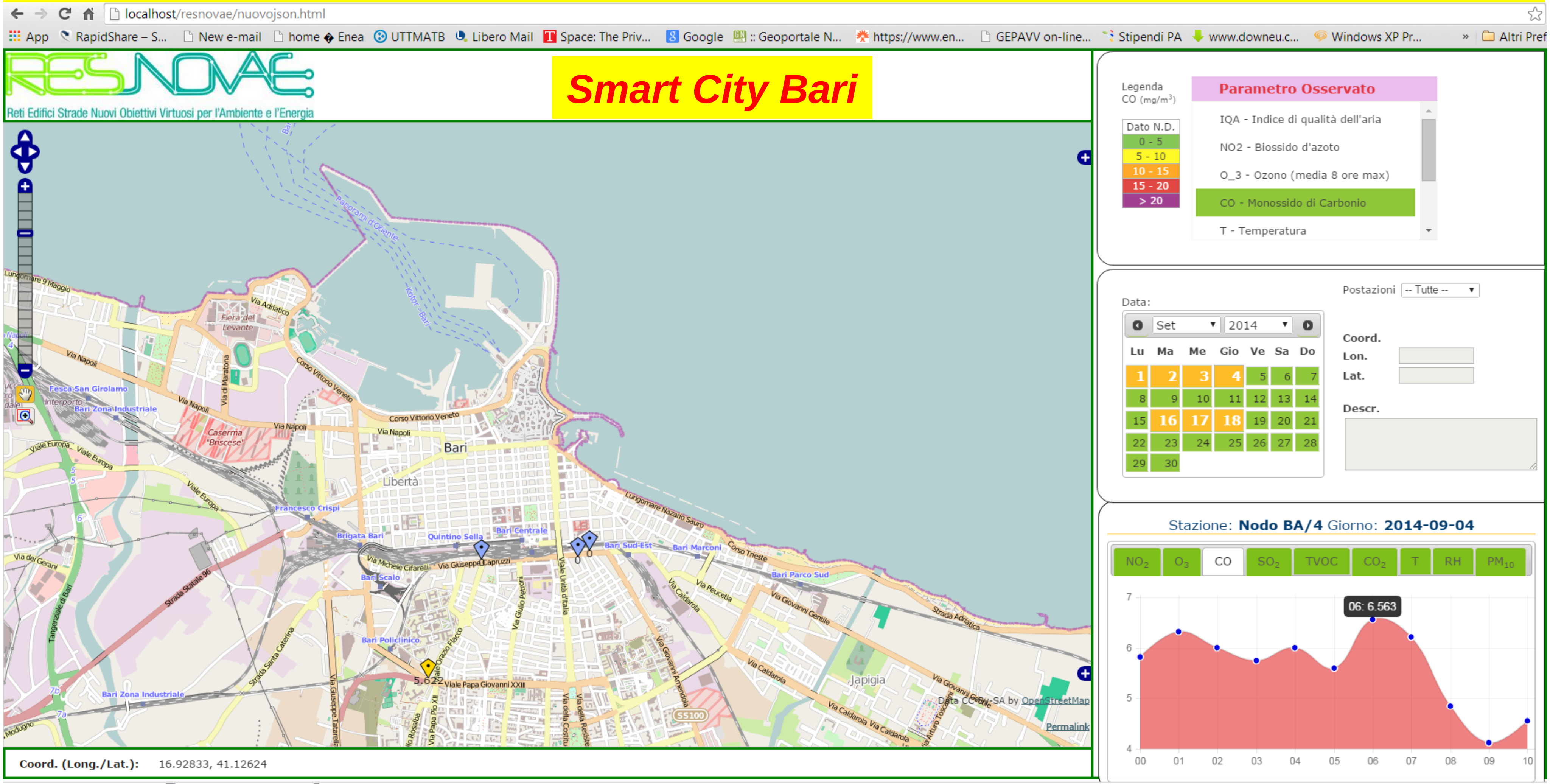
AQ ENEA Sensors Fixed Nodes Network distributed in Bari (Italy)
Urban Control Center (UCC) collects data from City.



Sensor-Node

IT NATIONAL PROJECT *RES-NOVAE*: OUTDOOR APPLICATIONS

AQ ENEA Sensors Fixed Nodes Network distributed in Bari (Italy)
Urban Control Center (UCC), hosted by ENEA server, senses *real-time* City



Air Quality Index (AQI): *Simple Provision of Real-Time Data*

AQI for each Pollutant:

$$AQI = \frac{CurrentPollutionLevel}{PollutionStandardLevel} * 100$$

EU Air Quality Directive 2008/50/EC

Pollutant	Limit Standard Level
NO_x	100 ppb (200 μg/m^3) 200 ppb (400 μg/m^3)
CO	8 ppm (10 mg/m^3)
SO_2	130 ppb (350 μg/m^3) 190 ppb (500 μg/m^3)
O_3	120 μg/m^3 (90 ppb)
PM_{10}	50 μg/m^3
$PM_{2.5}$	25 μg/m^3
BTEX	5 μg/m^3
PAH (BaP)	1 ng/m^3

Air Quality Index (AQI): *Categories & Risk for Health*

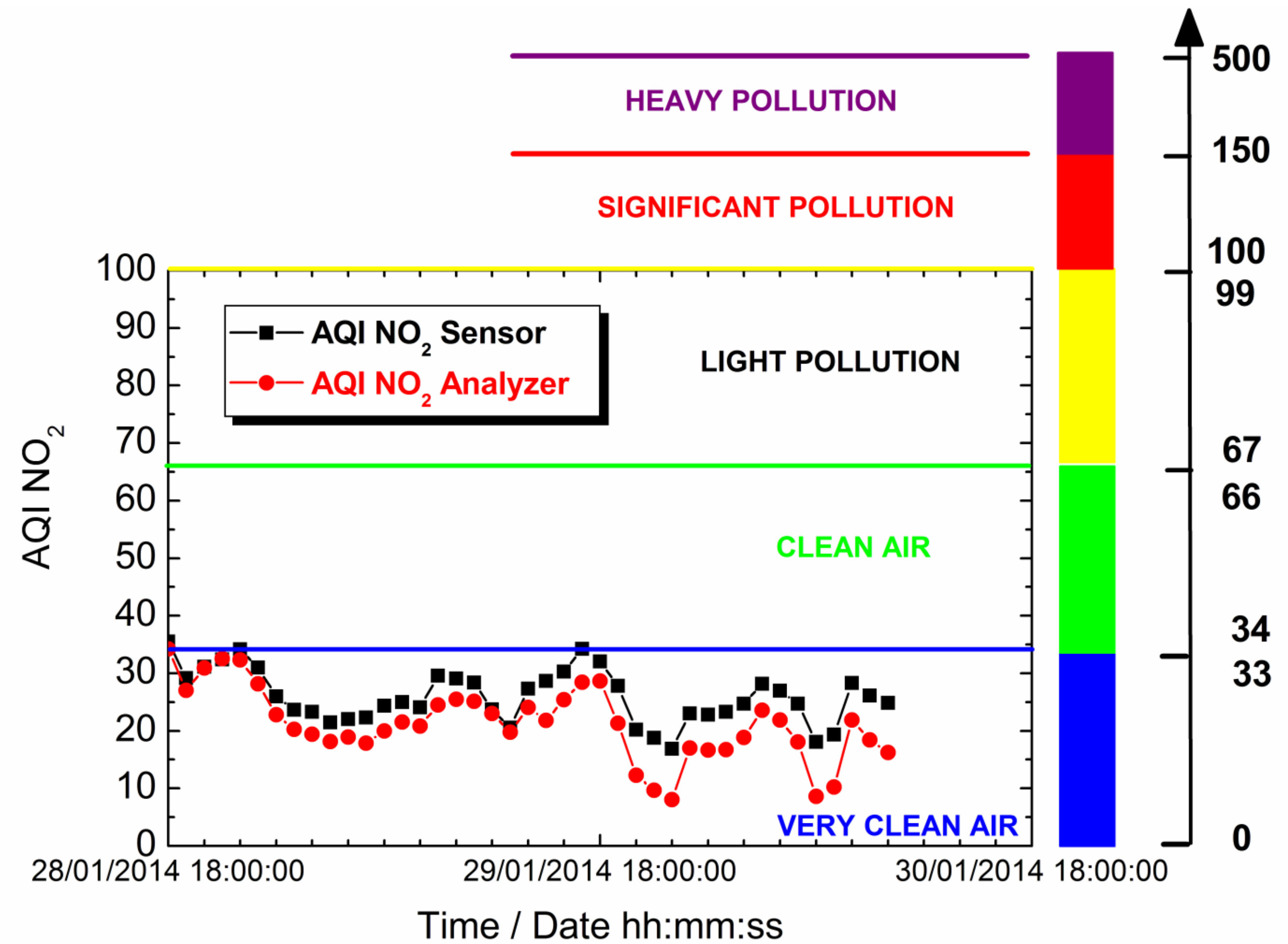
US EPA AQIs Classification

AQI Values	Levels of Health Concern	Colours
When AQI is in this range	*…. air quality conditions are:*	*… as symbolized by this colour:*
0 to 33	**VERY CLEAN AIR - *Excellent***	**BLUE**
34 to 66	**CLEAN AIR - *Good***	**GREEN**
67 to 99	**LIGHT POLLUTION - *Moderate***	**YELLOW**
100 to 150	**SIGNIFICANT POLLUTION - *Bad***	**RED**
> 150	**HEAVY POLLUTION - *Worse***	**PURPLE**

Air Quality Index (AQI): *Sensors versus Analyzers*

NO_2 detection at an air quality station (*JRC-IES, Ispra*) and related AQI by sensor and analyzer for general public

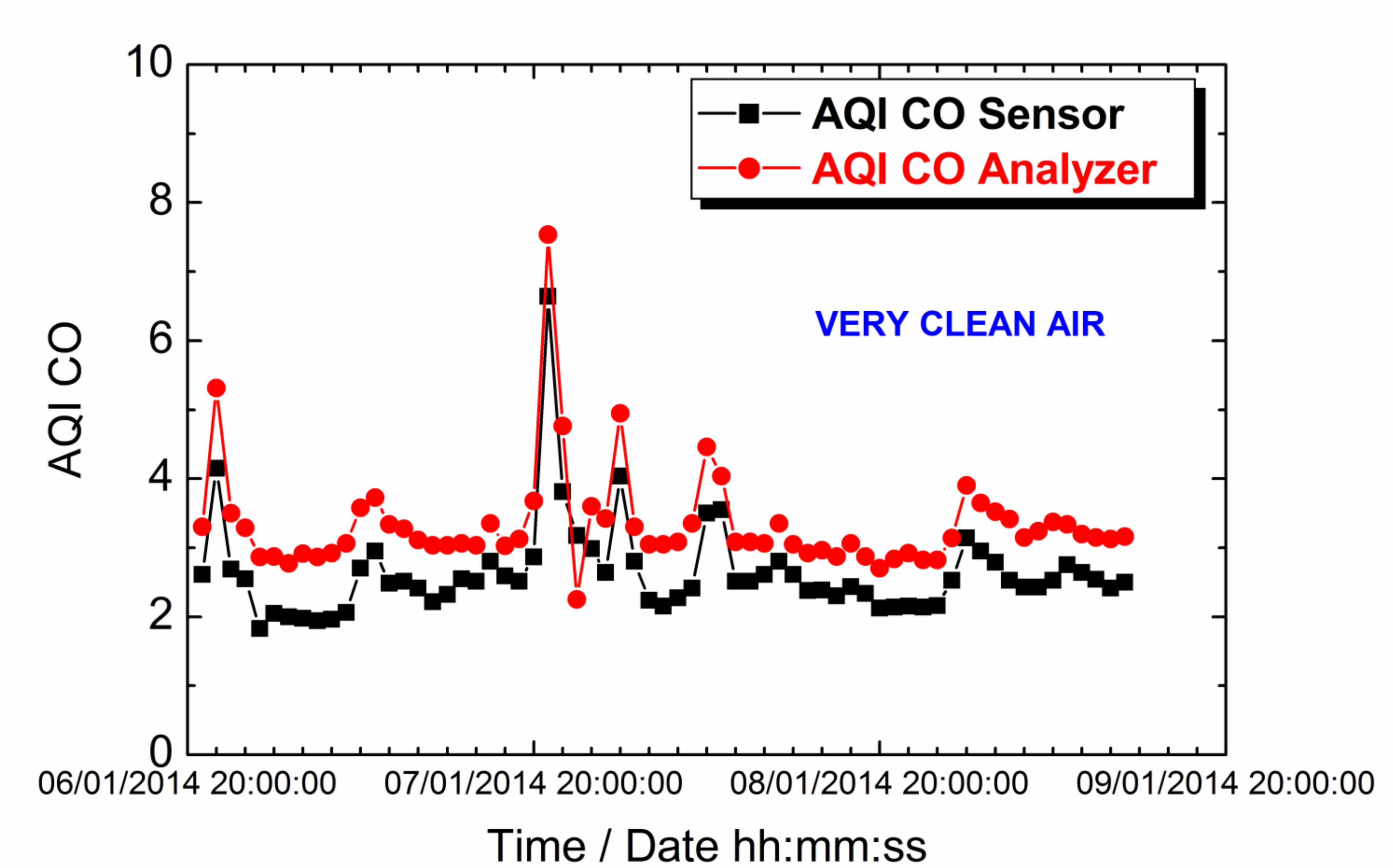
Very Good Correlation



Air Quality Index (AQI): *Sensors versus Analyzers*

CO detection at an air quality station (*ARPA-Puglia, Brindisi*) and related AQI by sensor and analyzer for general public

Very Good Correlation



CONCLUSIONS and Future Activities

- **Low-cost Micro-sensors should not substitute but supplement routine monitoring devices, at the moment**.
- Use of **portable systems** based on ***low-cost solid-state gas sensors*** to supplement high-cost standard chemical analyzers should be possible for some pollutant gases.
- Further **long-term investigations** in order to extend the range of air-pollutants detectable by ***low-cost solid-state gas sensors*** at higher accuracy.
- Further **sensor-system miniaturization and integration** with commercial electronics (e.g., smartphones, tablets, etc.) for **community participatory environmental sensing**.
- **Air Quality Control Fixed/Mobile Sensors Network for Smart Cities Applications**
- **Air Quality Index (AQI) to inform general public**.

ACKNOWLEDGEMENTS: Partners

European Commission
JOINT RESEARCH CENTRE
Institute for Environment and Sustainability (IES)

JRC-Ispra - INSTITUTE for ENVIRONMENT AND SUSTAINABILITY (IES):

M. GERBOLES, L. SPINELLE, JRC-IES, Ispra (Varese), Italy

TECHNICAL COLLABORATION AGREEMENT ENEA & JRC-IES
ON AQ SENSORS PERFORMANCE ASSESSMENT (EMRP Project MACPOLL)

ARPA-PUGLIA:

G. ASSENNATO, A. NOCIONI, ARPA-Puglia, Bari-Brindisi, Italy

TECHNICAL COLLABORATION AGREEMENT ENEA & ARPA-PUGLIA
ON AQ SENSORS VALIDATION

ARPA PUGLIA

ENEA:

G. CASSANO, V. PFISTER, G. CAMPOREALE, M. PRATO, S. DIPINTO, F. DEPASCALIS, ENEA - Brindisi, Italy

Mariagabriella VILLANI, ENEA - Ispra, Italy

ENEA
AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

ACKNOWLEDGEMENTS: Projects

- **CONSORTIUM COST Action TD1105 EuNetAir**

European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability - EuNetAir

EuNetAir
European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

- **PON1 BAITAH:**

Methodology and Instruments of Building Automation and Information Technology for pervasive models of treatment and Aids for domestic Healthcare

BAITAH

- **PON4a RES-NOVAE:**

Networks, Buildings, Streets - New Challenging Targets for Environment and Energy

RES NOVAE
Reti Edifici Strade Nuovi Obiettivi Virtuosi per l'Ambiente e l'Energia

THANK YOU VERY MUCH FOR YOUR KIND ATTENTION !

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Any Questions ?

....