European Commission

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

*COST Action TD1105*

# *MACPoll Project: Metrology for Low-Cost Sensor Technologies in Air Quality Control*


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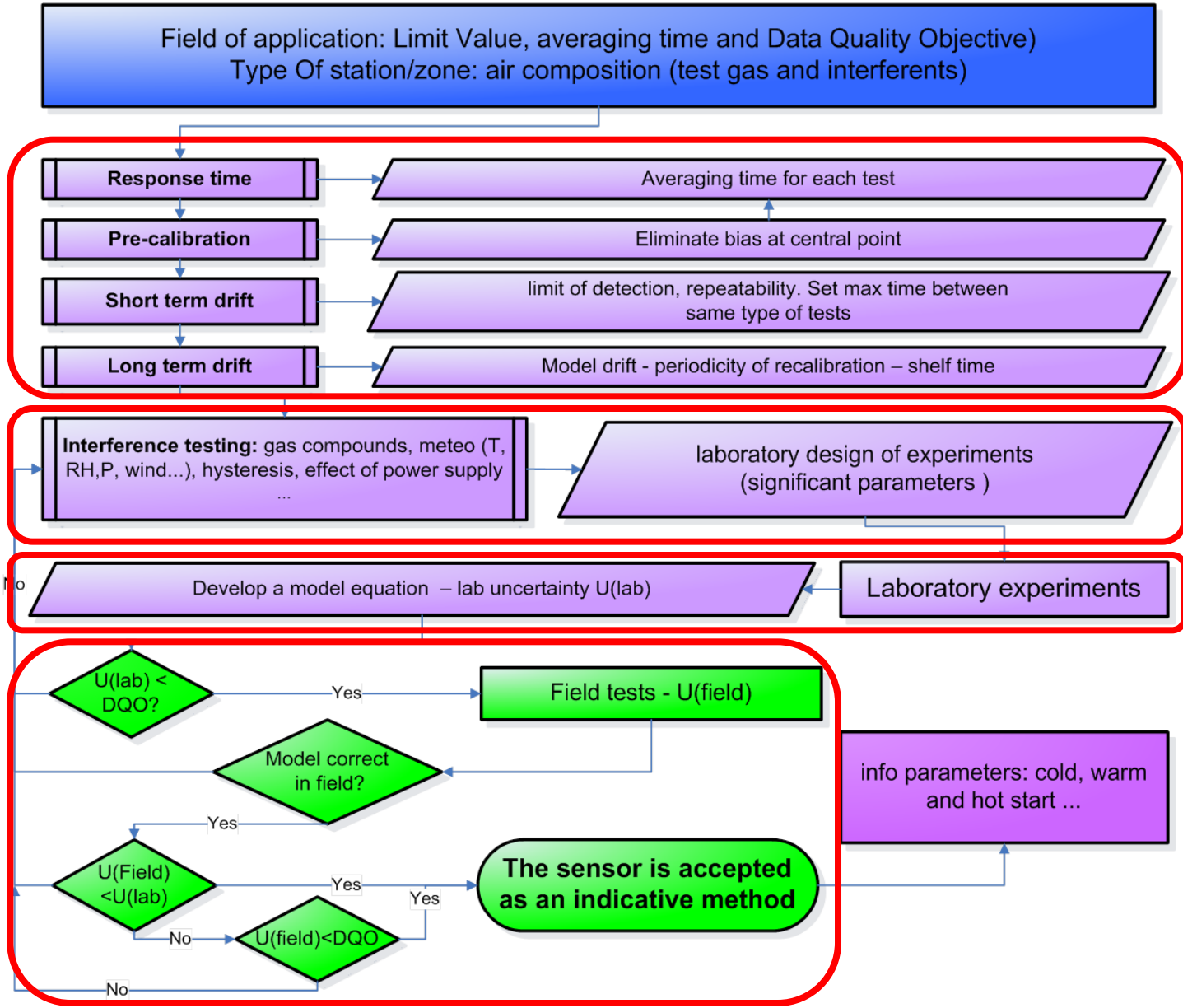
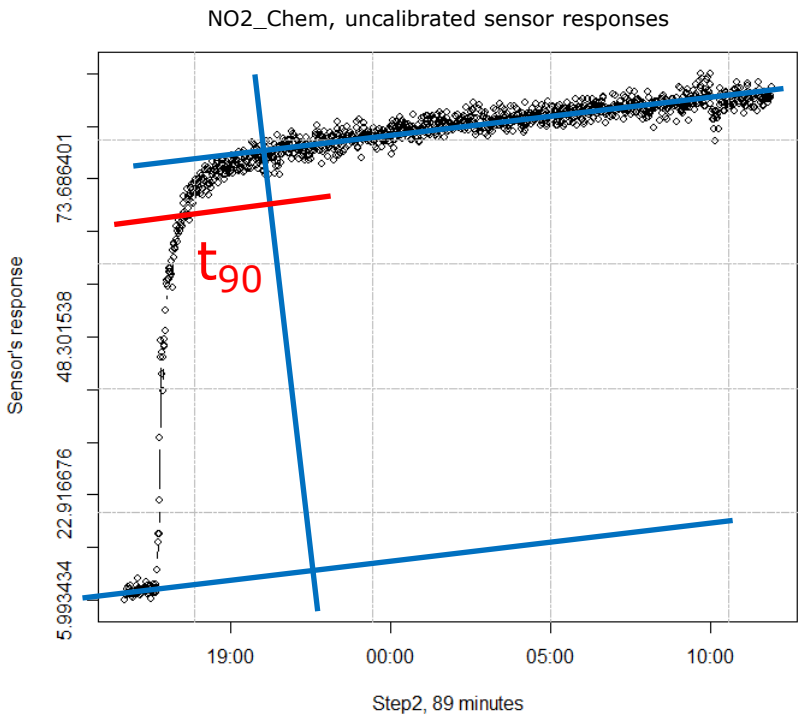
# Evaluation Validation Protocol



# Metrological parameters

## Response Time

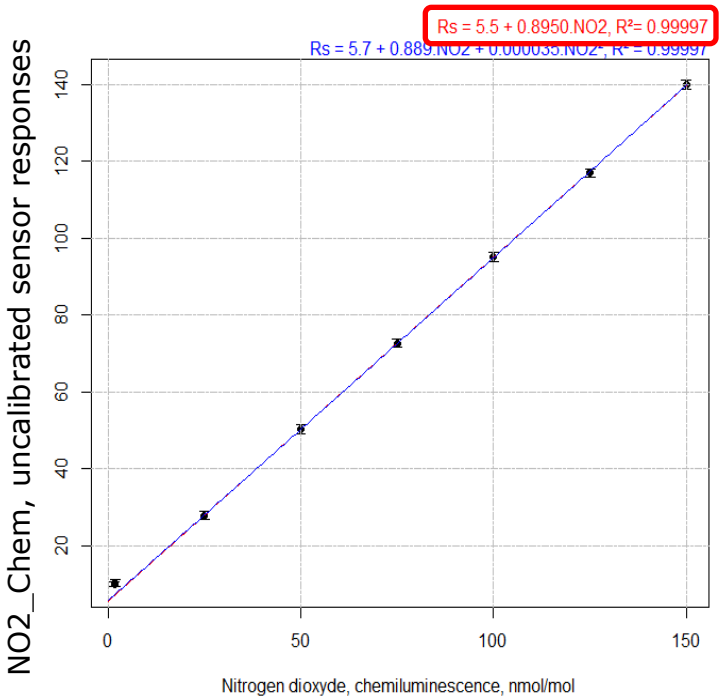
$t_{90}$: time needed by the sensor to reach 90 % of the final stable value




| $O_3$ sensors | | Average Time | Response time per type |
|---|---|---|---|
| Chamber – UV analyser (substracted) | | 4 ‘ | |
| MOx | Res_1 | 50 ' | Ave: 40’<br>Rise: 33’<br>Fall: 47’ |
| | Res_2 | 5 ' | |
| | Res_3 | 56' | |
| | Res_4 | 10 ' | |
| | Res_5 | 23 ‘ | |
| | Res_6 | > 146 ‘ | |
| | Res_7 | 23' | |
| | Res_8 | 10 ' | |
| Elec | Chem_1 | 1 ' | Ave: 1,3’<br>Rise: 1’<br>Fall: 1,7’ |
| | Chem_2 | 1.3 ' | |
| | Chem_3 | 1.5 ' | |
| | Chem_4 | 1.7 ' | |

# Metrological parameters

## Pre-calibration




| | $NO_2$ | Fitting equation |
|---|---|---|
| Mox | Res_1 | Linear |
| | | Linear |
| | Res_2 | Parabolic |
| Elect | Chem_1 | Linear |
| | | Linear |
| | Chem_2 | Linear |
| | Chem_3 | Linear |
| | | Linear |
| | Chem_4 | Not Linear |
| | Chem_5 | Linear |

| | $O_3$ | Fitting equation |
|---|---|---|
| Mox | Res_1 | Not linear |
| | Res_2 | Not linear |
| | Res_3 | Not Linear and limited in range |
| | Res_4 | Not linear |
| | Res_5 | - |
| | Res_6 | - |
| | Res_7 | - |
| | Res_8 | Slightly parabolic |
| Elec | Chem_1 | Slightly parabolic |
| | Chem_2 | Out of work |
| | Chem_3 | Linear |
| | Chem_4 | Strongly parabolic |
| | Chem_5 | Strongly parabolic |

# Metrological parameters

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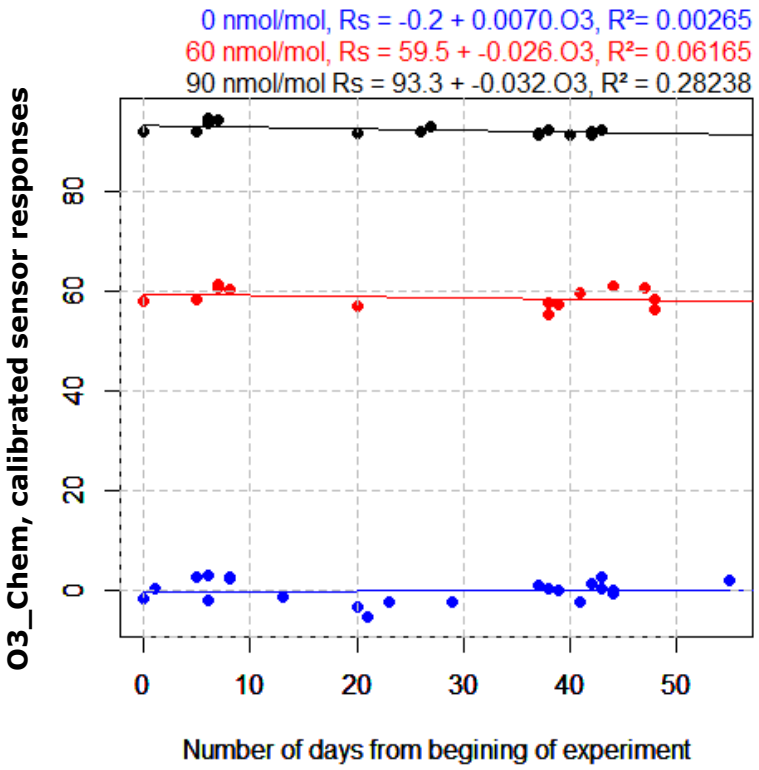
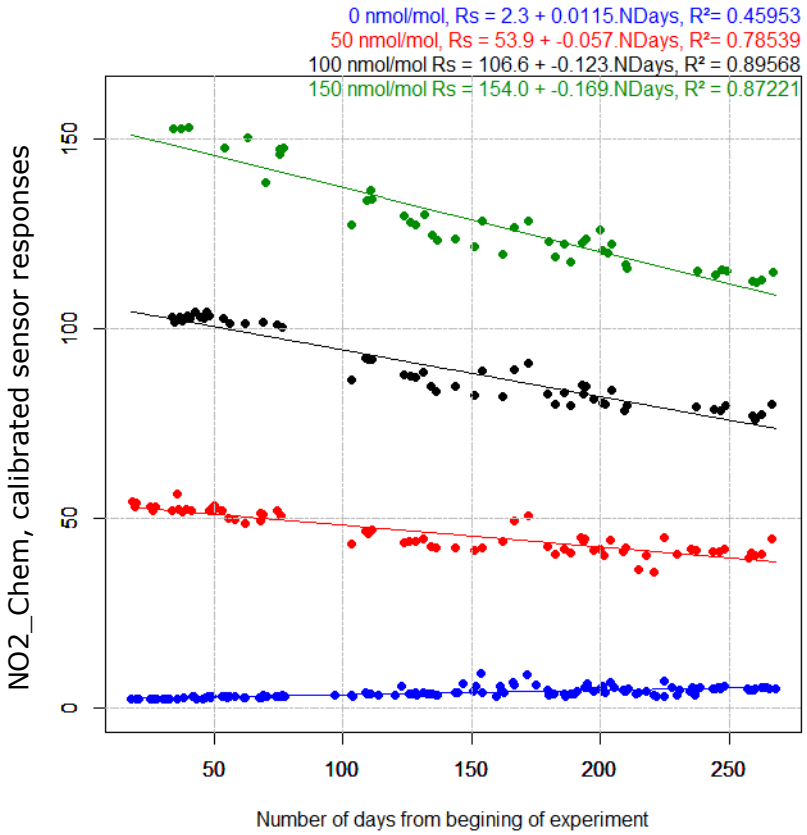
## Long term Drift




$D_{ls}$ = 1.7 ± 1.9 nmol/mol

$D_{ls}$ = f([NO2].[Ndays])

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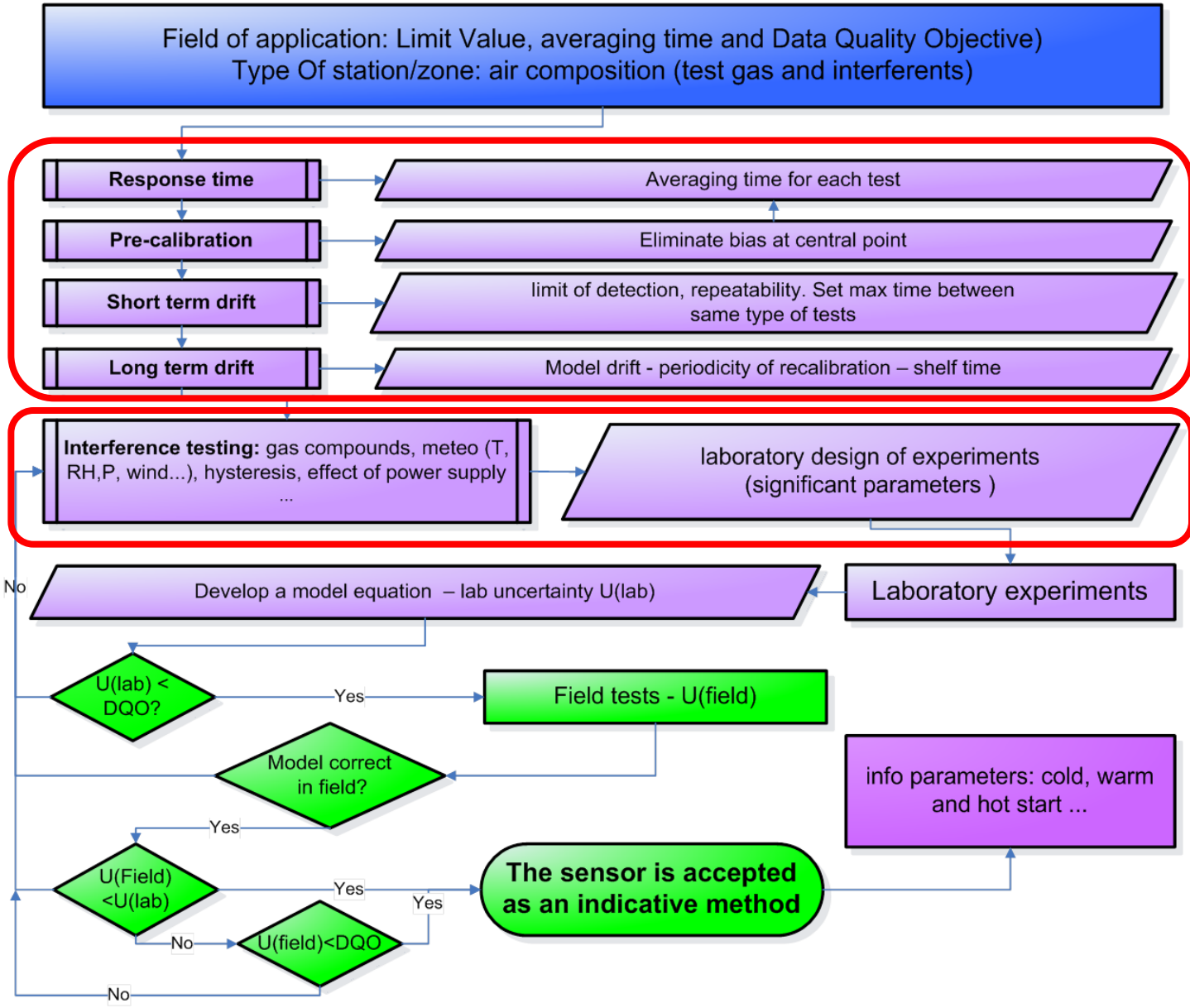
# Evaluation Validation Protocol



# Interfering effect

## Gaseous compounds

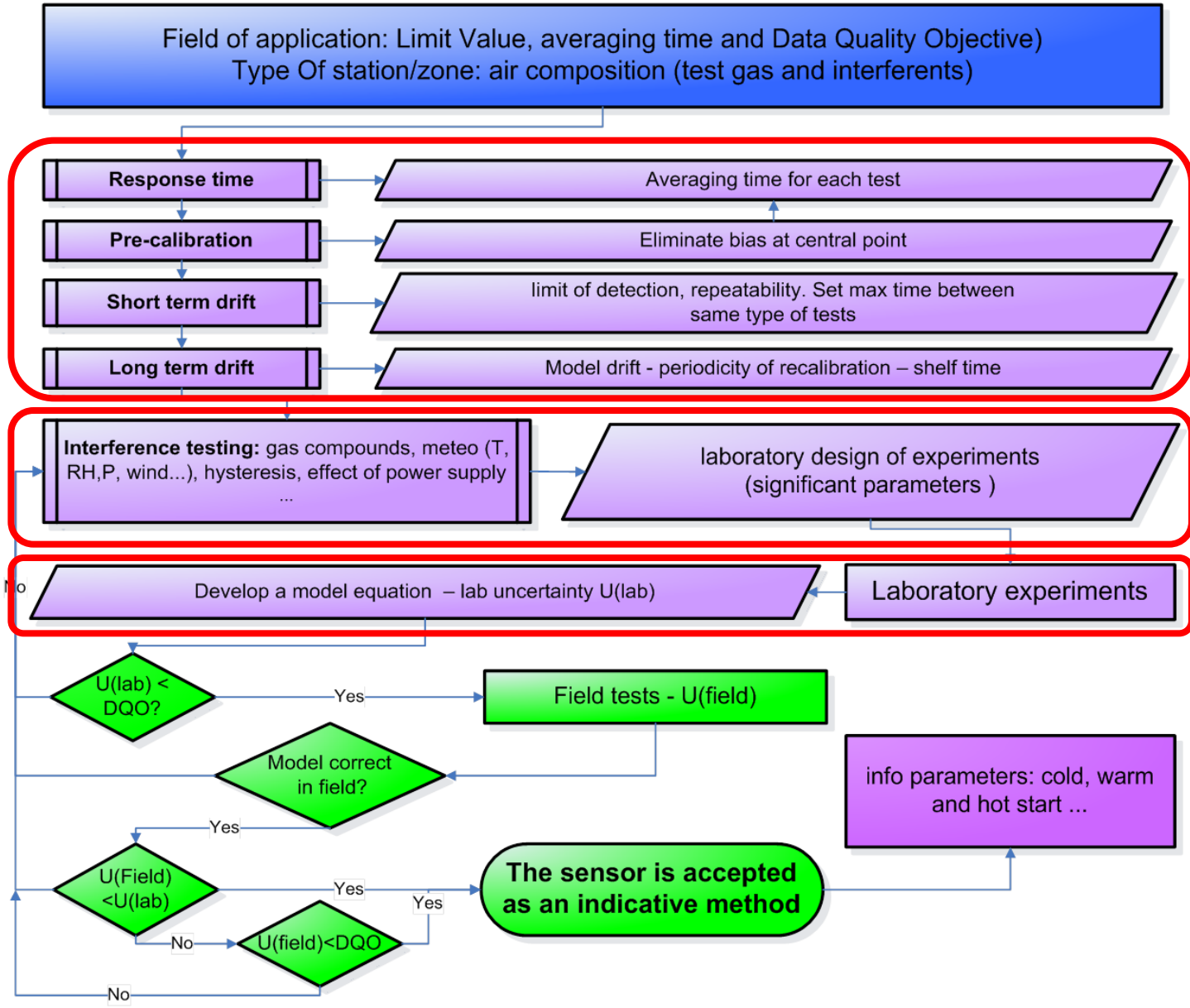
| $NO_2$ | $O_3$ | NO | CO | $CO_2$ | $NH_3$ |
|---|---|---|---|---|---|
| Chem_1 | 80.3 % | -6.4 % | -34.8 % | -31.9 % | -26.8 % |
| | 81.2 % | -5.9 % | -36.8 % | 5.3 % | -24.1 % |
| Chem_2 | 71.2 % | -10.0 % | -10.7 % | -4.6 % | -18.9 % |
| Chem_3 | 69.3 % | -10.0 % | -27.6 % | 7.5 % | -17.3 % |
| | 63.9 % | -9.7 % | -22.7 % | 5.2 % | -14.2 % |
| Chem_4 | 79.3 % | - | -34.9 % | 2.5 % | -36.4 % |
| Chem_5 | 38.8 % | -1.8 % | -7.8 % | 8.3 % | -6.3 % |
| Res_1 | - | - | - | - | - |
| | - | - | - | - | - |
| Res_2 | 63.9 % | -25.3 % | -44.2 % | 12.9 % | -88.7 % |

**Main interferent gas: $O_3$**

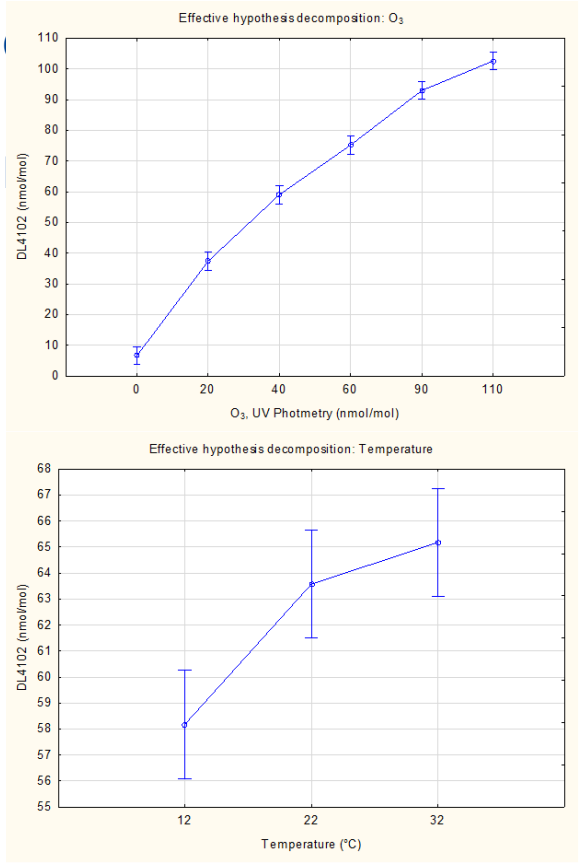
| $O_3$ | $NO_2$ | NO | CO | $CO_2$ | $NH_3$ |
|---|---|---|---|---|---|
| Res_1 | 14.1 % | -5.3 % | 9.8 % | -6.2 % | 6.0 % |
| Res_2 | -3.3 % | - | 3.6 % | -0.1 % | -0.3 % |
| Res_3 | 14.5 % | -10 % | 13.4 % | 5.0 % | 18 % |
| Res_4 | 12.6 % | -1.6 % | -8.9 % | 1.0 % | 3.5 % |
| Res_5 | - | - | - | - | - |
| Res_6 | - | - | - | - | - |
| Res_7 | - | - | - | - | - |
| Res_8 | 1.2 % | -0.8 % | 0.1 % | -0.2 % | -1.9 % |
| Chem_1 | 89.3 % | 1.3 % | -0.9 % | 0.2 % | 1.2 % |
| Chem_2 | - | - | - | - | - |
| Chem_3 | 33.7 % | -7.7 % | -1.2 % | -0.4 % | 0.1 % |
| Chem_4 | 107.7 % | -1.5 % | -2.4 % | 0.4 % | 2.3 % |

**Main interferent gas: $NO_2$**

# Evaluation Validation Protocol



# Design of Experiment




**108 experiments**

**126 experiments**

**Multiple analysis of Variance (MANOVA)**

**Multiple Linear Regression (MLR)**

**Laboratory uncertainty:**
sum of Variance

$$var(\sum_{i=1}^{n} X_i) = \sum_{i=1}^{n} var(X_i)$$

$$Sr_{DL4102} = 17.3_{\pm 4.5} + 0.84_{\pm 0.02} \times [O_3] + 0.36_{\pm 0.11} \times [T] - 0.16_{\pm 0.06} \times [RH] + 0.0039_{\pm 0.024} \times [NO_2]$$

# Design of Experiment

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## Laboratory uncertainty

| $NO_2$ | $U_c^2$ | | | | |
|---|---|---|---|---|---|
| Chem_1 | $U_{lof}^2 + U(O3)^2$ | $+ U(T)^2 + U(RH)^2$ | | | $+ cst^2$ |
| | $U_{lof}^2 + U(O3)^2$ | $+ U(RH)^2$ | | | $+ cst^2$ |
| Chem_2 | $U_{lof}^2 + U(O3)^2$ | $+ U(T)^2 + U(RH)^2$ | | | $+ cst^2$ |
| Chem_3 | $U_{lof}^2 + U(O3)^2$ | $+ U(T)^2$ | | | $+ cst^2$ |
| | $U_{lof}^2 + U(O3)^2$ | $+ U(T)^2 + U(RH)^2$ | $+ U(NO)^2$ | | $+ cst^2$ |
| Chem_4 | $U_{lof}^2 + U(O3)^2$ | $+ U(T)^2$ | | | $+ cst^2$ |
| Chem_5 | $U_{lof}^2 + U(O3)^2$ | | | | $+ cst^2$ |
| Res_1 | $U_{lof}^2 + U(O3)^2$ | $+ U(T)^2$ | | | $+ cst^2$ |
| | $U_{lof}^2 + U(O3)^2$ | $+ U(T)^2$ | | | $+ cst^2$ |
| Res_2 | $U_{lof}^2 + U(O3)^2$ | $+ U(T)^2$ | $+ U(NO)^2$ | $+ U(CO)^2$ | $+ cst^2$ |

$$U_c^2{}_{Chem\_5} = 3.2^2 + 11.0^2 + 5.02^2 \Rightarrow U_{c,Chem\_5} = 12{,}51$$

$U_{lof}^2$ $U(O3)^2$ $cst^2$

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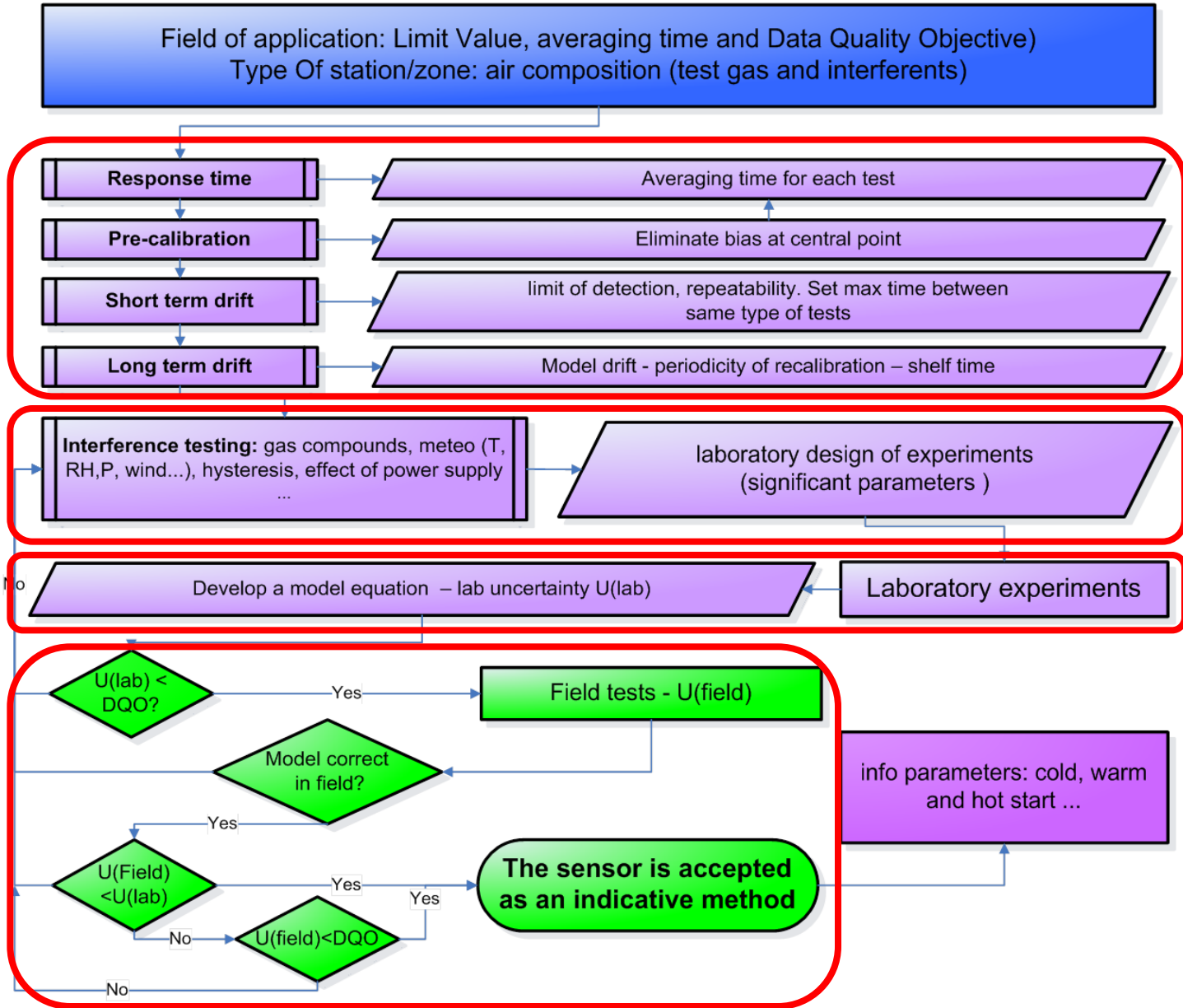
# Evaluation Validation Protocol



# Field campaign

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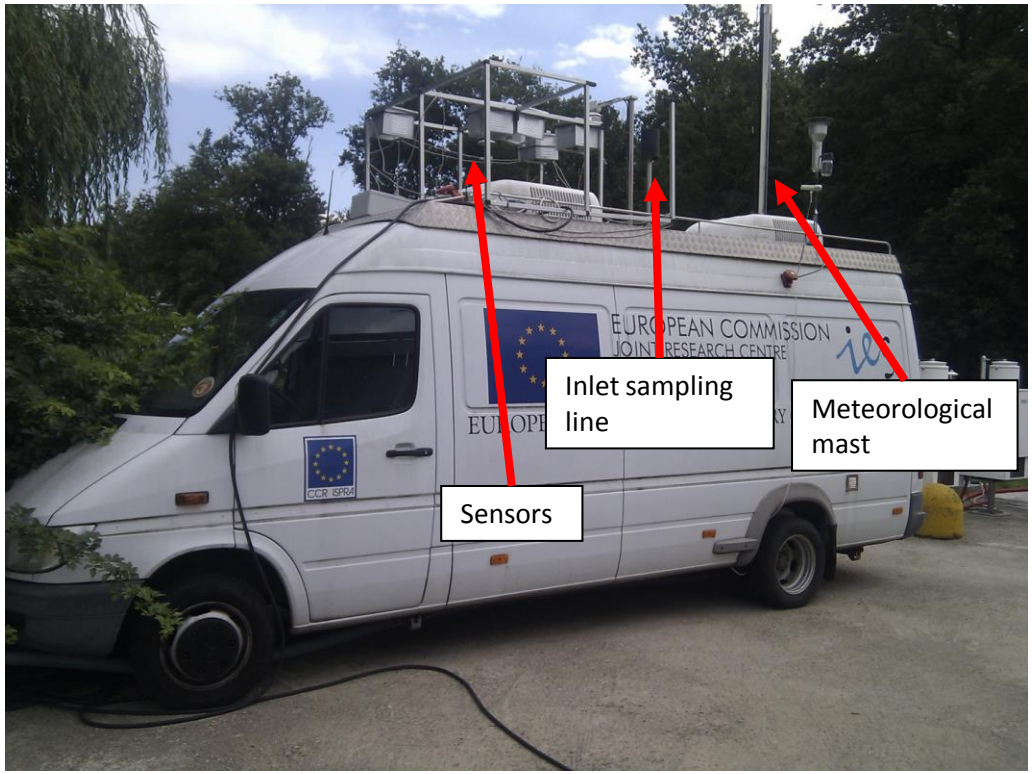
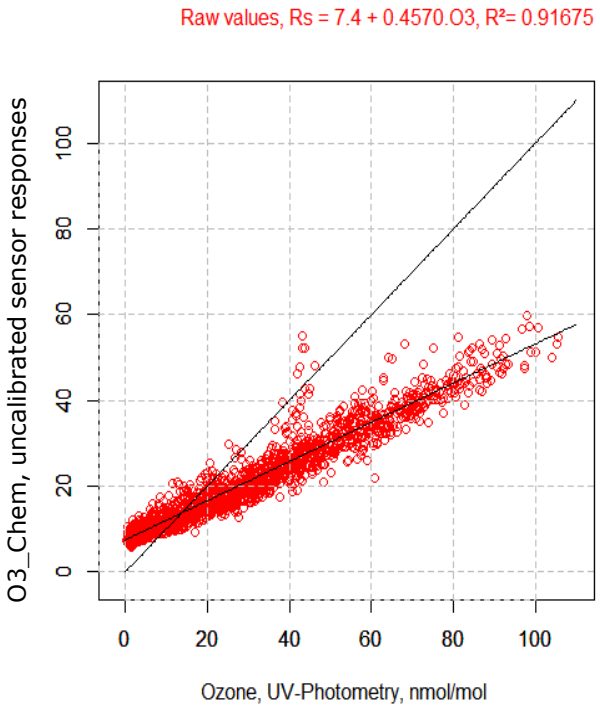
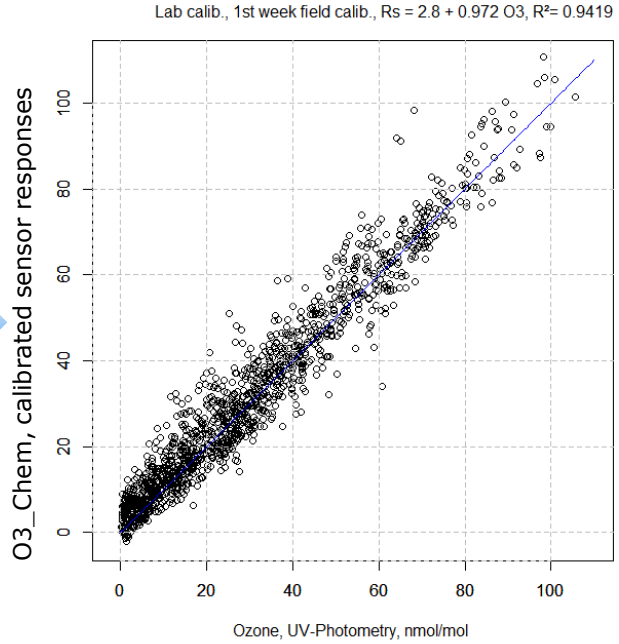
## Monitoring station




# Field campaign




Calibration + Model



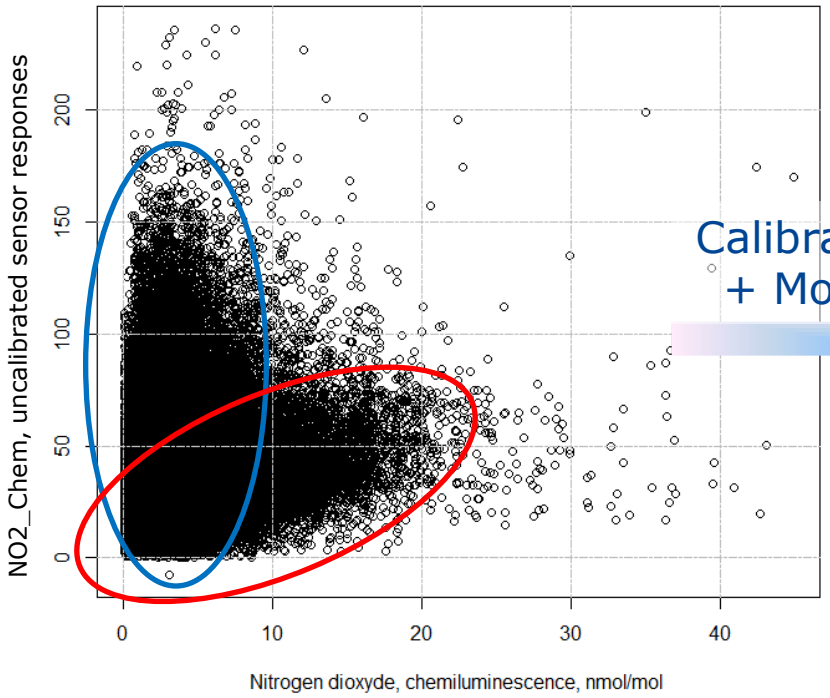

**Calibration:** first week of exposure

**Model:** Laboratory model

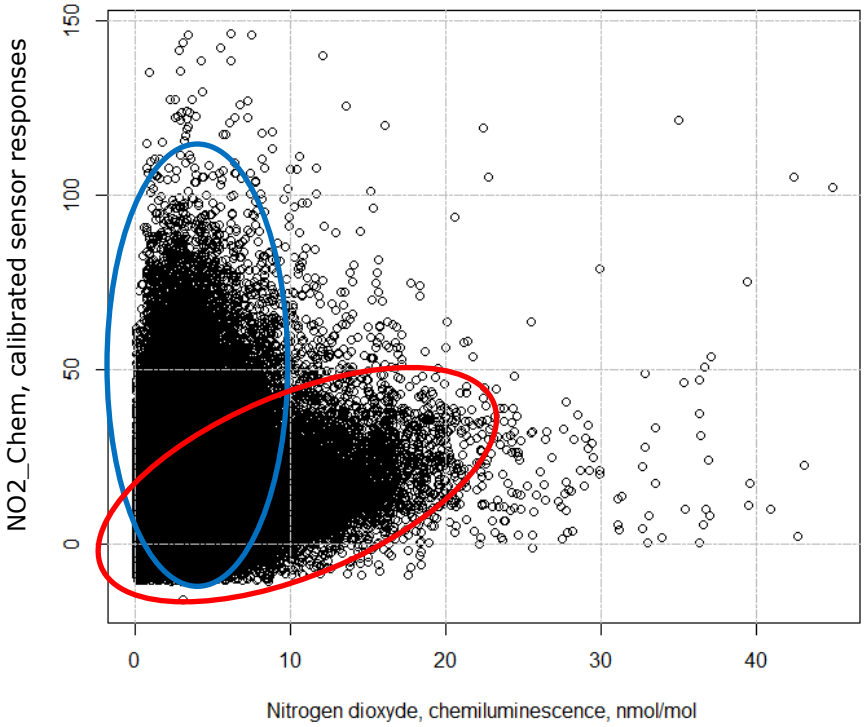
**Expanded relative uncertainty**
(Guidance to Demonstration of Equivalence)

**19.4%** < 30% of the Data Quality Objective

# Field campaign




Calibration + Model




**Calibration:** first 10 days of exposure

**Model:** Laboratory model

**low NO2 level: field campaign conditions un-adapted to the sensor**

# Thank You.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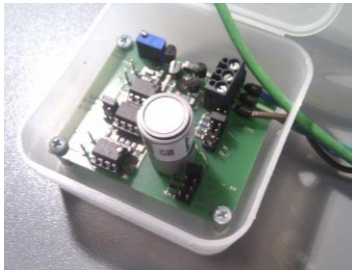
# Data Quality Objectives (DQO) of the European Air Quality Directive

| Uncertainty for | $O_3$ | $NO_2$/NO/NOx |
|---|---|---|
| fixed measurements | 15 % | 15 % |
| indicative measurements | 30 % | 25 % |





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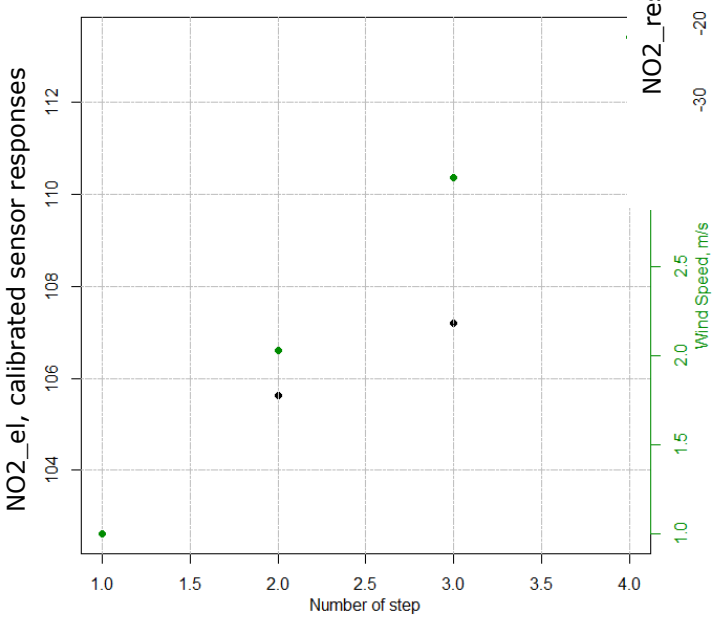
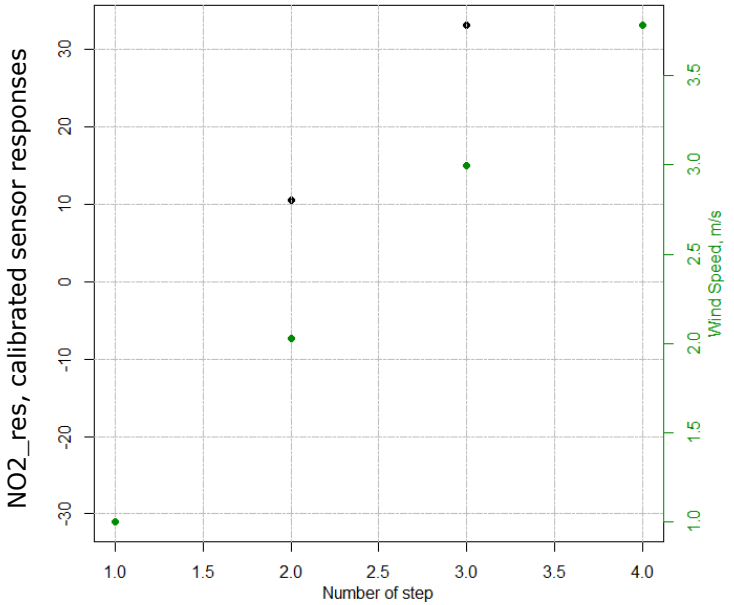
# Interfering effect

## Wind

| $NO_2$ | Wind (nmol/mol) |
|---|---|
| Chem_1 | 2.66 |
| | 1.16 |
| Chem_2 | 0.91 |
| Chem_3 | 0.48 |
| | 0.25 |
| Chem_4 | 0.07 |
| Chem_5 | < 3.40 |
| Res_1 | 0.01 |
| | 0.07 |
| Res_2 | 1.31 |



# Interfering effect

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| Chem_4 | 0.07 |
| Chem_5 | < 3.40 |
| Res_1 | 0.01 |
| | 0.07 |
| Res_2 | 1.31 |