The European Approach to Lower Cost Sensor Use and Evaluation of Low Cost Sensors

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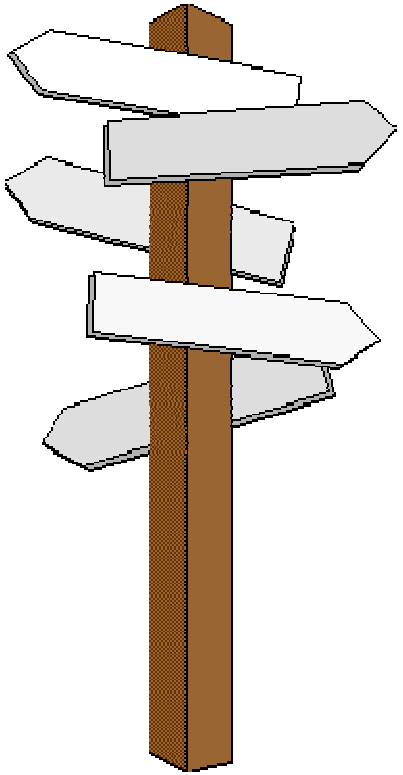


Road map: Monitoring with Air Pollution Sensors for Regulatory Purposes

- Evaluating low cost sensor systems: the indicative method concept
- Systematic evaluations of gas phase sensors
- On-going validation of sensors

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

Fixed measurements: definition

'fixed measurements' means measurements taken at fixed sites, either continuously or by random sampling, to determine the levels in accordance with the relevant *Data Quality Objectives* (DQO);

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

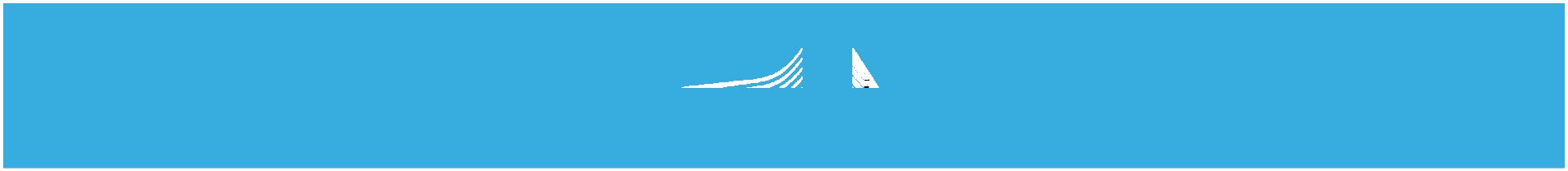
AQD: Data Quality Objectives (DQO)

	SO_2, NO_2/NO /NOx, CO	Benzene	O_3
Uncertainty for **fixed measurements**	15 %	25 %	15 %
	Fluoresc., chemil., NDIR	automatic GC or pumped sampling	UV photometry
Uncertainty for **indicative measurements**	**25 %**	**30 %**	**30 %**
	diffusive samplers, ***micro-sensors***		

Indicative methods, what for?
upper assessment threshold: definition

'upper assessment threshold' shall mean a level below which a combination of fixed measurements and/or indicative measurements may be used to assess ambient air quality;
Generally, upper thresholds are 60-70 % of limits values (health effect related and requiring a plan for mitigation)

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



N° of stations with data in Airbase – Fixed measurements

	Stations in Airbase in 2010
SO_2	2289
NO_2/NO/NOx	3336/2195/2616
O_3	2353
CO	1421
Benzene	809
PM_{10}	3079
$PM_{2.5}$	1016
Total	4918

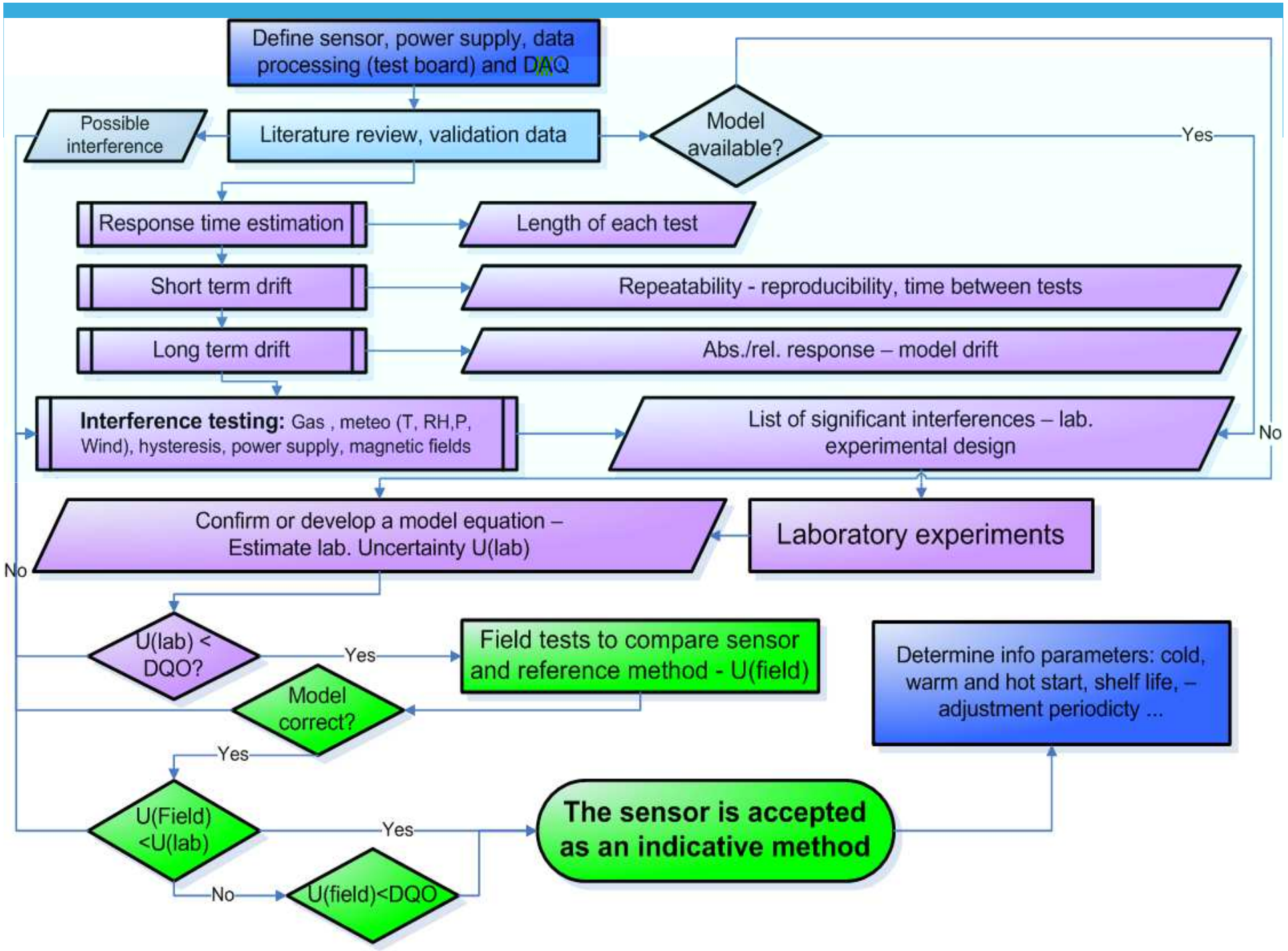
European Commission

Directive: minimum number of fixed stations

Population of agglomeration or zone (thousands)	If maximum concentrations exceed the upper assessment threshold (1)		If maximum concentrations are between the upper and lower assessment thresholds	
	Pollutants except PM	PM (2) (sum of PM_{10} and $PM_{2,5}$)	Pollutants except PM	PM (2) (sum of PM_{10} and $PM_{2,5}$)
0-249	1	2	1	1
250-499	2	3	1	2
500-749	2	3	1	2
750-999	3	4	1	2
1 000-1 499	4	6	2	3
1 500-1 999	5	7	2	3
2 000-2 749	6	8	3	4
2 750-3 749	7	10	3	4
3 750-4 749	8	11	3	6
4 750-5 999	9	13	4	6
≥ 6 000	10	15	4	7

Systematic evaluation of sensors:

Draft protocol


Define sensor, power supply, data processing (test board) and DAQ
Literature review, validation data
Possible interference
Model available?
Yes
No
Response time estimation
Length of each test
Short term drift
Repeatability - reproducibility, time between tests
Long term drift
Abs./rel. response – model drift
Interference testing: Gas , meteo (T, RH,P, Wind), hysteresis, power supply, magnetic fields
List of significant interferences – lab. experimental design
Confirm or develop a model equation – Estimate lab. Uncertainty U(lab)
Laboratory experiments
No
U(lab) < DQO?
Yes
Field tests to compare sensor and reference method - U(field)
Model correct?
Determine info parameters: cold, warm and hot start, shelf life, – adjustment periodicty ...
Yes
U(Field) <U(lab)
Yes
The sensor is accepted as an indicative method
No
U(field)<DQO

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 (O3B4)	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
CairPol – F	CairClip O3	3 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

CairClip O3/NO2 - CairPol

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Response time

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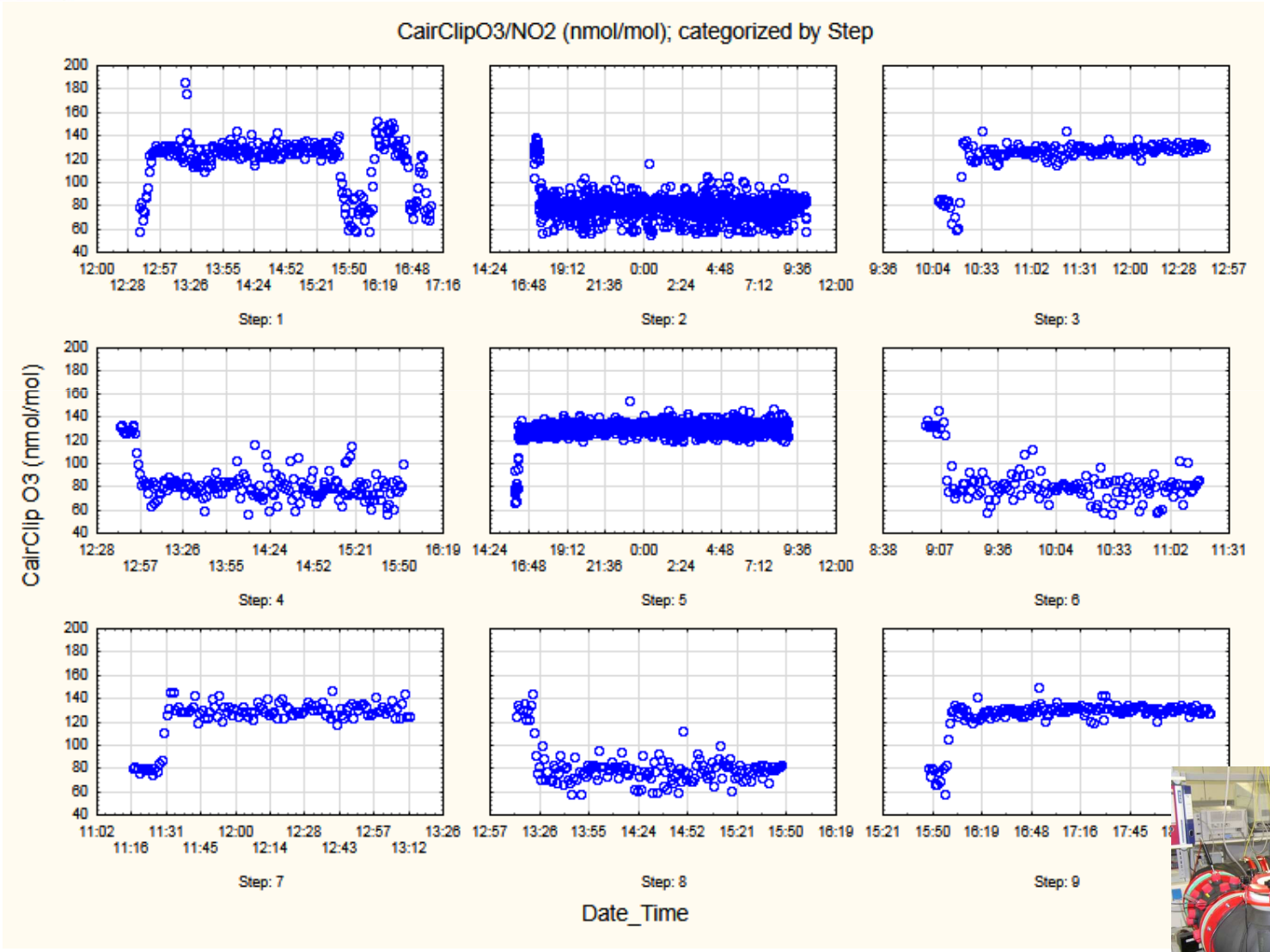

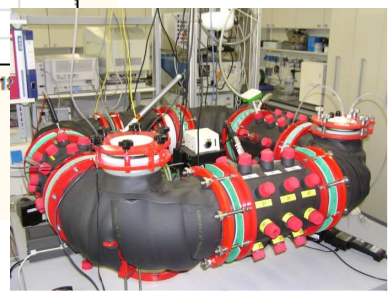

Response time

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	Step2: 0 ppb	Step3: 90 ppb	Step4: 0 ppb	Step5: 90 ppb	Step6: 0 ppb	Step7: 90 ppb	Step8: 0 ppb	Step9: 90 ppb
Ozone, UV	**13 min**	**4 min**	**5 min**	**3 min**	**4 min**	**3 min**	**5 min**	**3 min**
Cairclip	**16 min**	**9 min**	**6 min**	**8 min**	**8 min**	**5 min**	**5 min**	**5 min**

Stability	Step2	Step3	Step4	Step5	Step6	Step7	Step8	Step9
Temperature	22.0	22.1	22.1	22.0	22.0	22.0	22.0	22.0
Humidity	58	60	60	60	60	60	60	60
Pressure	995	999	998	1000	1000	1000	999	997
Wind Speed	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
O3 stability	0	92	3	91	0	92	0	92
NO2	0.7	0.7	1.0	0.7	0.7	0.7	0.7	0.7
NO	1.7	1.8	1.8	1.7	1.8	1.8	1.8	1.8

Long-term drift

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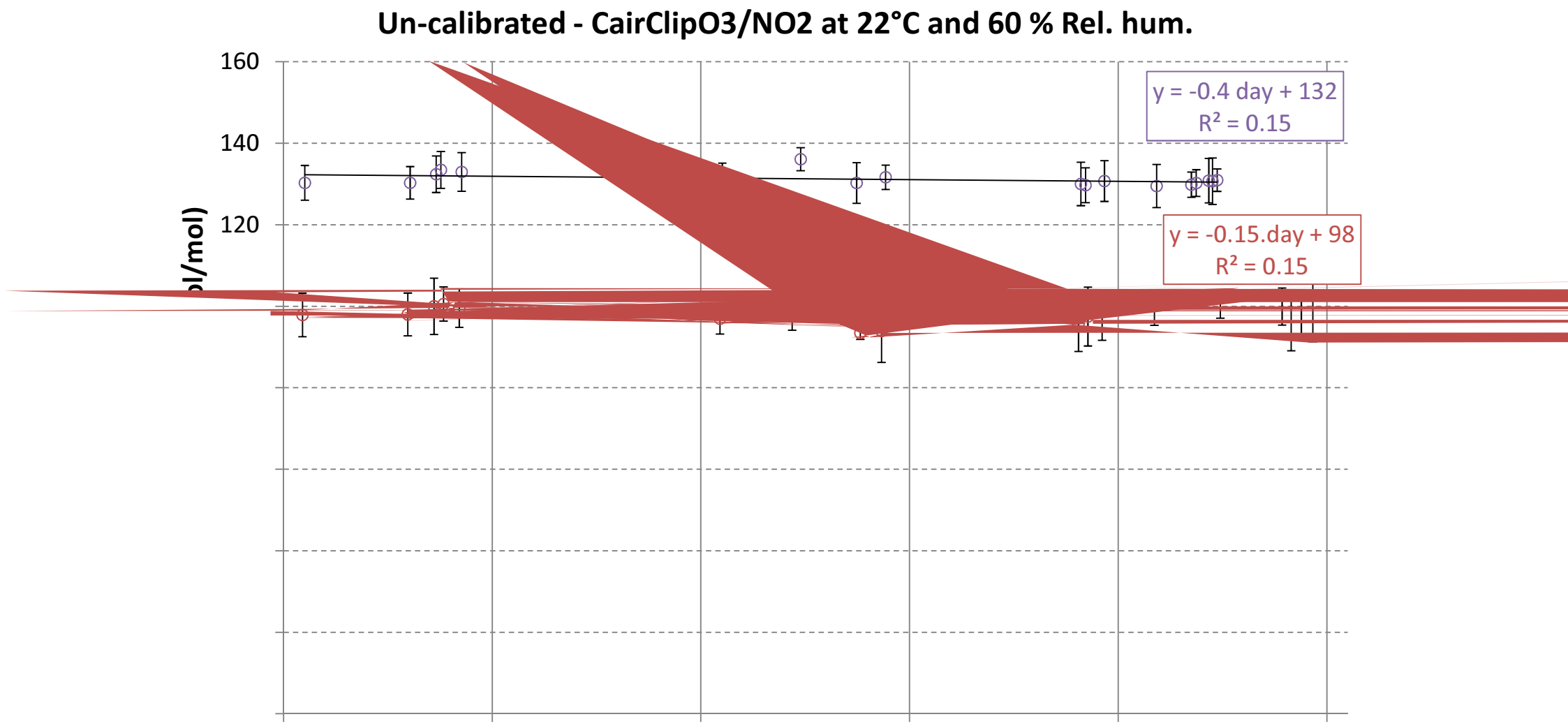

Response time

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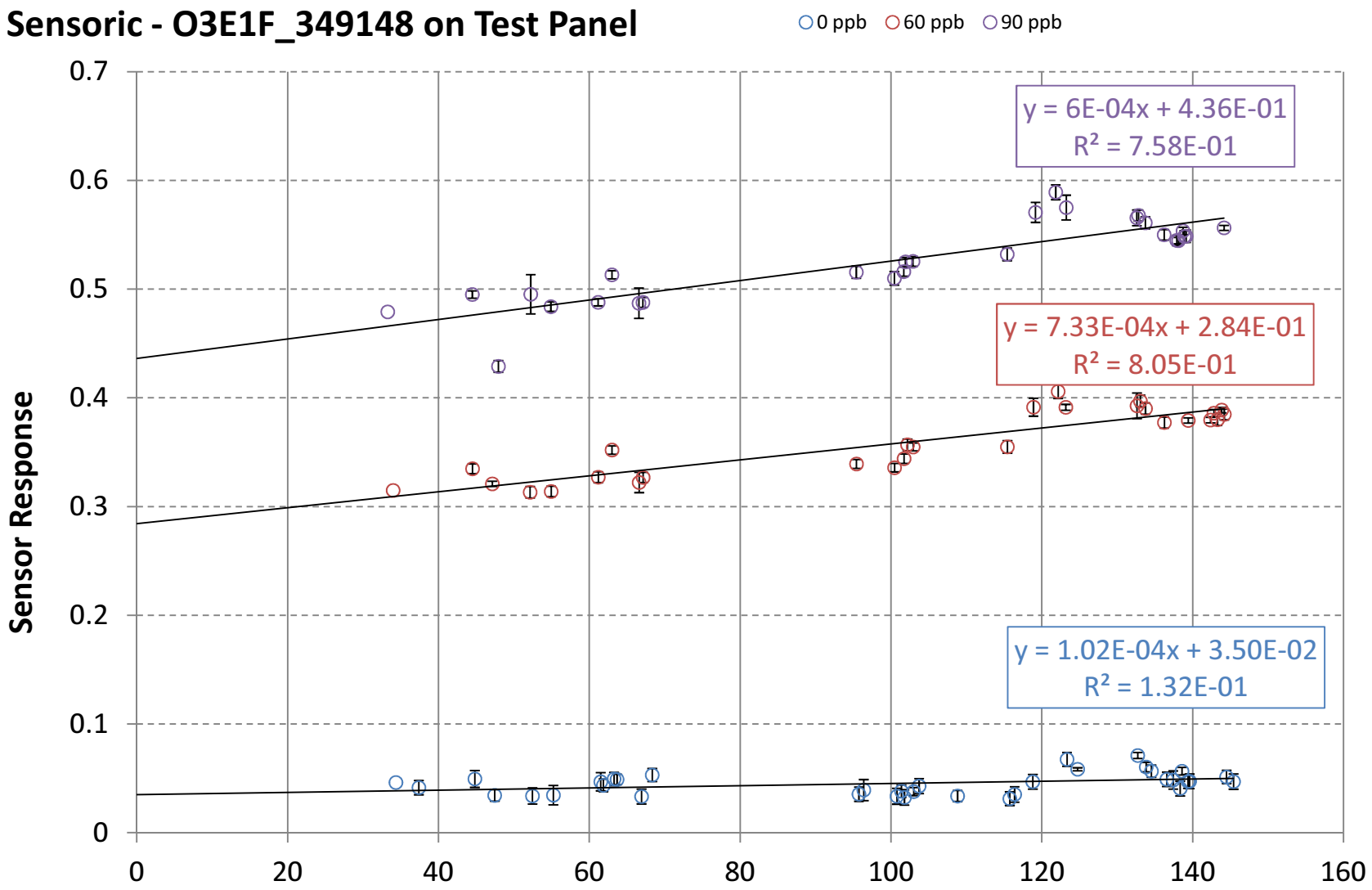

Interference

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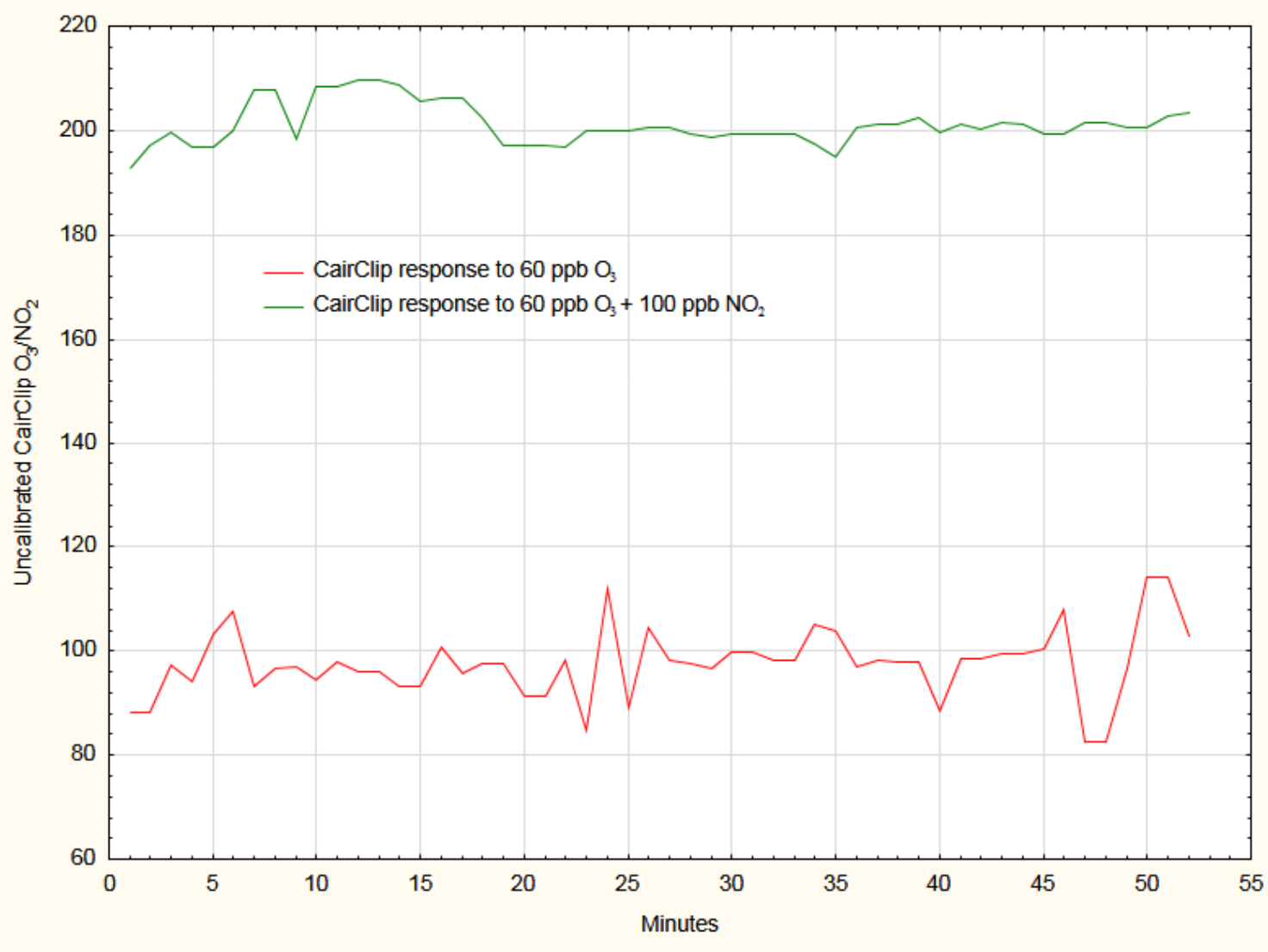

Experimental design for modelling sensor response

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O_3	NO_2	Temp.	Rel. Hum.	Total
6 levels	2 levels	3 levels	3 levels	108 trials

Humidity effect

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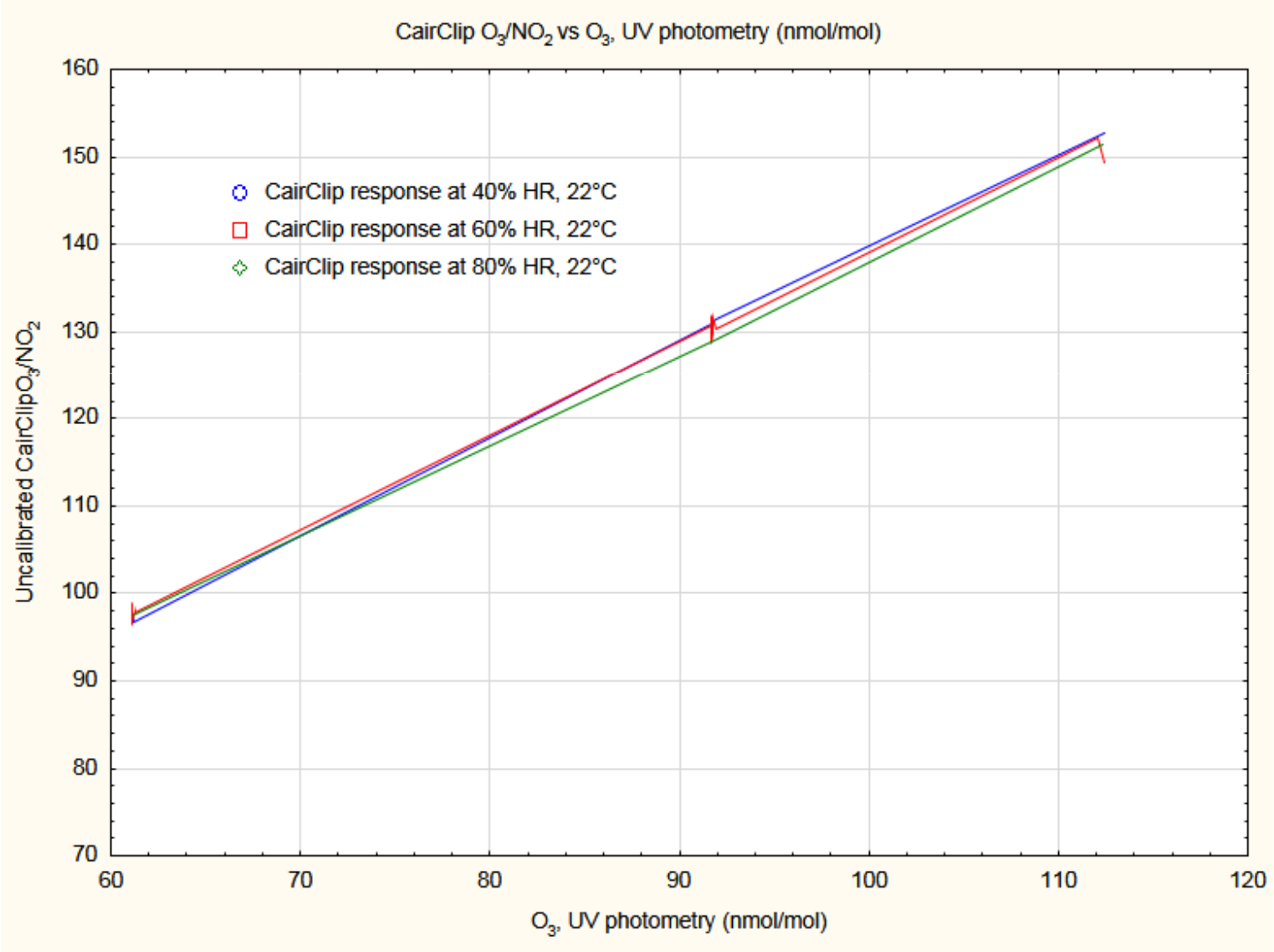

Field tests, hourly values

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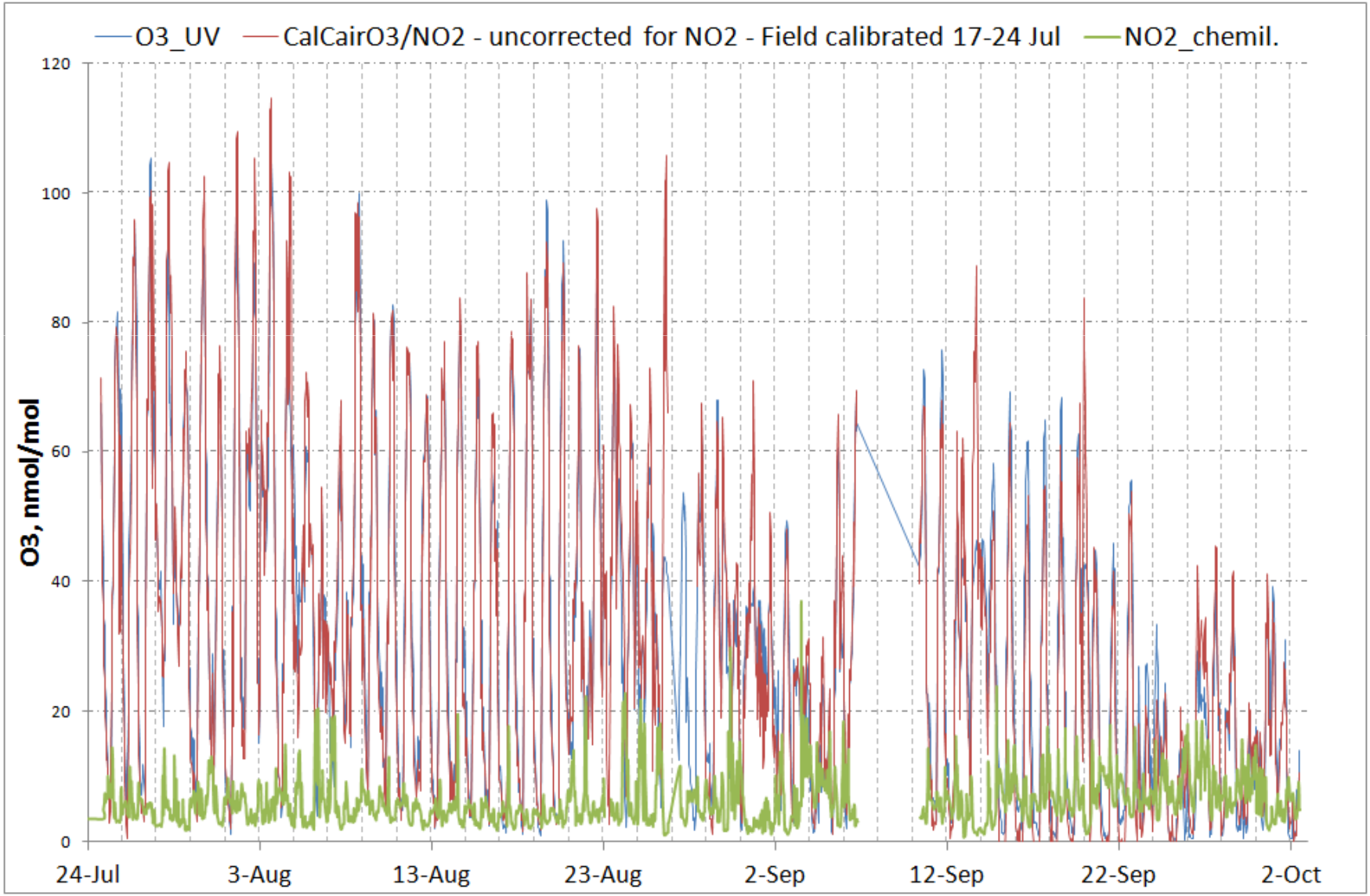

Field tests, hourly values

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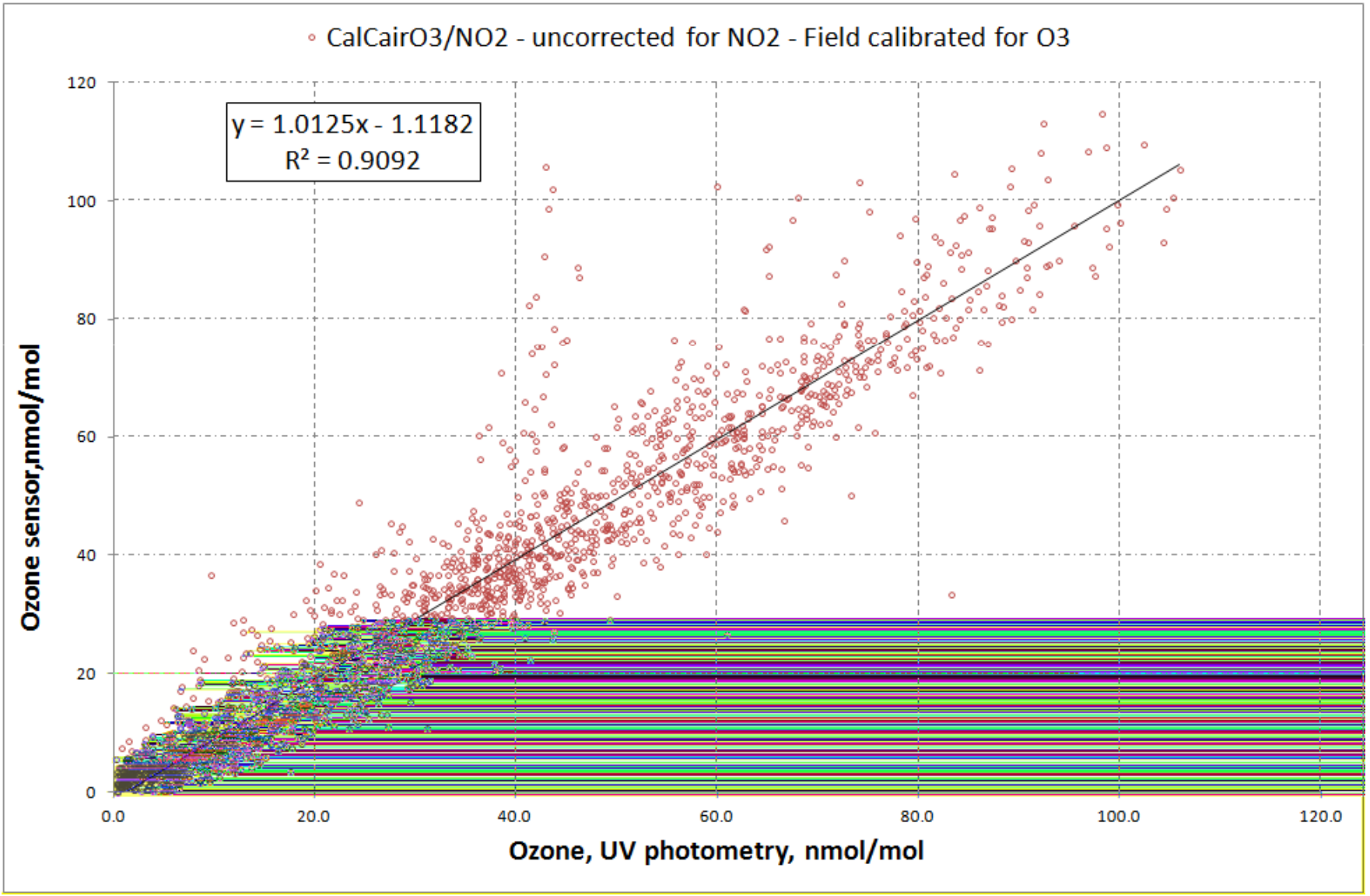

Uncertainty and DQO

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- $U = 2 (s^2_{lof} + s^2_{bias} - s_{r,UV}^2)$

	U, Hourly values, Validation dataset
60 ppb	26 %
90 ppb	19 %
120 ppb	17 %

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)
Citytech – G	Sensoric 4-20 mA Transmitter Board with 3E50/3E100 sensor
Citytech – UK	A3OZ EnviroceL (for now without test board?)
MIKES – FI	Prototype graphene sensors
InRim – IT	Prototype graphene sensors
CairPol – F	CairClip NO2/O3 - filtered

NO_2 epitaxial graphene sensor

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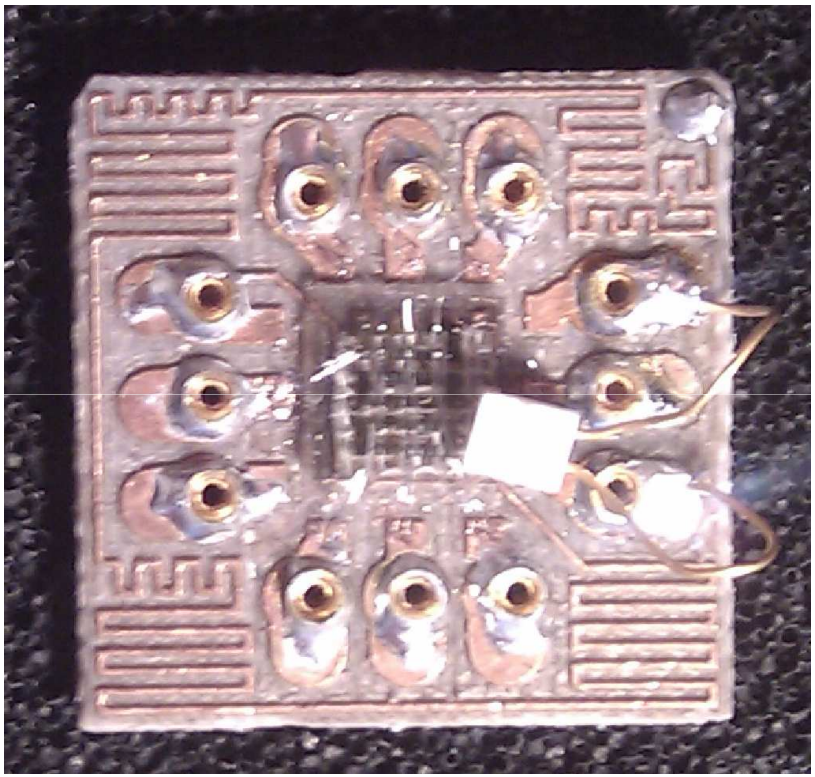

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Conclusions

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Not yet: data treatment is on-going for O3 – NO2 tests just started

Just wait a bit … ☹