Calibration of a cluster of low-cost sensors for the measurement of air pollution in ambient air

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Introduction

Several calibration methods of low-cost sensors are compared using data from a measuring campaign. NOx, O_3, CO, CO_2 and SO_2 were registered using sensors collocated with reference monitors and meteo data (temperature, relative and absolute humidity, wind and pressure). The field calibration methods included: simple linear models (LM), multi linear regression models (MLR) established in previous laboratory studies [1] and artificial neural networks with raw, standardised and calibrated (MLR) sensor responses. The performance of each calibration method was compared taking the measurement uncertainty as an indicator of the calibration efficiency. An example is given for the estimation for hourly O_3 values.

Cluster of sensors

Manufacturer	Model	R^2 of linear regression	Multivariate linear model	R^2
Sense	O3 sensors B4	0.07	$O_3 = \frac{Rs - bNO_2 - cNO_2.H_2O - d}{a}$	0.49
Citytech	**O3_3E1F**	**0.87**	$\mathbf{O_3 = \frac{Rs - bNO_2 - c}{a}}$	**0.91**
CairPol	CairclipO3/NO2	Unknown	$O_3 = \frac{Rs - bNO_2 - c}{a}$	Unknown
Sense	NO2-B4	0.06	$NO_2 = \frac{Rs - bO_3 - cT - dRH - e}{a}$	0.56
Citytech	NO2 3E 50	0.01	$NO_2 = \frac{Rs - bO_3 - cT - dRH - e}{a}$	0.63
	NO 3E 100	0.05	Unknown	Unknown
e2V	**2710 sensor**	**0.31**	$\mathbf{NO_2 = \frac{Rs - bO_3 - cT - d}{a}}$	**0.36**
	4514 sensor	**0.34**	$\mathbf{NO_2 = \frac{Rs - bO_3 - cNO - dT - e}{a}}$	**0.42**
CairPol	CairClip NO2	0.37	$NO_2 = \frac{Rs - bO_3 - c}{a}$	0.74
Figaro	5042 sensor	0.17	$CO = \frac{Rs - bT - cRH - d}{a}$	0.23
e2V	4514 sensor	0.56		0.58
Edinburgh Sensors	Gascard NG	0.14	$CO_2 = \frac{Rs - bT - cRH - d}{a}$	0.47
ELT Sensors	S-100H	0.58		0.62
NASUS Sense	NO2 sensors NO2-A1	0.46	Unknown	Unknown
	NO2 sensors NO2-B4	0.01		
	CO sensor CO-AF	0.09		
	CO sensor CO-B4	0.08		
	SO2 sensor	Unknown		

Choice of variables

- *Linear regression:* for each sensor responses
- *Multivariate non-linear estimation:* O_3 and NO_2 sensor responses
- *Neural network:* MultiLayer Perceptron with feedback and input bias, one hidden layer of variable number of nodes. The initial input consisted of sensor responses and meteo data. Initially, all sensors that were correlated with O_3 and independent between each other were selected. Using sensitivity analysis, variables that were not found significant were discarded. The best results were obtained with only 3 sensors and without any meteo data. The output of the ANN consisted in the average of an ensemble of the 5 best networks within 100 tested networks with different MLP architectures.

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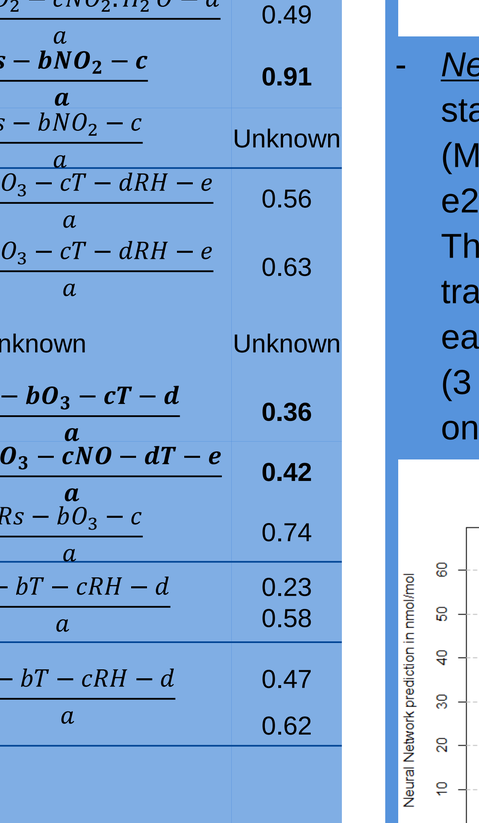
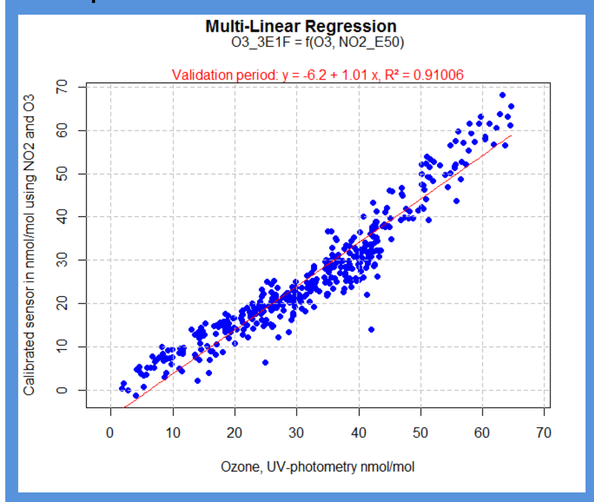
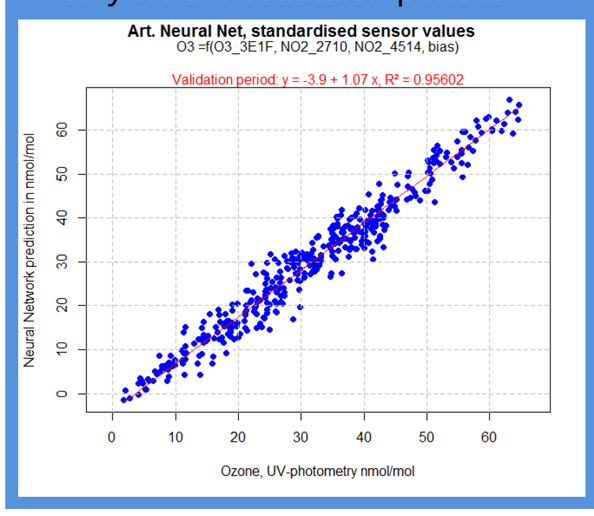


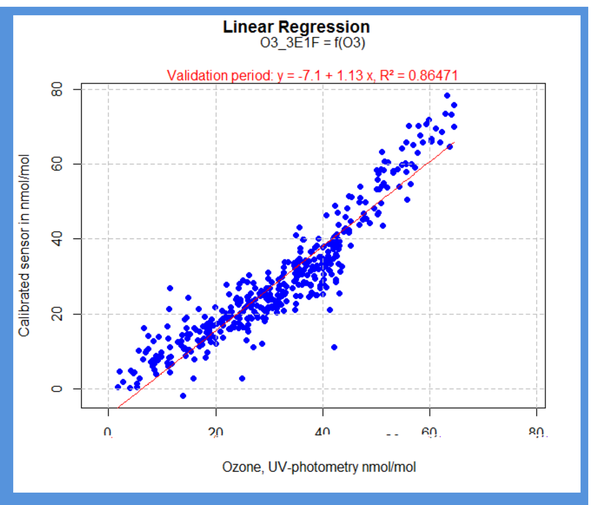
Calibration Methods:

- *LM:* sensor responses plotted versus UV photometry analyser, calibration established by the least square method

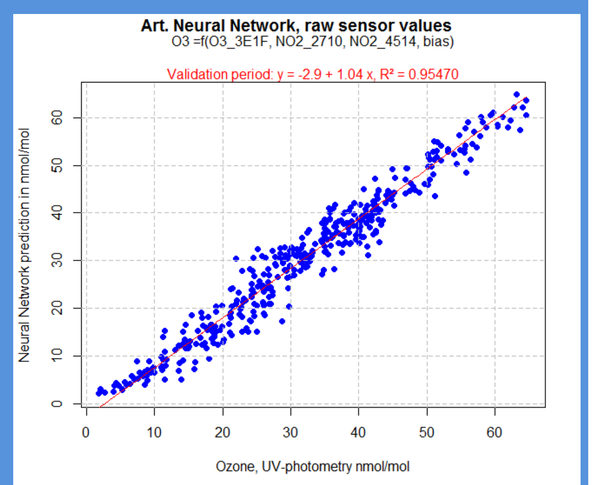


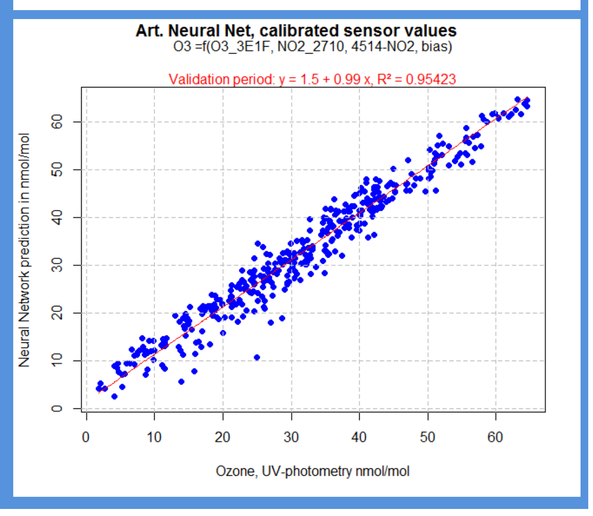
- *Neural network:* raw data, standardized and calibrated (MLR) of sensors O3-3E1f, e2v 2710 and e2V 4514 NO2. The dataset was divided in training- test periods (1 week each) and a validation period (3 weeks). The graphs are given only for the validation period.





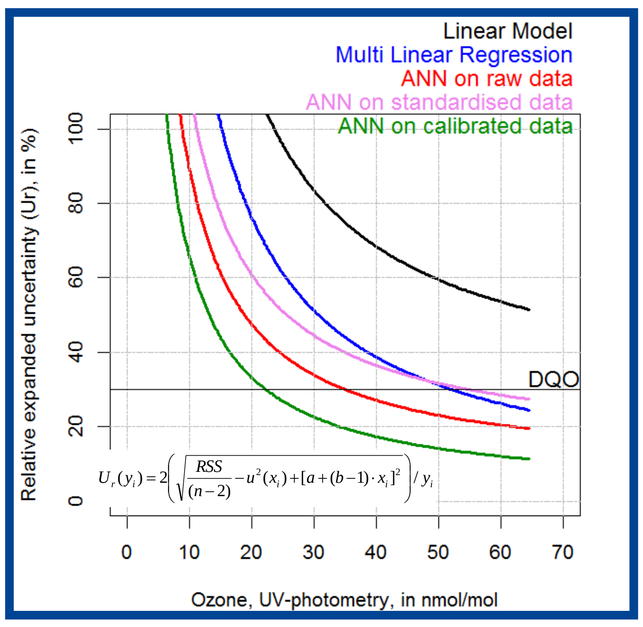
- *MLR:* parameters of models Rs = f(Xi) (see sensors table), fitted by the least square method using reference data and sensors





Conclusion

Based on the measurement uncertainty estimated with orthogonal regressions of the estimated outputs versus reference data, the best calibration method appears to be ANN using calibrated sensors. Simple LR was shown to produce high measurement uncertainty. While MLR needs meteo data for calibration of most sensors, ANN using a cluster of only 3 sensors of different types (1 O_3 chemical and 2 NO_2 resistive sensors) is able to solve the NO_2 interference on the O_3 sensor and to assure independence to the meteo parameters.



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Reference:
L. Spinelle L, Aleixandre M, Gerboles M. Protocol of evaluation and calibration of low-cost gas sensors for the monitoring of air pollution. EUR 26112.
Luxembourg (Luxembourg): Publications Office of the European Union; 2013

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