

CZECH HYDROMETEOROLOGICAL INSTITUTE



ČESKÝ  
HYDROMETEOROLOGICKÝ  
ÚSTAV



# Testování malých senzorů ČO na Observatoři Tušimice



PMS5003



PMS7003

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# Základní charakteristiky malých senzorů PRO a PROTI



- Malé rozměry a hmotnost
- Nízká cena (obvykle < \$2500)
- Schopnost okamžitého použití
- Nenáročná údržba
- Autonomní baterie i úložiště
- přenositelnost



- Původ z čidel pro indoorové měření
- **! vlhkost vzduchu / teplota ! -> POTŘEBA verifikace dat**
- Zvýšené riziko náhodných chyb
- Vyšší detekční limity, snížená přesnost měření
- **Limitovaná/žádná možnost kalibrace**
- **Ne vždy víme, co měříme (interference polutantů)**



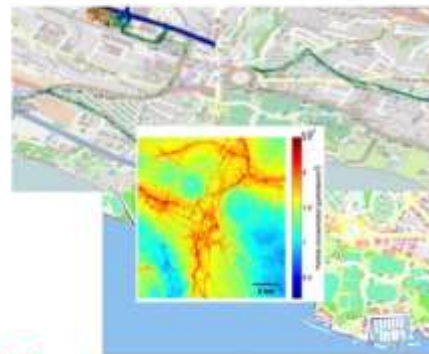
# Nejčastější motivace pro využívání malých senzorů

- **Smart Cities** projekty
- Možnost měření **ČO** v těžko dostupných místech a ve vertikálním profilu
- Použití v měření za **pohybu**
- Využití naměřených dat v modelování ČO



**OpenSense project** - ETH Zurich, CH  
**DISCOVER project** - NASA, Houston, USA  
**CAIRSENSE project** – US EPA, Georgia, USA

## Air Pollution in a Smart City



- Collaborative acquisition
- Self-diagnosis
- Localized measurements
- Heterogeneous data sources
- City Health Studies
- Open Air Quality Index
- Citizen Science
- Data Privacy



# Kategorie senzorů - Report EU Commission



Measuring air pollution with low-cost sensors  
Thoughts on the quality of data measured by sensors



## Metal oxide sensors (used to measure NO<sub>2</sub>, O<sub>3</sub>, CO)

- Low cost: around 10 - 15 € for a sensor.
- Good sensitivity, from mg/m<sup>3</sup> to µg/m<sup>3</sup>.
- Results are affected by temperature and humidity variations.
- Long response time (5 - 50 min).
- Output depends as well on history of past inputs.
- Instability can be observed.

## Electrochemical sensors (used to measure NO<sub>2</sub>, SO<sub>2</sub>, O<sub>3</sub>, NO, CO)

- Medium cost: around 50 - 150 € for a sensor.
- Good sensitivity, from mg/m<sup>3</sup> to µg/m<sup>3</sup>.
- Fast response time (30-200s).
- Highly sensitive to temperature and humidity variations (change in meteorology) depending on electrolyte.
- Selectivity: show cross-reactivity with similar molecule types



# Kategorie senzorů - Report EU Commission



Measuring air pollution with low-cost sensors

## Photo Ionization Detector (used to measure VOC)

- Moderate price: 400 € for a sensor to 5000 € for handled device.
- Good sensitivity, down to  $\text{mg}/\text{m}^3$ , some down to  $\mu\text{g}/\text{m}^3$ .
- Limited temperature dependence and humidity effects.
- Very fast response time (few seconds).
- Not selective: reacts to all VOCs that can be ionised by the UV lamp.
- Significant signal drift.



## Optical particulate counter (used to measure PM)

- Moderate cost: 300 € for a sensor to 2000 € for handled device.
- Fast response time (1 s).
- Sensitivity in the range of  $1 \mu\text{g}/\text{m}^3$ .
- Able to identify the size of the particle (PM10, PM2.5, ...).
- Conversion from particle counts to PM mass is based on theoretical model.
- The measured signal depends on a variety of parameters such as particle shape, color and density, humidity, refractive index, ...



555-555-555

# Cairpol (FR) Sensors SO<sub>2</sub>, CO, NO<sub>2</sub> and O<sub>3</sub>/NO<sub>2</sub>

## Miniature air quality monitoring sensors network

### SPECIFICATIONS:

- LCD display with concentration levels of the measured pollutants
- Internal data logging capacity: up to 1 year, depending of the setting.
- Internal microprocessor for value and time calculation
- Low battery indication
- Operating time: 24 to 36 hours when fully charged for USB versions (daily recharge for optimal use)
- Power supply: 5VDC /200 mA rechargeable by USB via PC or 220V/110V with 5V adaptor (solar panel option)
- Output: USB or UART (Analog signal on demand)
- Dimensions: diameter 32 mm (1,26"), length 62 mm (2,44")
- Weight: 55 g (1,94 oz)
- IP 42 (according IEC60529)
- Storage condition: 5 to 20°C (41°F to 68°F), 10 to 90% RH, mbar 1013 ffl 200 (psi 14,69 ffl 2,90)
- Operating condition: depending of the sensor, in general -20°C to +45 °C (-4°F to 113°F), 10 to 90% RH, mbar 1013 ffl 200 (psi 14,69 ffl 2,90)
- Electric standards: CEI/UL/CSA N°61010-1: 2008 / EN 61010-1:2001

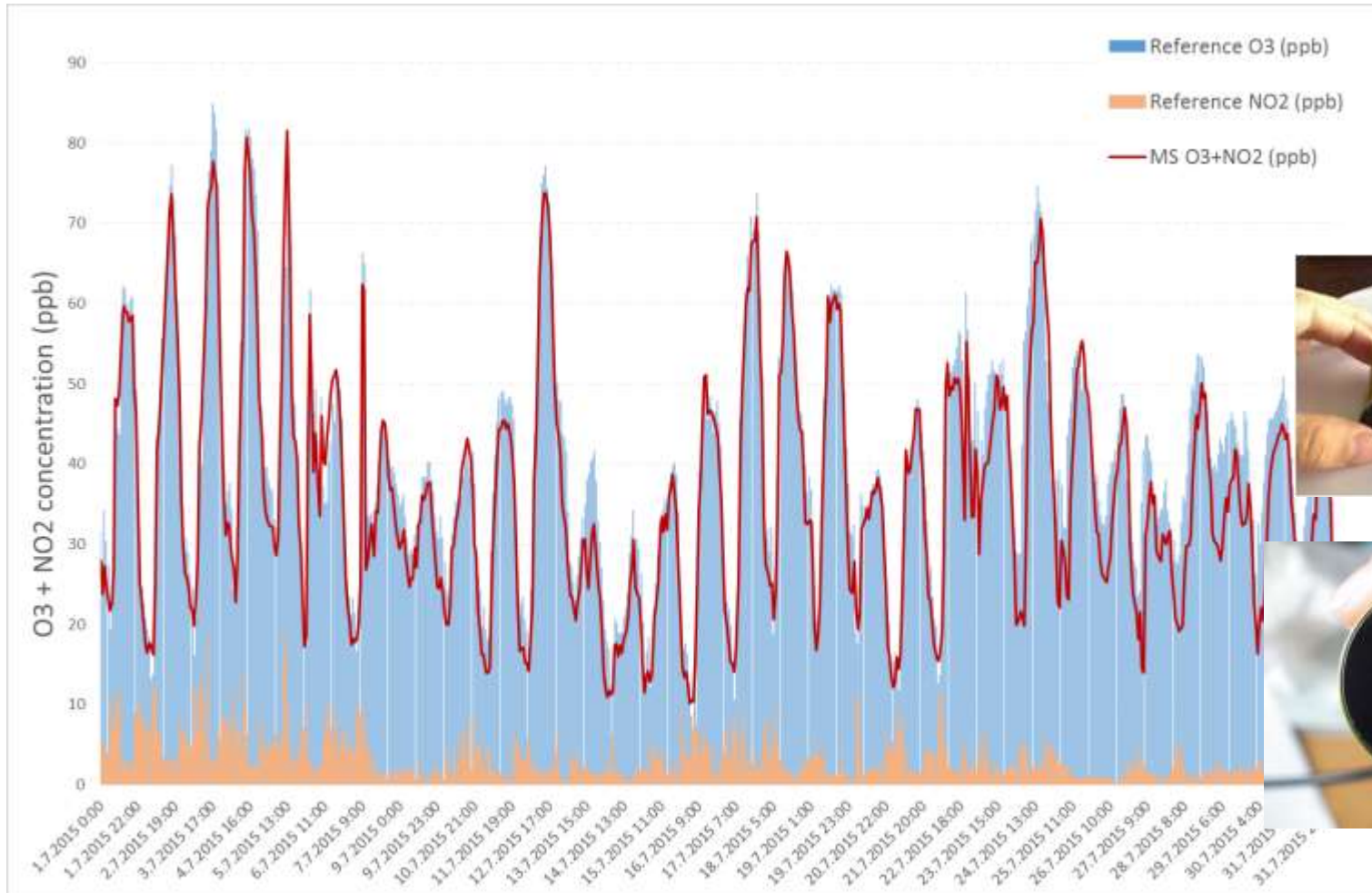
\* Detailed specification per sensor on request

	Ranges :
O <sub>3</sub> / NO <sub>2</sub>	0-250 ppb
NO <sub>2</sub>	0-250 ppb
CO	0-20 ppm
H <sub>2</sub> S / CH <sub>4</sub> S	0-1000 ppb / 0-20 ppm / 0-200 ppm
NH <sub>3</sub>	0-25 ppm
SO <sub>2</sub>	0-1000 ppb
CH <sub>2</sub> O / Organic solvents	0-1000 ppb
nM VOC	0-16 ppm



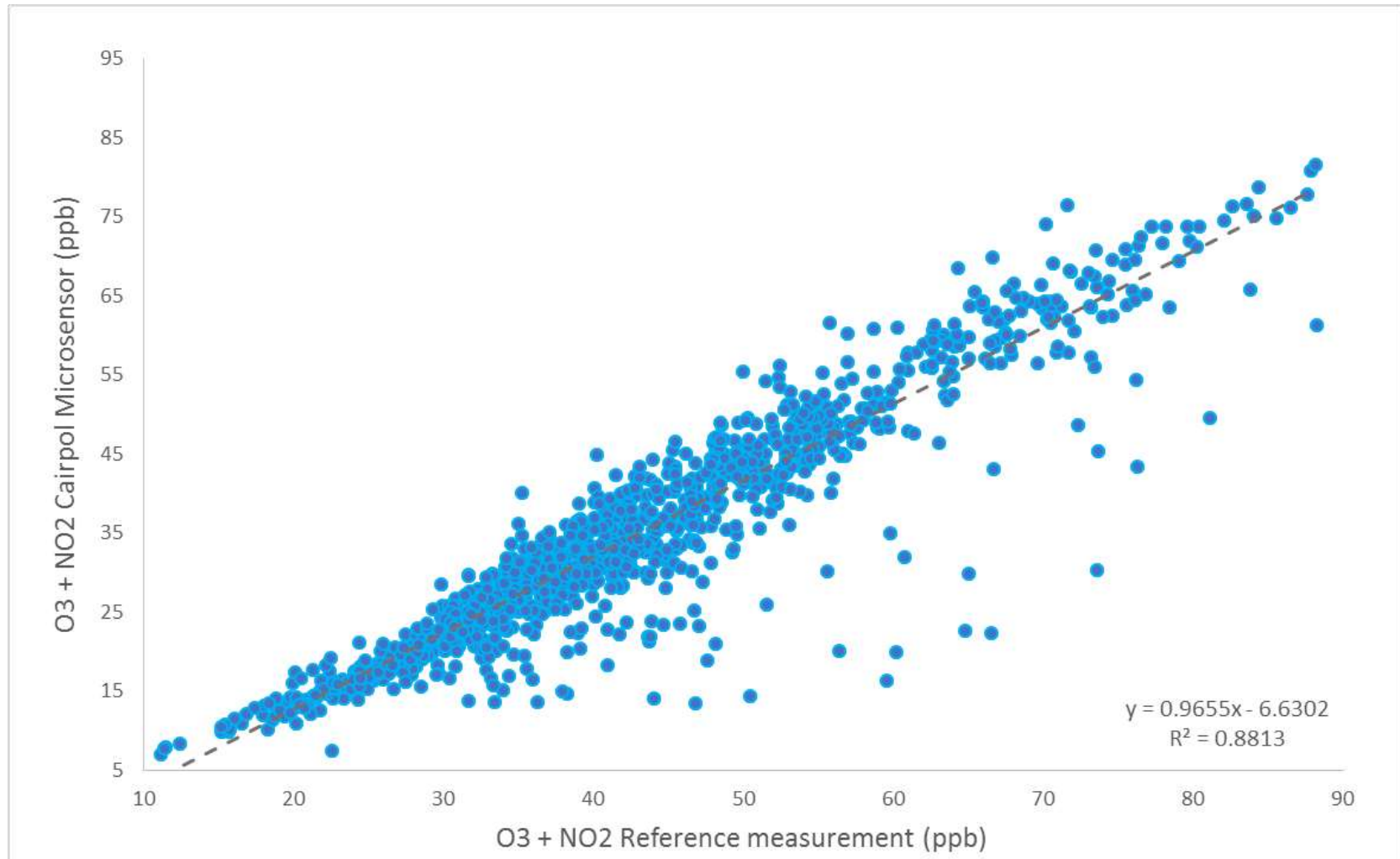
# Porovnávání Cairclip sensoru O<sub>3</sub>/NO<sub>2</sub> s AIM

## *letní období 06 - 09/2015*



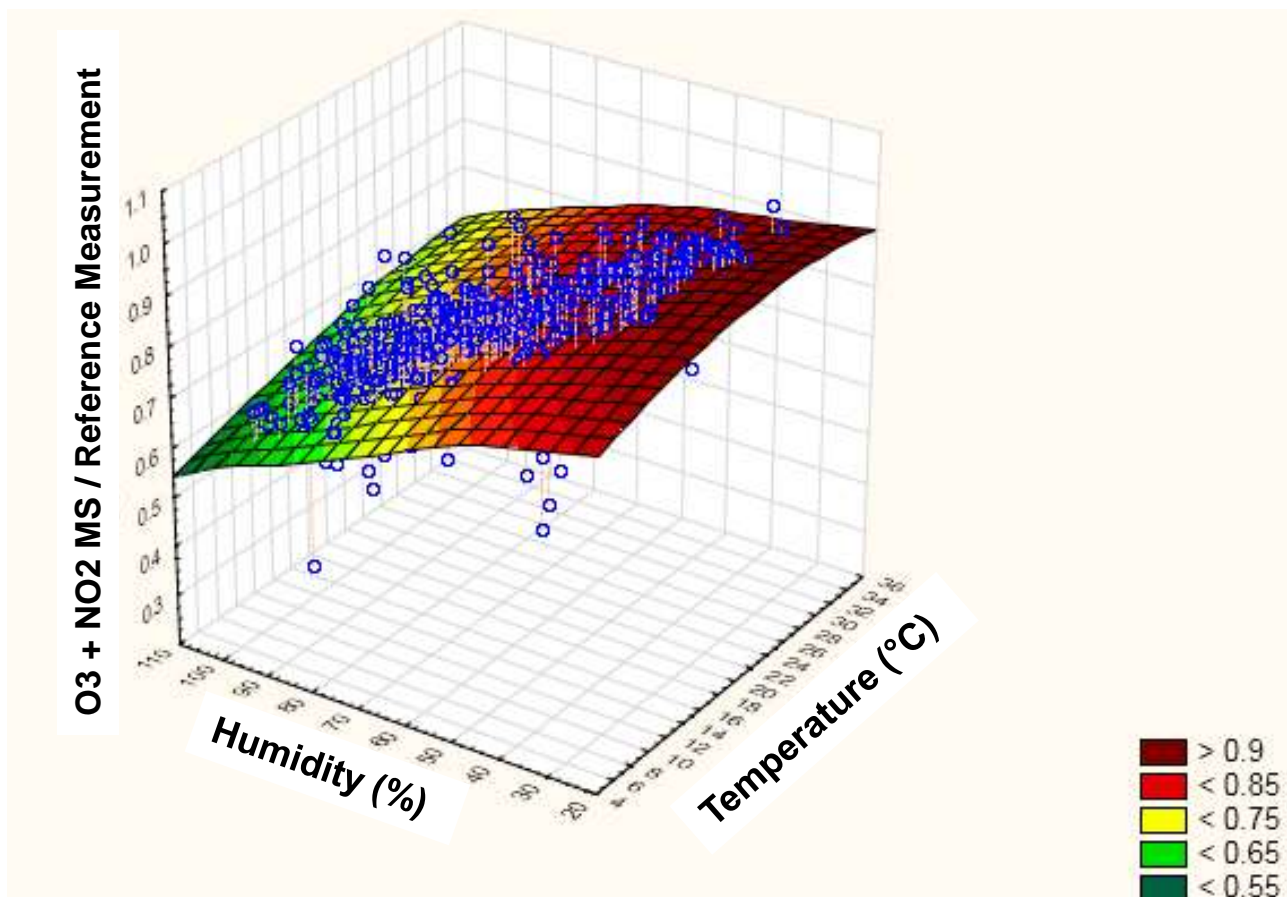
# Porovnávání Cairclip sensor O<sub>3</sub>/NO<sub>2</sub> s AIM

## *letní období 06 - 09/2015*



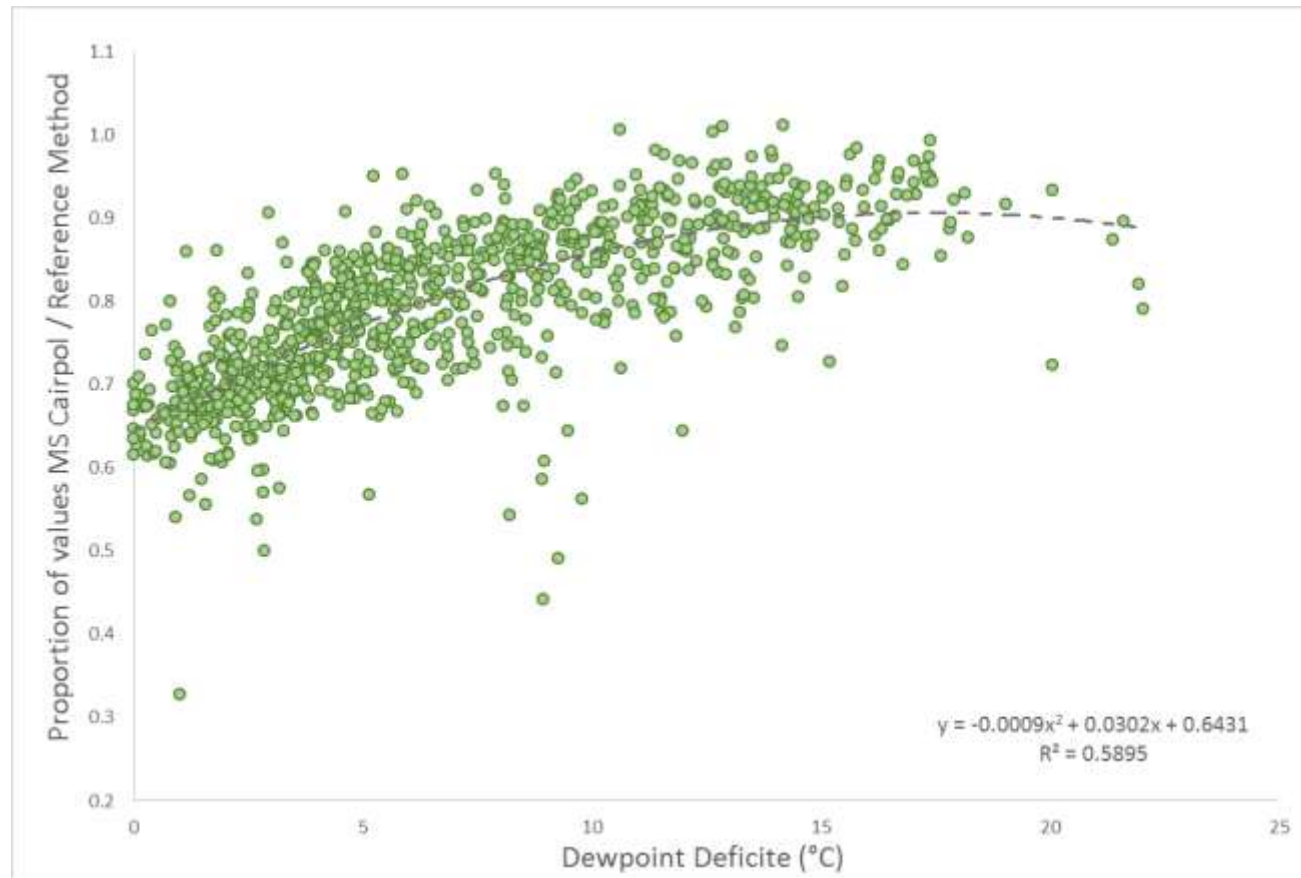


# Vliv teploty a relativní vlhkosti vzduchu na přesnost měření senzoru



- Největší odchylky mezi senzorem a AIM při nízkých teplotách a vysoké vlhkosti vzduchu

# Kvalita měření senzoru roste s klesající vlhkostí vzduchu

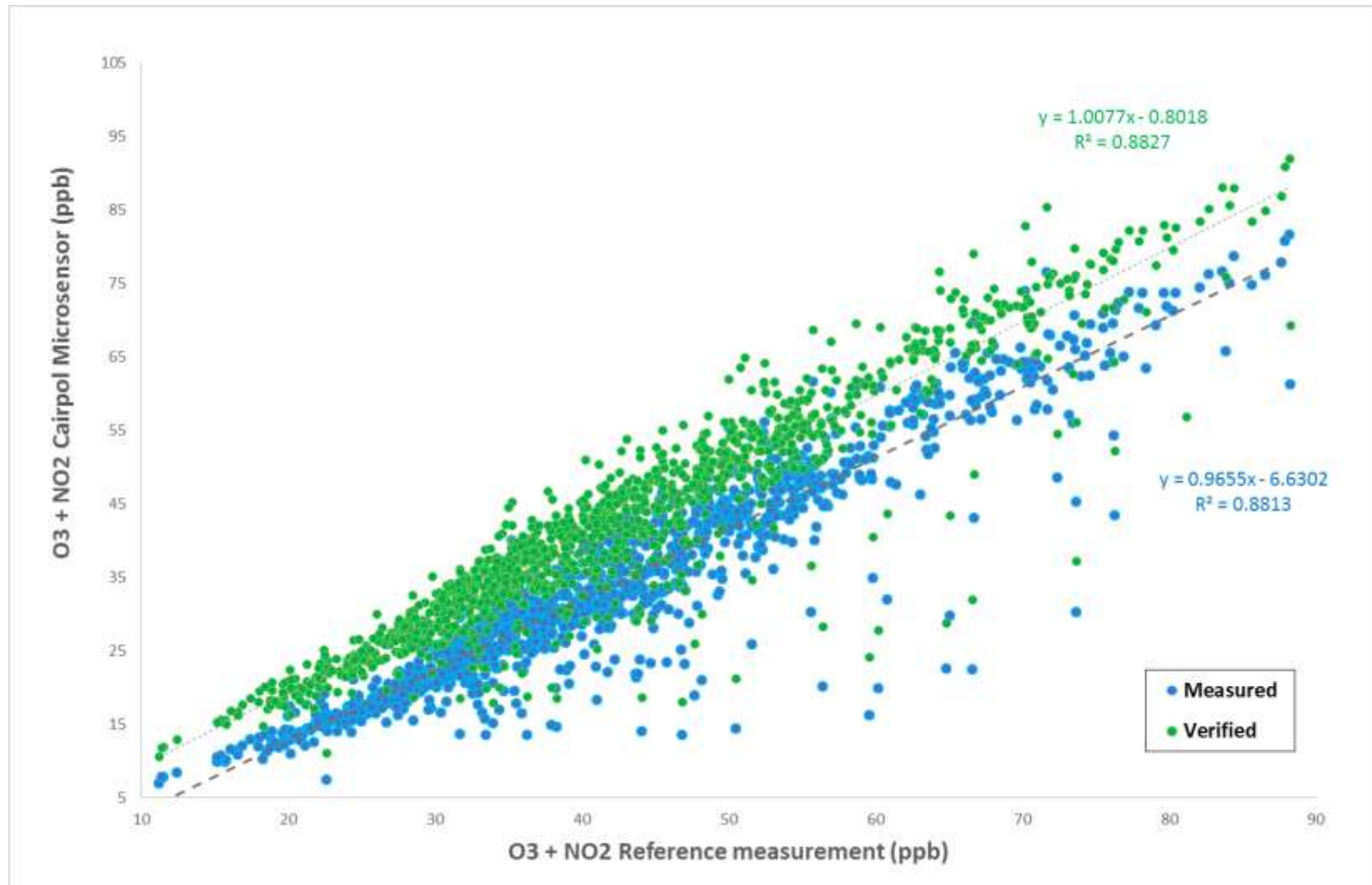


$$T_d = \frac{240.97}{[(17.502/A) - 1]}$$

$$A = [\ln(RH / 100)] + \left[ \frac{(17.502 \cdot t)}{(240.97 + t)} \right]$$

$$T_{d \text{ deficite}} = T - T_d$$

# Verifikace naměřených dat podle Td deficitu



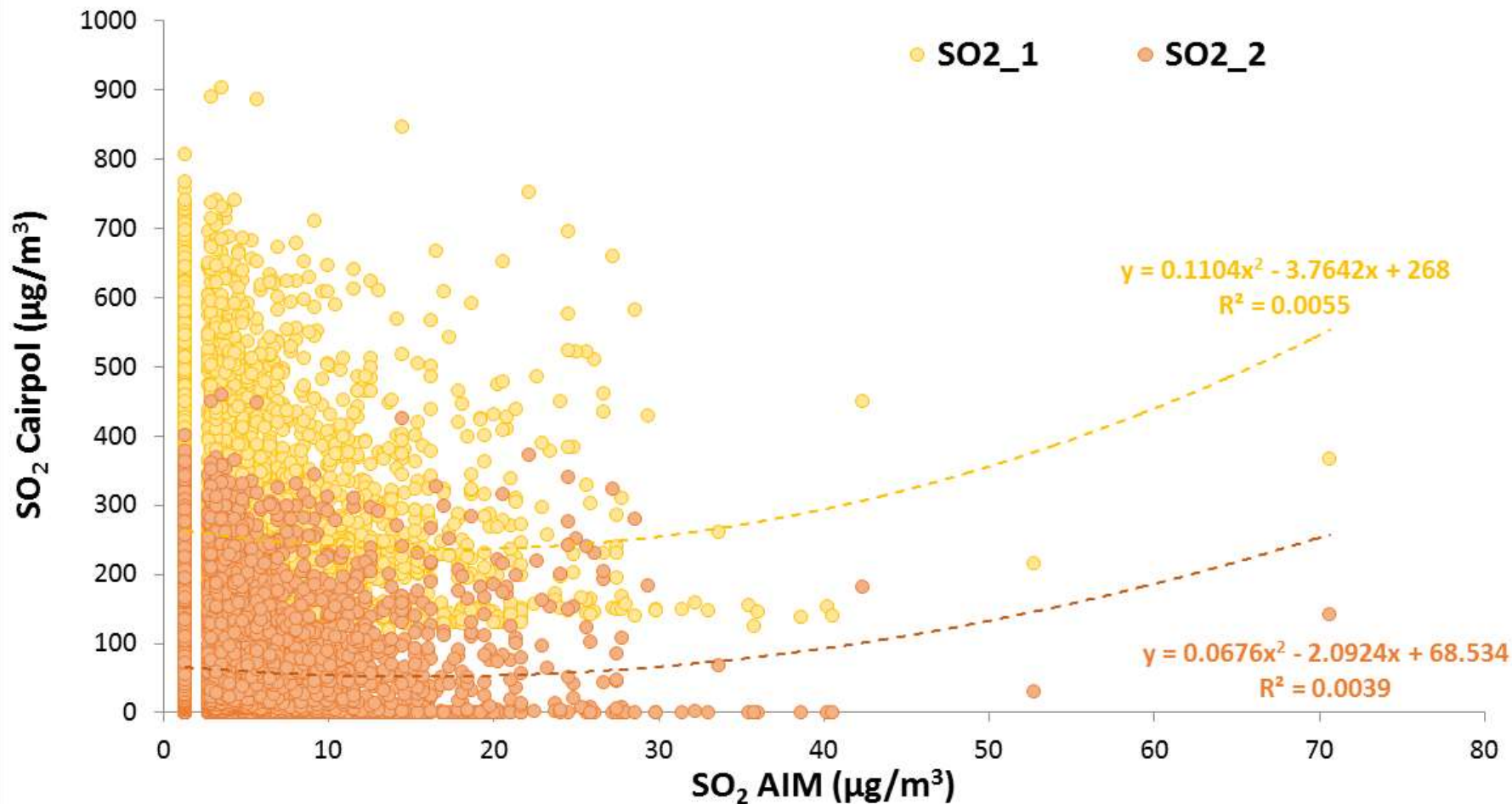
# Cairclip sada: SO<sub>2</sub>, CO, NO<sub>2</sub> a O<sub>3</sub>/NO<sub>2</sub>

*Testovací období konec 11/2017 – konec 09/2018*



# Cairclip SO<sub>2</sub> nevyhovující

## testovací období konec 11/2017 – konec 09/2018



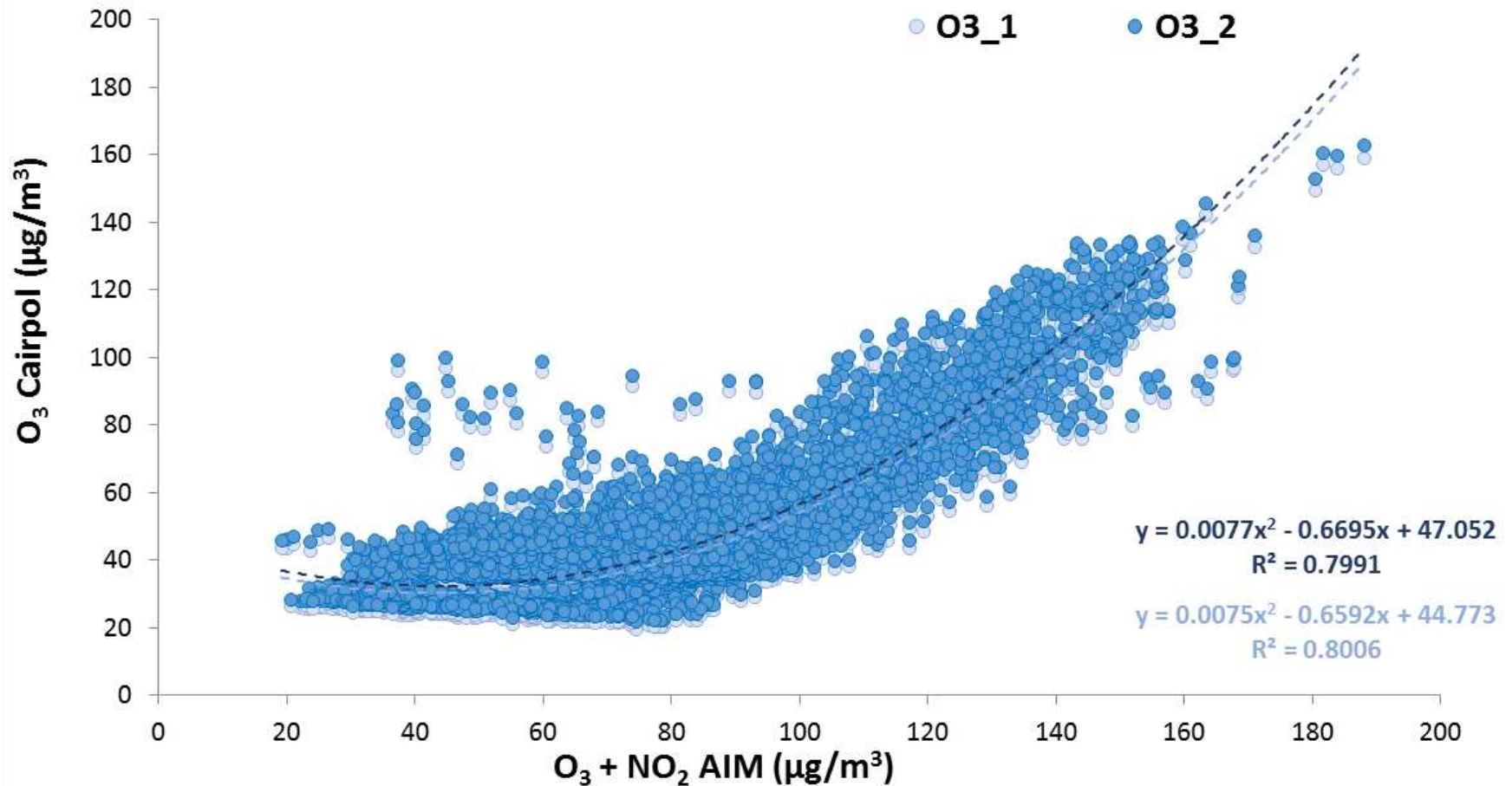
# Senzory SO<sub>2</sub> a CO nesouměřily v párech

## *testovací období konec 11/2017 - konec 09/2018*

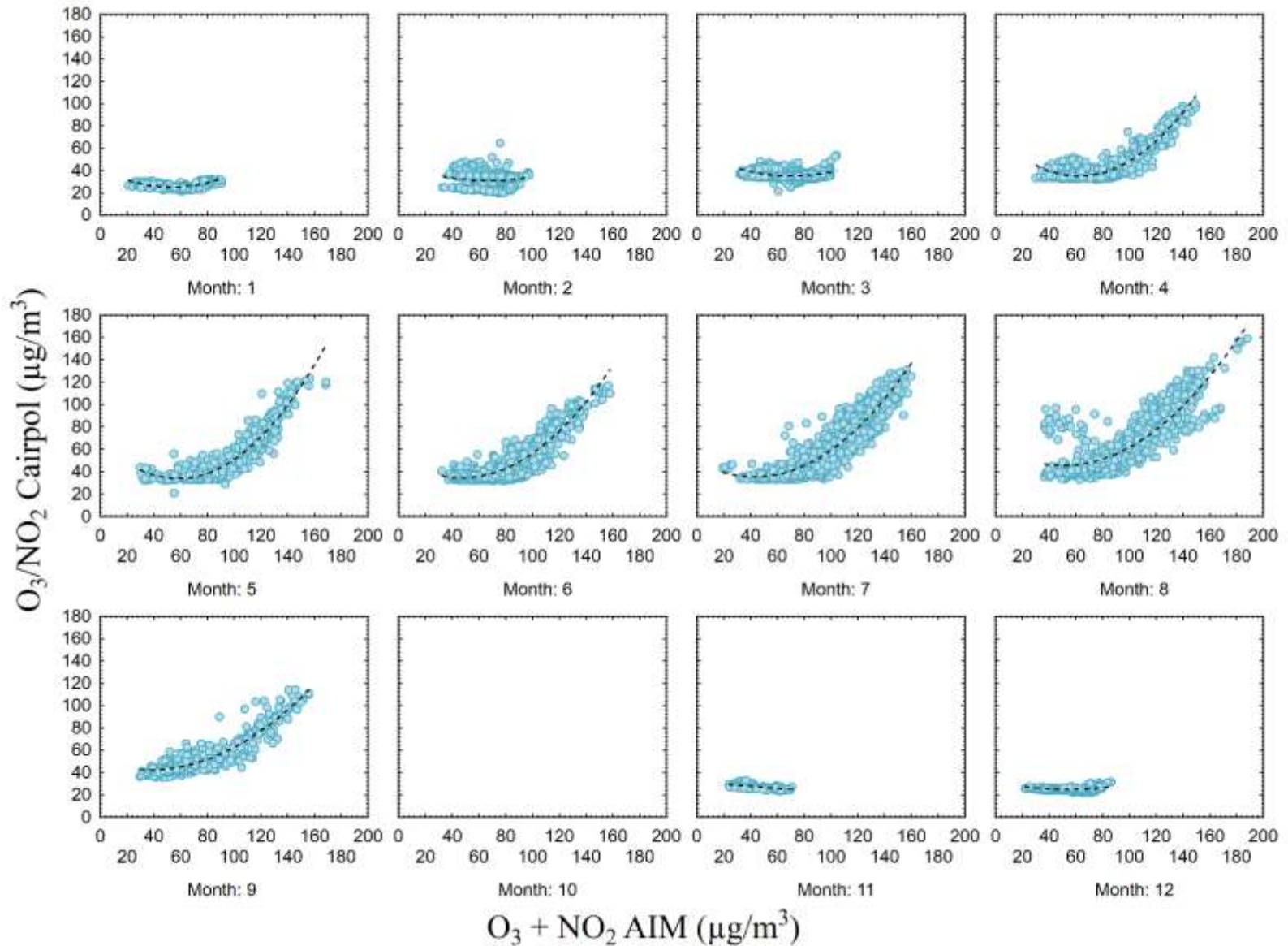
Measurement	Analyzer	N	Mean	Min	Max	SD	SE
SO <sub>2</sub> _1 (µg/m <sup>3</sup> )	Cairclip	7031	255.62	119.87	904.42	121.56	1.45
SO <sub>2</sub> _2 (µg/m <sup>3</sup> )	Cairclip	7029	61.90	0.00	500.64	80.44	0.96
SO <sub>2</sub> AIM (µg/m <sup>3</sup> )	<b>T100</b>	<b>6885</b>	<b>4.45</b>	<b>1.30</b>	<b>70.60</b>	<b>4.52</b>	<b>0.05</b>
NO <sub>2</sub> _1 (µg/m <sup>3</sup> )	Cairclip	7031	58.31	33.08	169.04	20.34	0.24
NO <sub>2</sub> _2 (µg/m <sup>3</sup> )	Cairclip	7031	56.52	31.58	167.00	20.46	0.24
NO <sub>2</sub> AIM (µg/m <sup>3</sup> )	<b>T200</b>	<b>6936</b>	<b>1.59</b>	<b>0.60</b>	<b>56.40</b>	<b>3.05</b>	<b>0.04</b>
O <sub>3</sub> /NO <sub>2</sub> _1 (µg/m <sup>3</sup> )	Cairclip	7031	44.58	19.78	165.09	21.90	0.26
O <sub>3</sub> /NO <sub>2</sub> _2 (µg/m <sup>3</sup> )	Cairclip	7031	46.86	21.78	168.71	22.26	0.27
O <sub>3</sub> AIM (µg/m <sup>3</sup> )	<b>T400</b>	<b>6959</b>	<b>65.01</b>	<b>1.00</b>	<b>181.70</b>	<b>32.07</b>	<b>0.38</b>
CO_1 (µg/m <sup>3</sup> )	Cairclip	7031	2109.33	942.03	7759.15	1054.49	12.58
CO_2 (µg/m <sup>3</sup> )	Cairclip	7031	14260.29	1093.22	26214.02	8330.75	99.35

# Cairclip O<sub>3</sub>/NO<sub>2</sub>

*testovací období konec 11/2017 – konec 09/2018*



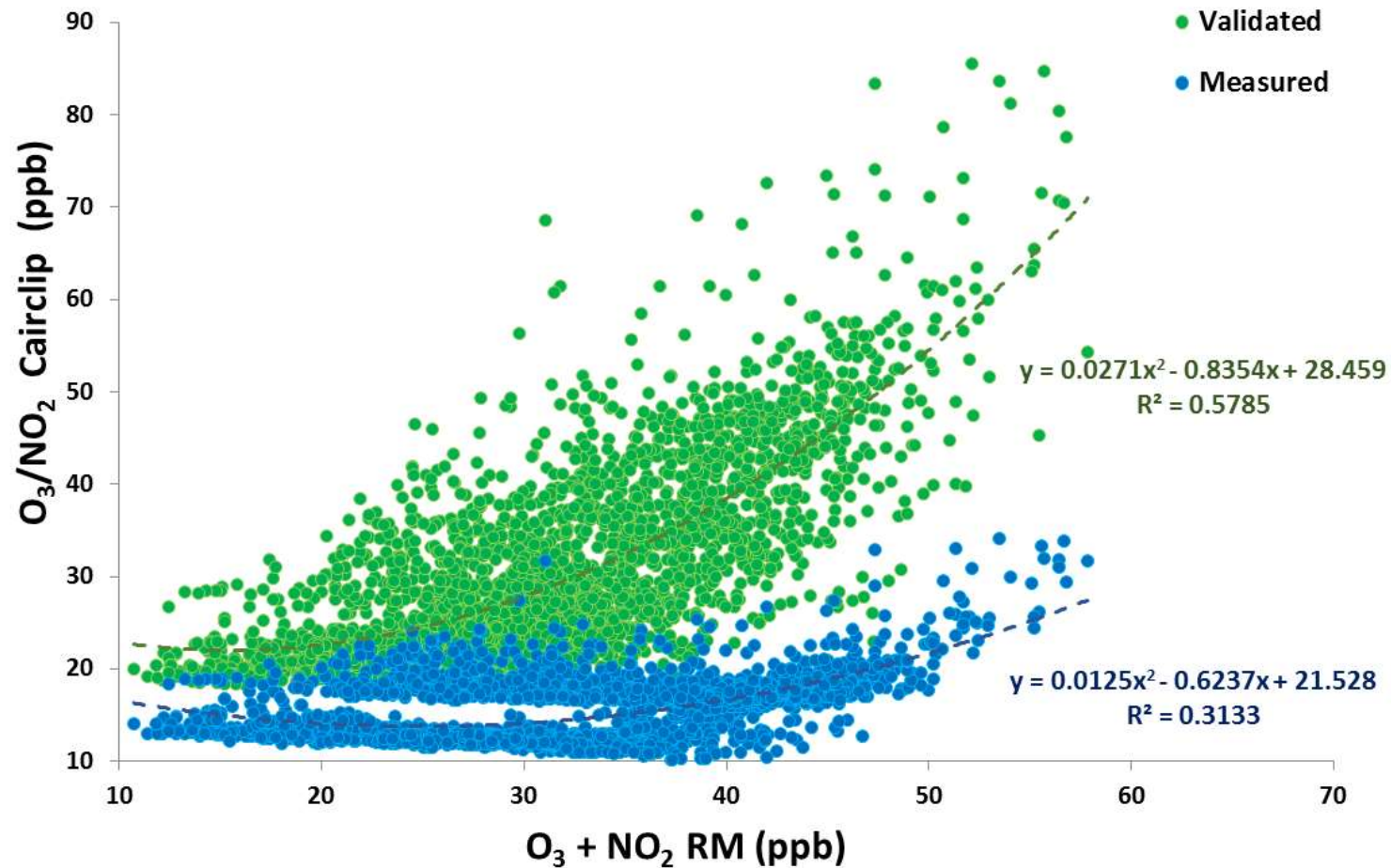
# Průběh měření $O_3/NO_2$ v jednotlivých měsících





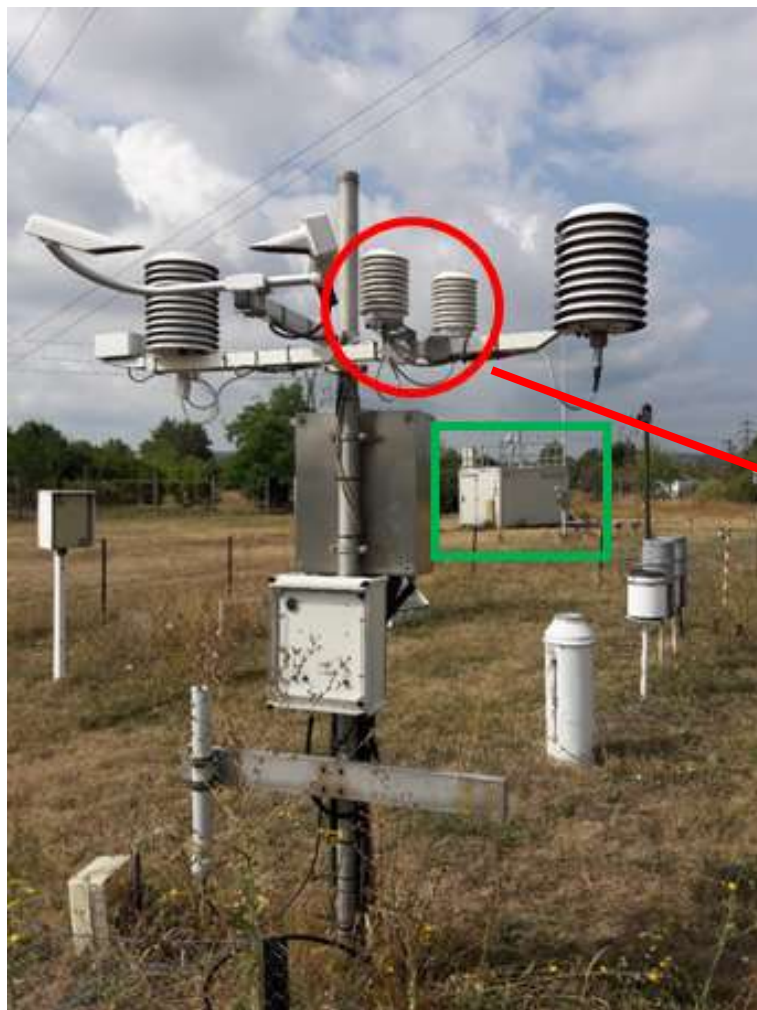
# Cairclip O<sub>3</sub>/NO<sub>2</sub> – měřené vs. validované hodnoty

*zimní období (konec 11/2017 - zač. 04/2018)*



# Sada Vaisala AQT420 (FIN): NO<sub>2</sub>, SO<sub>2</sub>, CO, O<sub>3</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>

## *Testovací období 09/2017 – konec 05/2018*



- Nový kompaktní senzor Vaisala AQT420 s integrovaným čidlem atm. tlaku, teploty a relativní vlhkosti vzduchu

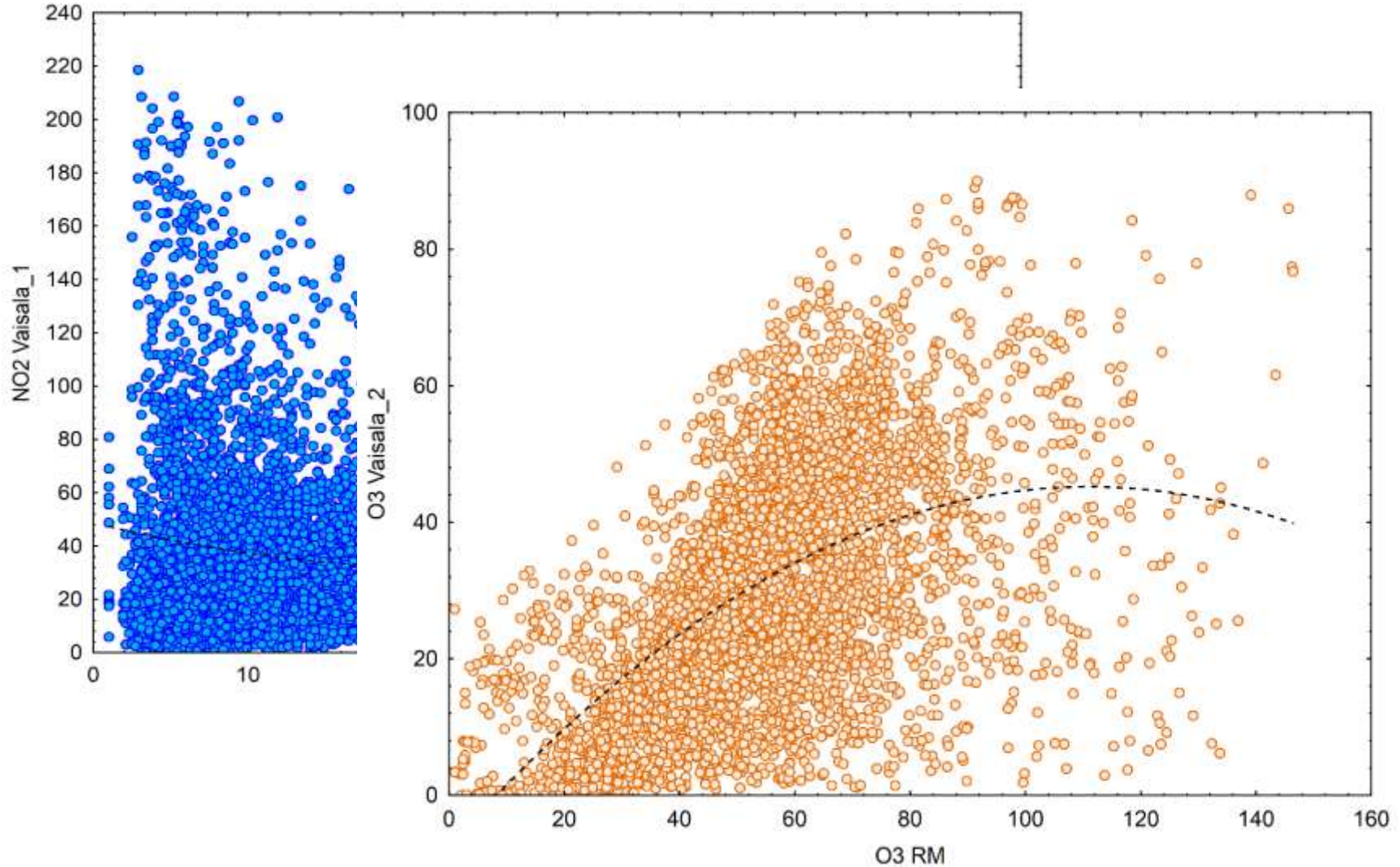


**Sada Vaisala AQT420****Testovací období 09/2017 – konec 05/2018**

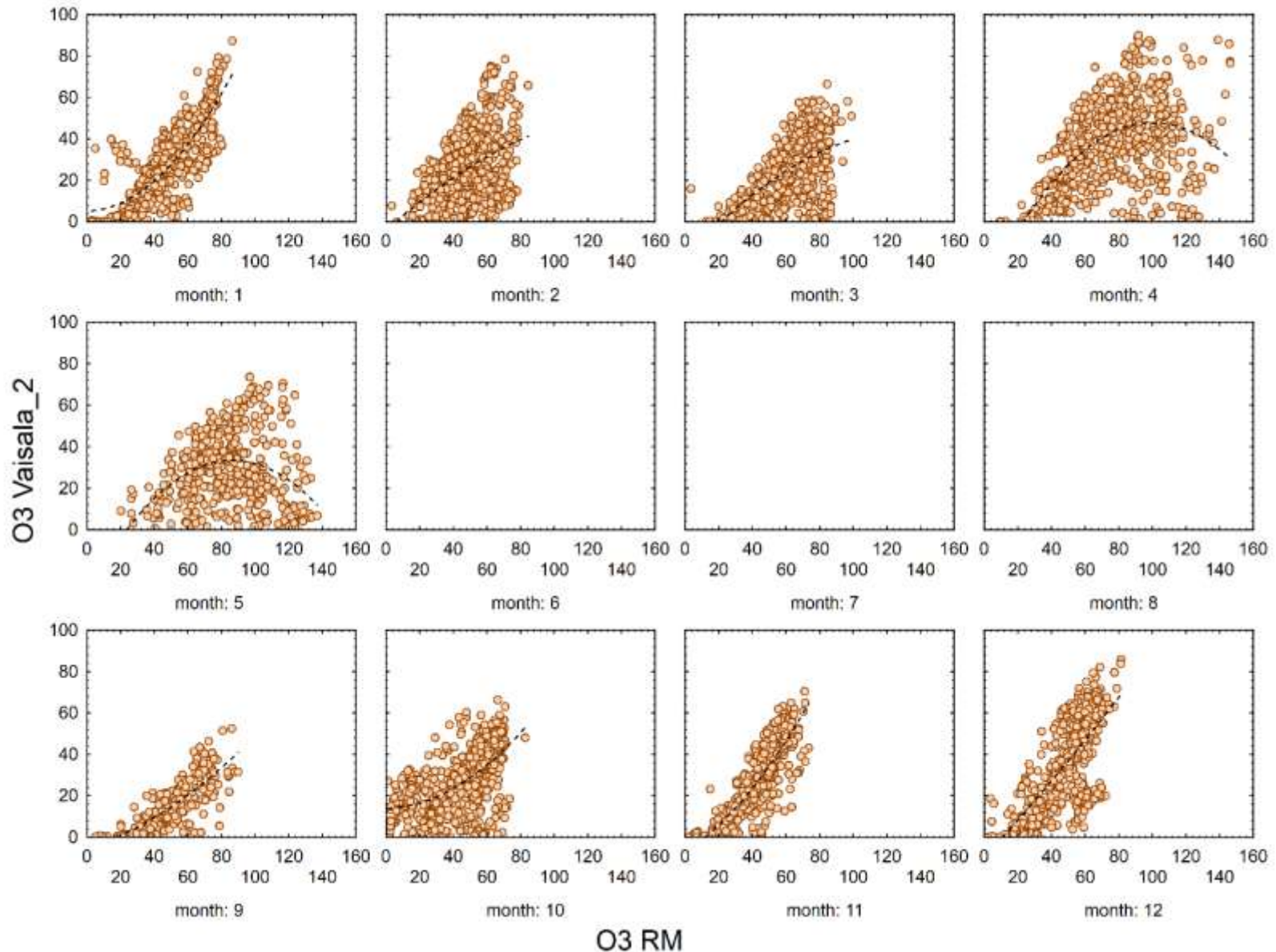
Variable	N valid	Average	Min	Max	St. Dev.
NO2_Vai1	5886	36.56	0.00	218.67	31.59
NO2_Vai2	5600	26.28	0.00	145.35	20.58
NO2_RM	5614	13.55	1.00	55.70	8.19
SO2_Vai1	5710	79.13	0.17	365.85	66.16
SO2_Vai2	5459	77.00	0.37	420.56	75.73
SO2_RM	5443	4.63	1.30	92.40	4.63
CO_Vai1	5899	0.19	0.08	0.57	0.06
CO_Vai2	5896	0.16	0.01	0.60	0.07
O3_Vai1	4810	36.39	0.00	127.35	27.16
O3_Vai2	4516	28.80	0.00	90.01	18.44
O3_RM	4599	53.33	1.00	146.40	23.72
PM2.5_Vai1	5897	1.47	0.10	23.99	1.91
PM2.5_Vai2	5897	0.76	0.10	12.31	1.36
PM2_5_RM	5897	17.16	1.00	101.00	14.74
PM10_Vai1	5885	8.65	0.10	618.98	38.61
PM10_Vai2	5885	10.46	0.10	974.22	55.75
PM10_RM	5885	23.81	1.00	167.00	20.03

# Sada Vaisala AQT420

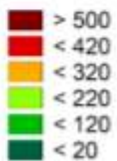
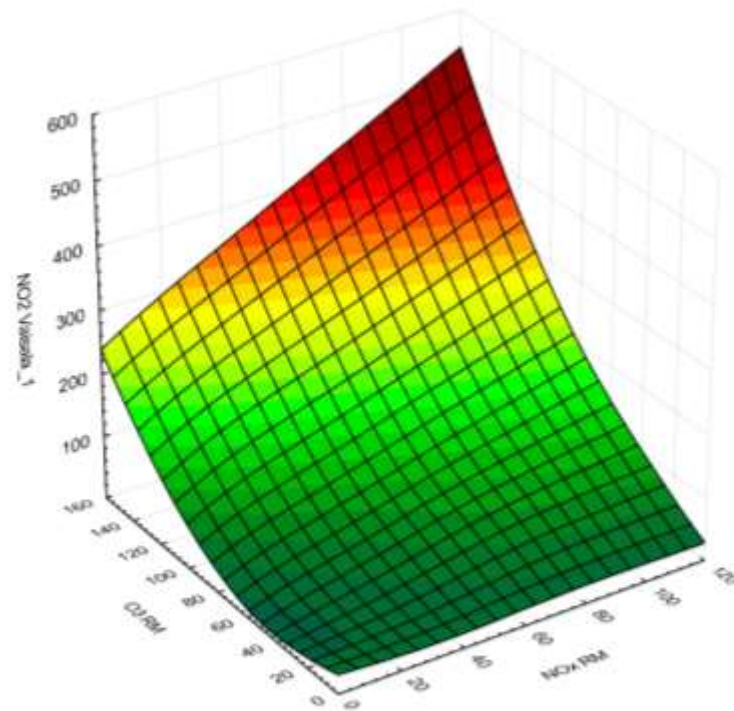
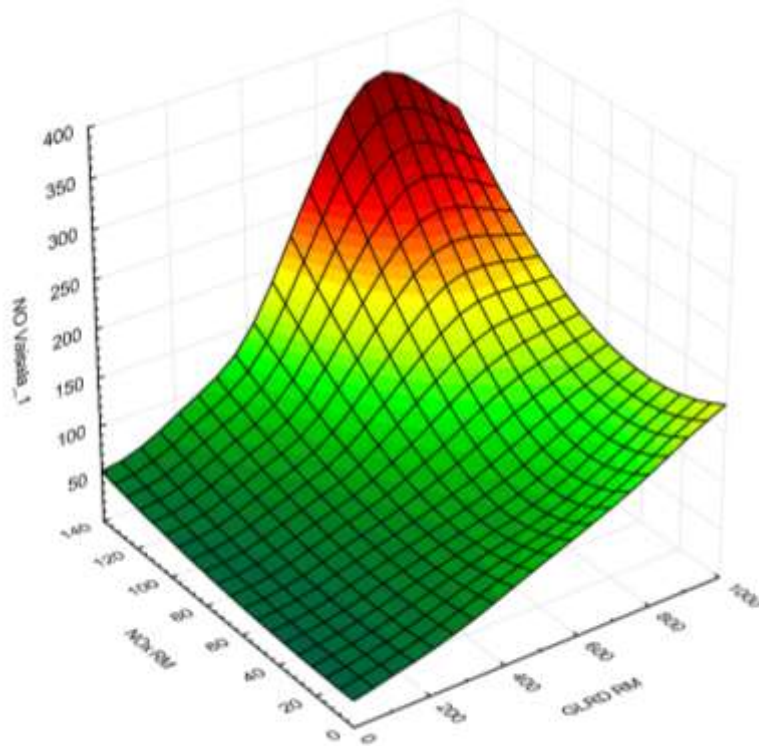
*Testovací období 09/2017 – konec 05/2018*



# Průběh O<sub>3</sub> v jednotlivých měsících



# Vliv fotochemických procesů a interference plynných látek



# Plantower PMS 7003 (CHN): PM<sub>1</sub>, PM<sub>2.5</sub> a PM<sub>10</sub>

## Testovací období 03/2018 – konec 09/2018



PMS5003



PMS7003



Optický čítač částic  
Plantower PMS 7003

# Plantower PMS 7003 (CHN)

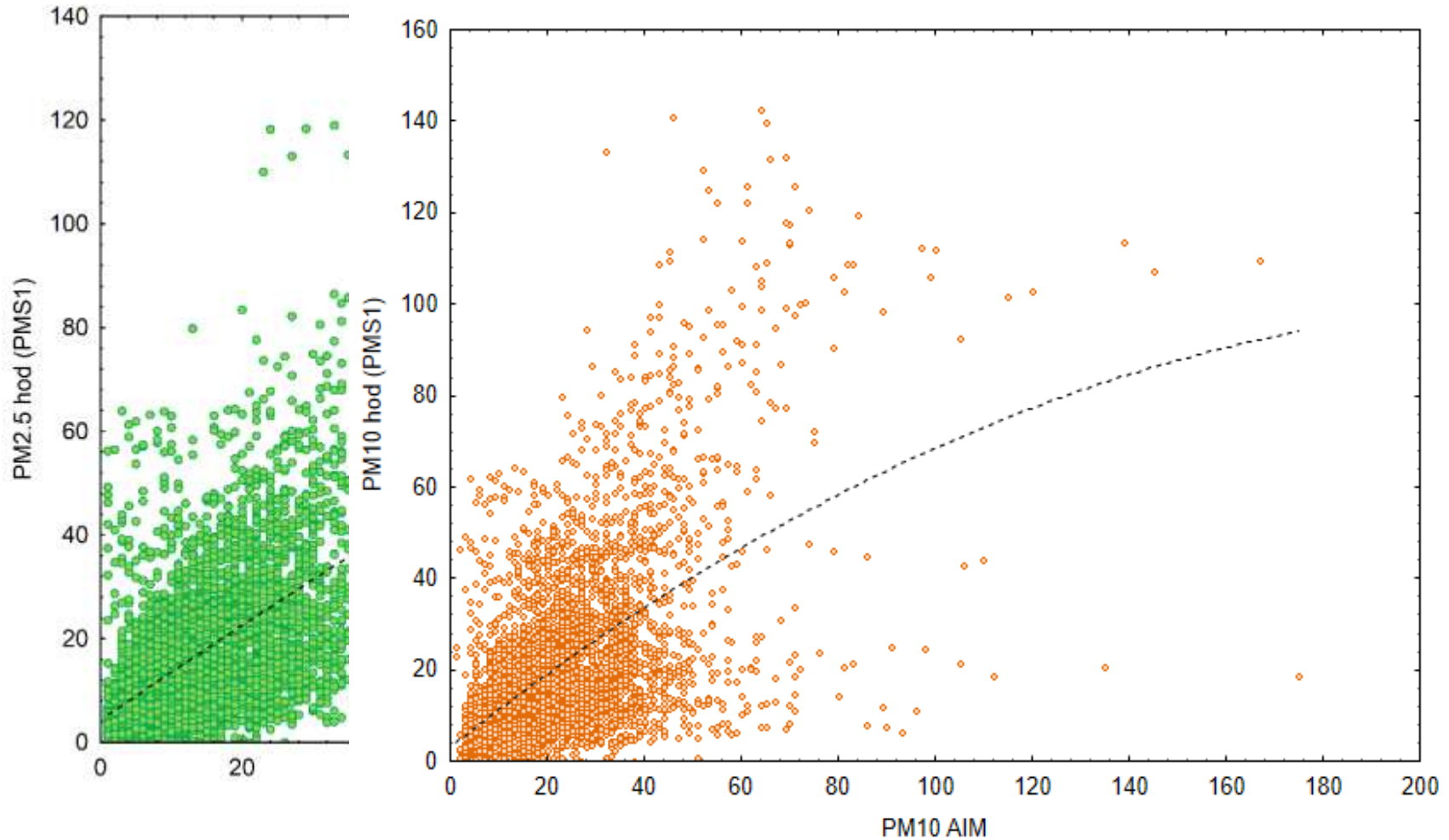
*Testovací období 03/2018 – konec 09/2018*

Variable	N valid	Average	Min	Max	St. Dev.
PM01_hod	4778	13.22	0.00	101.00	11.09
GM01_hod	4778	11.92	0.00	74.50	9.69
PM2.5_hod	4778	18.75	0.00	119.02	16.71
GM2.5_hod	4778	17.55	0.00	117.17	15.11
<b>PM2.5_AIM</b>	<b>4844</b>	<b>16.30</b>	<b>1.00</b>	<b>134.00</b>	<b>10.68</b>
PM10_hod	4778	20.57	0.02	142.42	18.87
GM10_hod	4778	19.38	0.00	87.17	15.67
<b>PM10_AIM</b>	<b>4822</b>	<b>23.07</b>	<b>1.00</b>	<b>175.00</b>	<b>14.69</b>

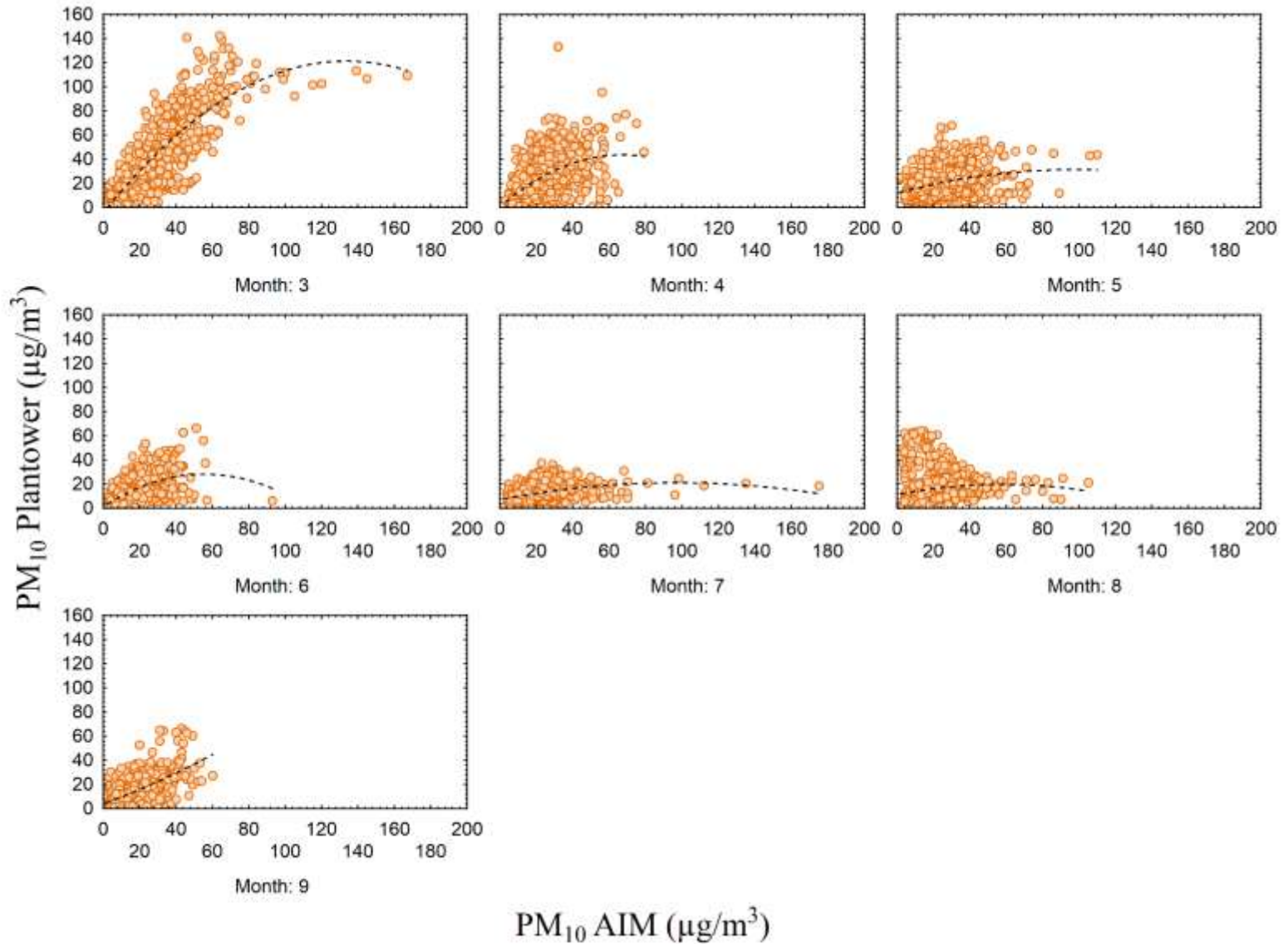


# Plantower PMS 7003 (CHN)

*Testovací období 03/2018 – konec 09/2018*

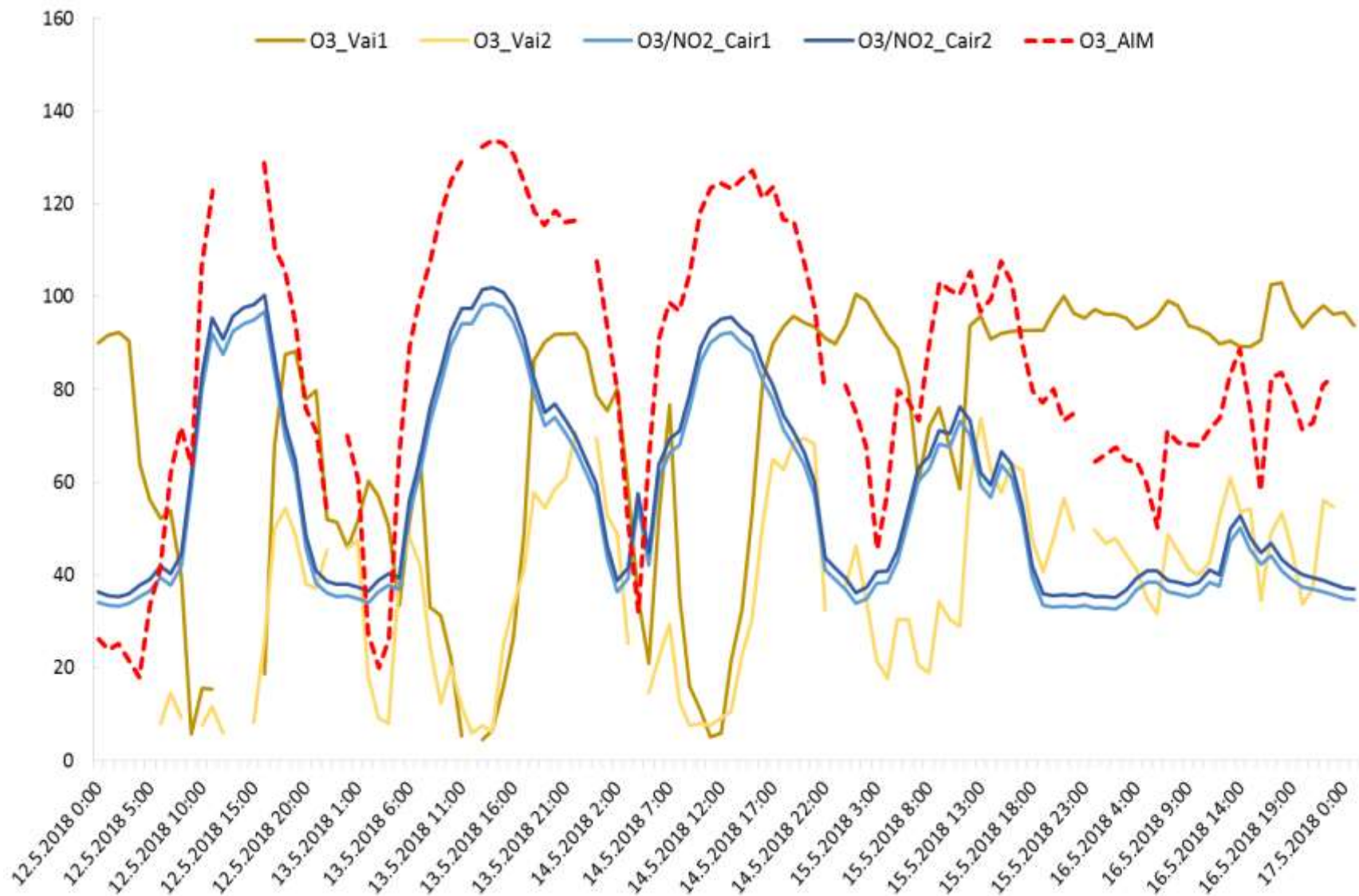


# Průběh PM<sub>2.5</sub> a PM<sub>10</sub> v jednotlivých měsících

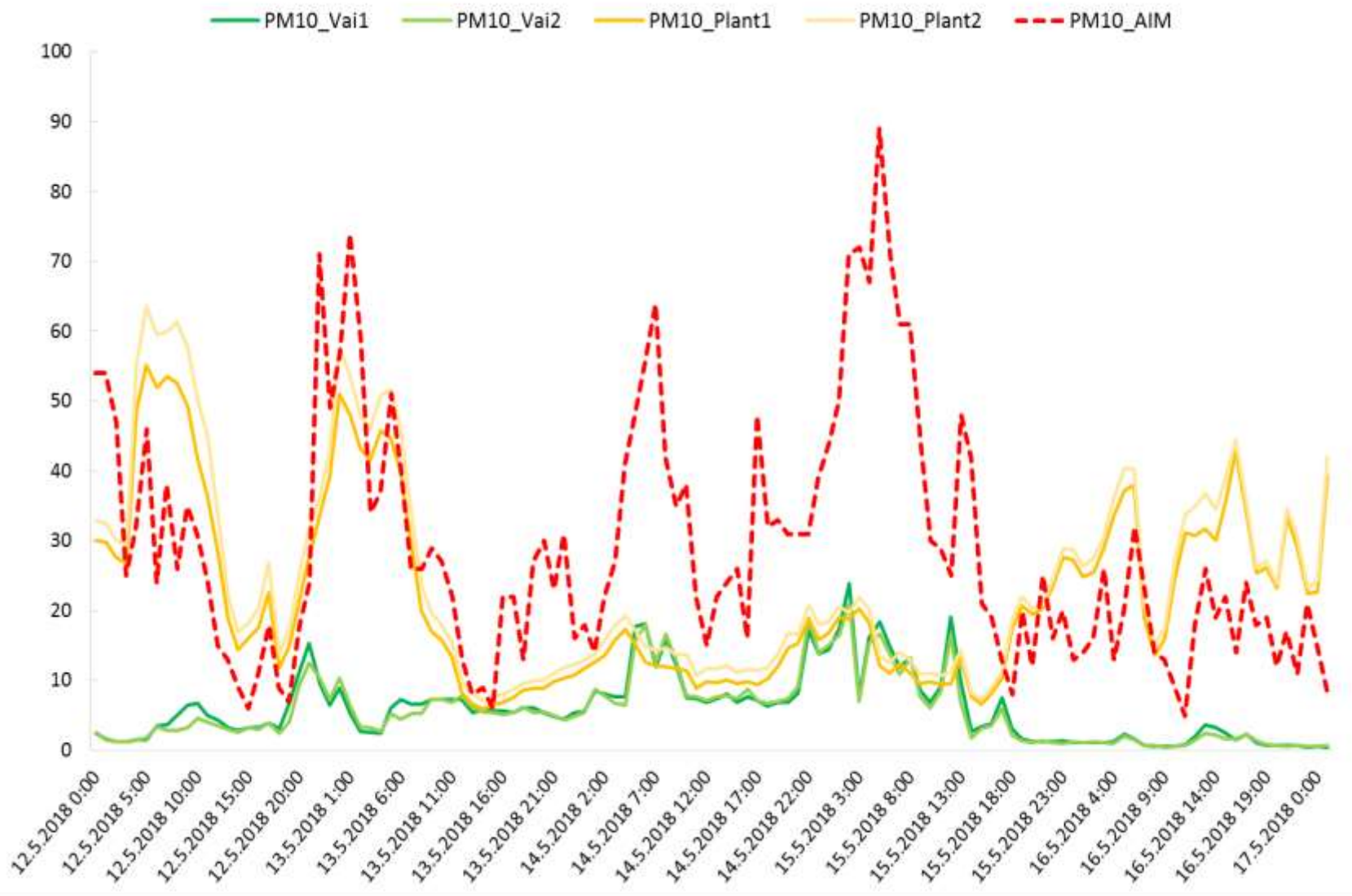


Proměnná	Analyzátor	N	Průměr	Min	Max	SD	SE
NO2_Vai1	AQT400	4003	39.18	0.03	218.67	33.91	0.54
NO2_Vai2	AQT400	3997	29.92	1.13	145.35	22.53	0.36
NO2_Cair1	Cairclip	3824	48.86	33.08	112.41	12.76	0.21
NO2_Cair2	Cairclip	3824	46.95	31.58	110.69	12.96	0.21
NO2_AIM	T200	4003	13.92	1.00	55.70	8.35	0.13
SO2_Vai1	AQT400	3865	77.96	0.17	365.85	64.49	1.04
SO2_Vai2	AQT400	3815	87.51	0.37	420.56	86.01	1.39
SO2_Cair1	Cairclip	3692	197.95	119.87	592.64	66.54	1.10
SO2_Cair2	Cairclip	3692	23.14	0.00	281.34	42.93	0.71
SO2_AIM	T100	3865	5.02	1.30	40.50	4.63	0.07
O3_Vai1	AQT400	3278	35.19	0.00	112.81	26.27	0.46
O3_Vai2	AQT400	3055	31.96	0.00	90.01	18.70	0.34
O3/NO2_Cair1	Cairclip	3137	34.59	20.24	100.38	11.83	0.21
O3/NO2_Cair2	Cairclip	3137	36.56	22.19	102.84	11.95	0.21
O3_AIM	T400	3278	58.19	2.00	146.40	23.59	0.41
CO_Vai1	AQT400	4195	0.20	0.08	0.57	0.07	0.00
CO_Vai2	AQT400	4192	0.17	0.01	0.60	0.08	0.00
CO_Cair1	Cairclip	4087	1.63	0.94	5.03	0.64	0.01
CO_Cair2	Cairclip	4087	9.18	1.09	22.05	7.34	0.11
PM2.5_Vai1	AQT400	4195	1.56	0.10	23.99	1.99	0.03
PM2.5_Vai2	AQT400	4195	0.73	0.10	11.98	1.33	0.02
PM2.5_Plant1 *	PMS7003	1807	25.78	0.00	119.02	21.62	0.51
PM2.5_Plant2 *	PMS7003	1807	24.18	0.00	117.17	19.50	0.46
PM2.5_AIM	MP101M	4195	19.25	1.00	101.00	15.75	0.24
PM10_Vai1	AQT400	4194	6.98	0.10	498.76	31.39	0.48
PM10_Vai2	AQT400	4194	7.76	0.10	887.49	43.68	0.67
PM10_Plant1 *	PMS7003	1806	28.69	0.05	142.42	24.83	0.58
PM10_Plant2 *	PMS7003	1806	26.09	0.00	87.17	19.53	0.46

# Porovnání hodinových koncentrací O<sub>3</sub>



# Porovnání hodinových koncentrací PM<sub>10</sub>



# Shrnutí: „Malé senzory ANO, ale s obezřetností vůči kontrole a dalšímu zpracování dat“

- Mimo přiznanou sníženou přesnost měření senzory **je zde vysoké riziko získání zkreslených informací o ČO** (vliv meteorologických podmínek, interference látek!)
- **Kontrola dat je nezbytná!**
- **Verifikace na základní meteorologické faktory (TMP, RH) může být velmi efektivní**
- **Vliv sezónnosti na kvalitu měření**
- **Životnost čidel! (zhruba 1rok)**

**Be aware of data quality!**

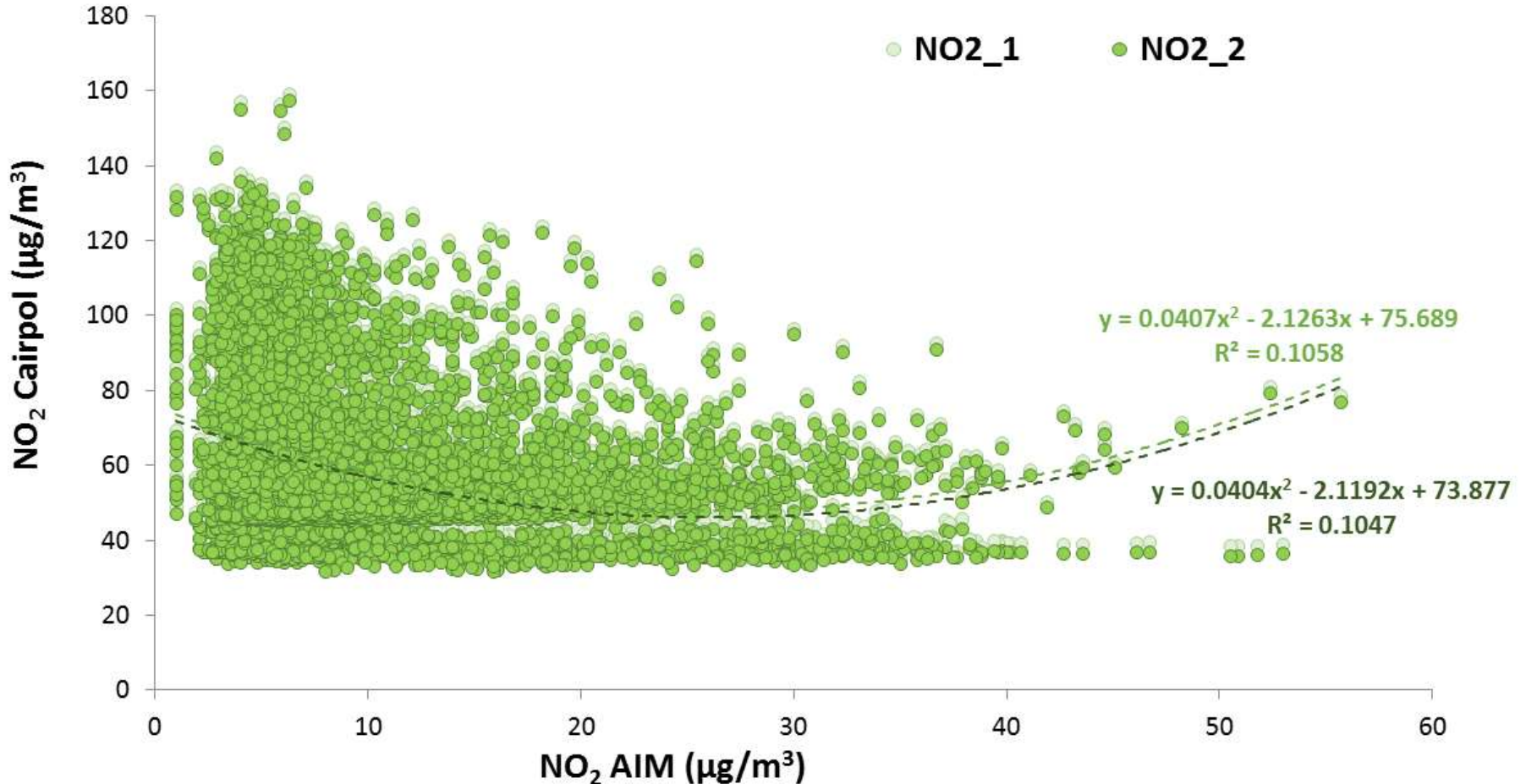


# Díky za pozornost!



# Cairclip NO<sub>2</sub>

testovací období konec 11/2017 – konec 09/2018







# O3/NO2



## Technical Data Sheet CairClip O<sub>3</sub>-NO<sub>2</sub>

(document prone to modifications)

Range	0-250 ppb (0 - 240 ppb analog)
Limit of detection <sup>(1,2)</sup>	20 ppb
Repeatability at zero <sup>(1,2)</sup>	+/- 7 ppb
Repeatability at 40 % of range <sup>(1,2)</sup>	+/- 15 %
Linearity <sup>(1,2)</sup>	< 10%
Uncertainty	< 30% <sup>(1,2)</sup>
Short term zero drift <sup>(1,2,4)</sup>	< 5 ppb/24 H
Short term span drift <sup>(1,2,4)</sup>	< 1% FS <sup>(3)</sup> /24 H
Long term zero drift <sup>(1,2,4)</sup>	< 10 ppb/1 month
Long term span drift <sup>(1,2,4)</sup>	< 2% FS <sup>(3)</sup> /1 month
Rise time (T10-90) <sup>(1,2)</sup>	< 90s (180s if large variation of RH)
Fall time (T10-90) <sup>(1,2)</sup>	< 90s (180s if large variation of RH)
Effect of interfering species <sup>(1)</sup>	Cl <sub>2</sub> : around 80% Reduced sulphur compounds : negative interference
Temperature effect on sensitivity <sup>(2)</sup>	< 0.5 % / °C
Temperature effect on zero <sup>(2)</sup>	+/- 50 ppb maximum under operating conditions
Maximum exposure	50 ppb
Annual exposure limit (1 hour average)	780 ppb
Operating conditions	- 20°C to 40°C / 10 to 90% RH non-condensing 1013 mbar +/- 200 mbar
Recommended storage conditions	Temperature: between 5°C and 20°C Air relative humidity: > 15% non-condensing
Power supply <sup>(6)</sup>	5 VDC/200mA (rechargeable by USB via PC or 100V-240V/5V 0.8A-1.0A with adapter)
Communication interface	USB, UART Analog (UART & 4-20 mA / 0-5 V converter)
Dimensions	Diameter: 32 mm - Length: 62mm
Weight	55g
Protection	IP42 (according IEC60529)
Electrical certification	 Conform to UL Std. 61010-1 Certified to CSA Std. C22.2 N° 61010-1 
Parameters Set up / Downloading	CairSoft

<sup>1</sup> According to our operating conditions during tests in laboratory: 20°C +/- 2°C / 30% RH +/- 10% / 1013 mbar +/- 5%

<sup>2</sup> Values possibly affected by exposures to high gradients of concentration

<sup>3</sup> In accordance with the Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe

<sup>4</sup> Full scale continuous exposure

<sup>5</sup> FS = Full Scale

<sup>6</sup> The complete discharge of a device (screen turned off) can lead to a deterioration of its performance

Any use of the sensor not complying with the conditions specified in herein, including exposures, even short ones, to environments other than ambient air, to dry and/or devoid of oxygen air or other atmosphere not composed in majority of air, even during calibration, will invalidate the warranty.

# CO



## Technical DataSheet CairClip CO (preliminary version)

(document prone to modifications)

Range	0 - 20 ppm (0 - 19 ppm analog)
Limit of detection <sup>(1,2)</sup>	0.05 ppm
Repeatability at zero <sup>(1,2)</sup>	+/- 0.05 ppm
Repeatability at 80 % of range <sup>(1,2)</sup>	+/- 15 %
Linearity <sup>(1,2)</sup>	< 10 %
Uncertainty	< 25 % <sup>(1,2)</sup>
Short term zero drift <sup>(1,2,4)</sup>	< 0.2 ppm / 24 H
Short term span drift <sup>(1,2,4)</sup>	< 1 % FS <sup>(3)</sup> / 24 H
Long term zero drift <sup>(1,2,4)</sup>	< 0.4 ppm / 1 month
Long term span drift <sup>(1,2,4)</sup>	< 2 % FS <sup>(3)</sup> / 1 month
Rise time (T10-90) <sup>(1,2)</sup>	< 60 s
Fall time (T10-90) <sup>(1,2)</sup>	< 60 s
Effect of interfering species <sup>(1)</sup>	H <sub>2</sub> < 60% Long term high concentration levels (> CO) of H <sub>2</sub> S, NOx, SO <sub>2</sub> or acid gases may interfere the signal
Temperature effect on sensitivity <sup>(2)</sup>	< 1 % / °C
Temperature effect on zero <sup>(2)</sup>	+/- 1 ppm maximum under operating conditions
Maximum exposure	100 ppm
Annual exposure limit (1 hour average)	9000 ppm
Operating conditions	-20°C to 50°C / 15 to 90 % RH non-condensing 1013 mbar +/- 200 mbar
Recommended storage conditions	Temperature: between 5°C and 20°C Air relative humidity: > 15 % non-condensing
Power supply <sup>(6)</sup>	5 VDC / 200 mA (rechargeable by USB via PC or 100 V-240 V / 5 V 0.8 A-1.0 A with adapter)
Communication interface	USB, UART Analog (UART & 4-20 mA / 0-5 V converter)
Dimensions	Diameter: 32 mm - Length: 62 mm
Weight	55 g
Protection	IP42 (according IEC60529)
Electrical certification	 Conform to UL Std. 61010-1 Certified to CSA Std. C22.2 N° 61010-1 
Parameters Set up / Downloading	CairSoft

<sup>1</sup> According to our operating conditions during tests in laboratory: 20°C +/- 2°C / 30% RH +/- 10% / 1013 mbar +/- 5%

<sup>2</sup> Values possibly affected by exposures to high gradients of concentration

<sup>3</sup> In accordance with the Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe

<sup>4</sup> Full scale continuous exposure

<sup>5</sup> FS = Full Scale

<sup>6</sup> The complete discharge of a device (screen turned off) can lead to a deterioration of its performance

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