



CZECH HYDROMETEOROLOGICAL INSTITUTE



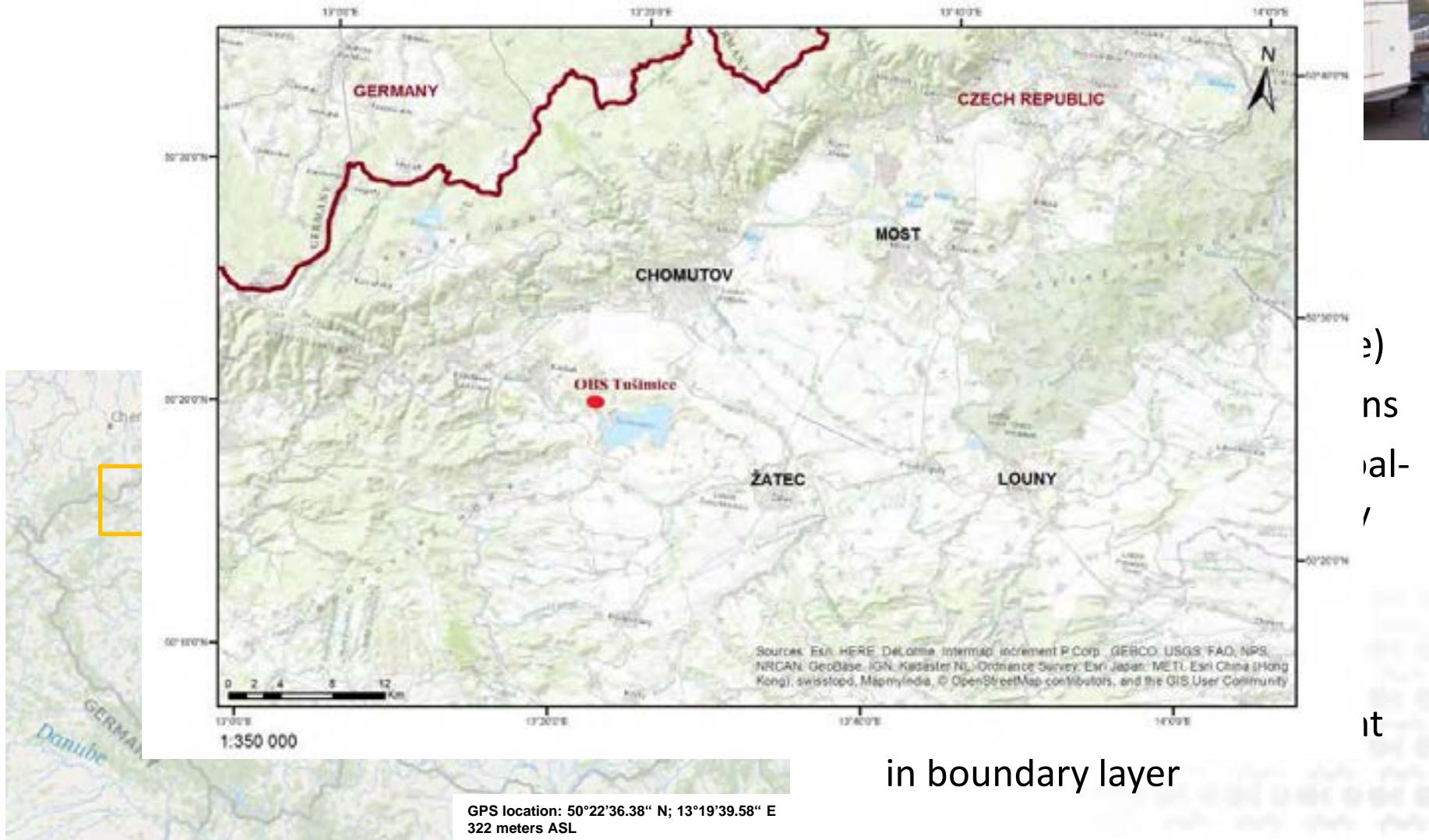
The Use of Microsensors for Real-Time Field Measurement and the Comparison of Cairpol Sensor with Reference Analysers

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Tušimice Observatory (CZ)



in boundary layer

Our focus and potential use of microsensors

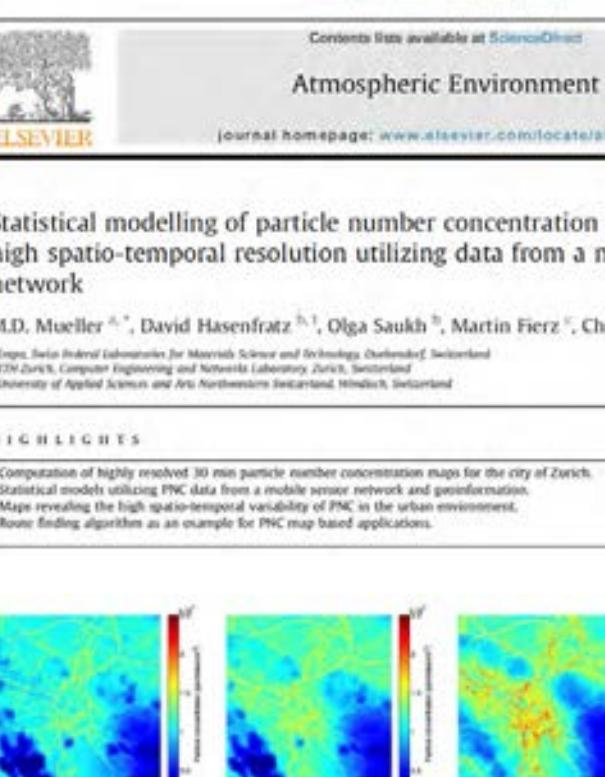
- Focus on **vertical transport of air pollution** (stagnation and normal meteorological conditions)
- Mast meteorological measurement (80 m), SODAR wind profiler (600 m), ceilometer (3 km), LIDAR (in preparation)
- **Use of microsensors for „in motion“ measurement** (in horizontal and vertical scale)
- In cooperation with UAVs producers and operators – Robodrone Industries, s.r.o. and Kelcom International, spol. s.r.o. (CZ)



Use of New Generation Light-weight Sensors

Experience from abroad:

- OpenSense project - ETH Zurich, CH (<http://www.opensense.ethz.ch/trac>)
- DISCOVER project - NASA Houston, USA



Atmospheric Environment
Contents lists available at ScienceDirect
journal homepage: www.elsevier.com/locate/atmosenv

Statistical modelling of particle number concentration high spatio-temporal resolution utilizing data from a n network

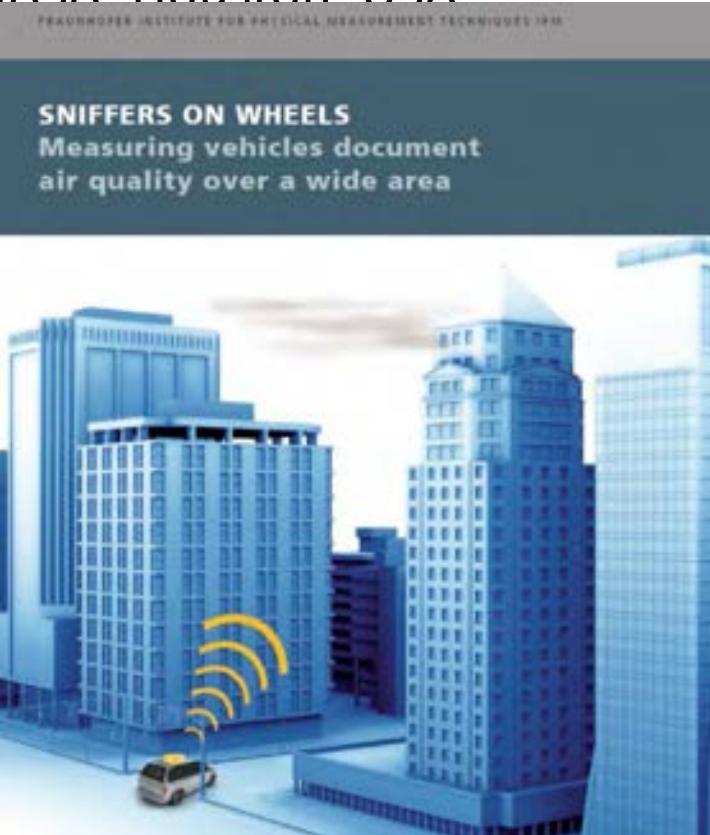
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HIGHLIGHTS

- Computation of highly resolved 30 min particle number concentration maps for the city of Zurich.
- Statistical models utilizing PNC data from a mobile sensor network and geoinformation.
- Maps revealing the high spatio-temporal variability of PNC in the urban environment.
- Route finding algorithm as an example for PNC map based applications.

Modelled ultrafine particle concentrations for Zurich based on the OpenSense measurements of one year (from left to right: spring, summer, winter).



SENSORS ON WHEELS
Measuring vehicles document air quality over a wide area

available sensors for air
trogen dioxide
Giulia Villani ^b, Manuel Aleixandre ^c,

ability (IEE) Air and Climate Unit, Via Ettore Fermi 27-39,
mobile, Italy, Italy

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air pollution in cities

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Characteristics that must be taken into account



- Low weight
- Low cost
- Immediately useable
- Portable
- Battery autonomy
- Internal datalogger
- +++ research purposes



- Usually constructed for the indoor measurement
- ! Air humidity / Temperature ! -> NEED FOR additional data control
- High risk of coincidence and errors
- Higher detection limits
- Lower measurement accuracy
- Limited calibration possibilities
- Limited time of power supply



Testing Light Sensors for UAVs platform



Robodrone



Kingfisher

- Dimensions 1200 x 1400 x 220 mm
- Load capacity up to 5 kg
- Flight duration up to 45 min (25 min with Max. load)
- Max. speed 70 km/h
- Max. altitude 1000 m AGL
- Wind resistance 10 m/s
- Temperature range -10 to +50 °C
- Camera + GPS in real-time, videorecords



Strix

- Load capacity 15 kg
- Flight duration 30 min (15 min with load)



Sparrow

- Load capacity 11 kg
- Flight time 60 min (35 min with Max. load)

Kingfisher - testing flights with particle analyser



Thermography of stack plumes

IR camera PI 450 (Optris)

- range: from -20°C up to 900°C
- spectral range: 7.5 to 13 µm
- weight: 320g
- Usable at ambient temperature up to 70 °C
- Detector with 382 x 288 pixels

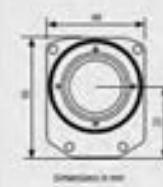
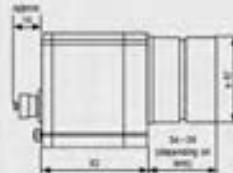


optris® PI 450

INFRARED CAMERA
WITH VERY HIGH OPTICAL RESOLUTION

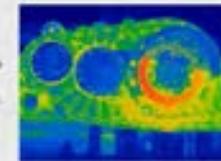
Detection of minimal temperature differences

- The smallest camera in its class (45 x 56 x 90 mm)
- Very good thermal sensitivity at 40 mK
- Thermal image recording in real time at up to 80 Hz
- Interchangeable lenses & industrial accessories
- Lightweight (320 g incl. lens)
- Detector with 382 x 288 pixels
- Usable at ambient temperatures of up to 70 °C without the need for additional cooling
- Includes license-free analysis software and full SDK



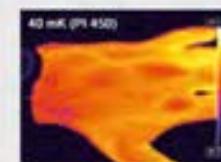
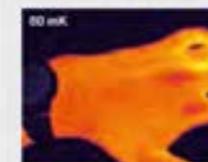
Highest temperature resolution of 40 mK

With an optical resolution of 40 mK, the optris® PI 450 is used for measuring the most subtle temperature differences, e.g. in the quality control of products or in preventive medicine.

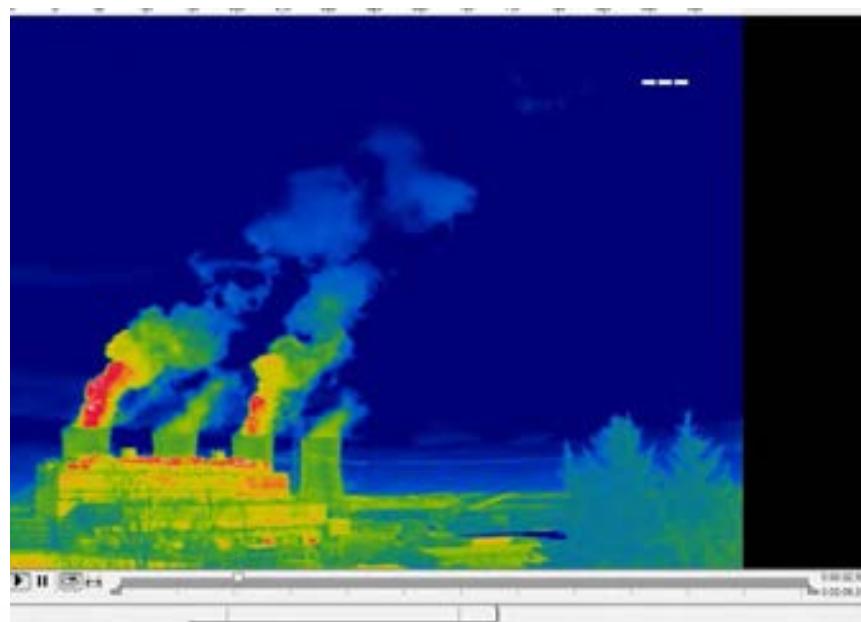


Highest temperature resolution in the medical sector

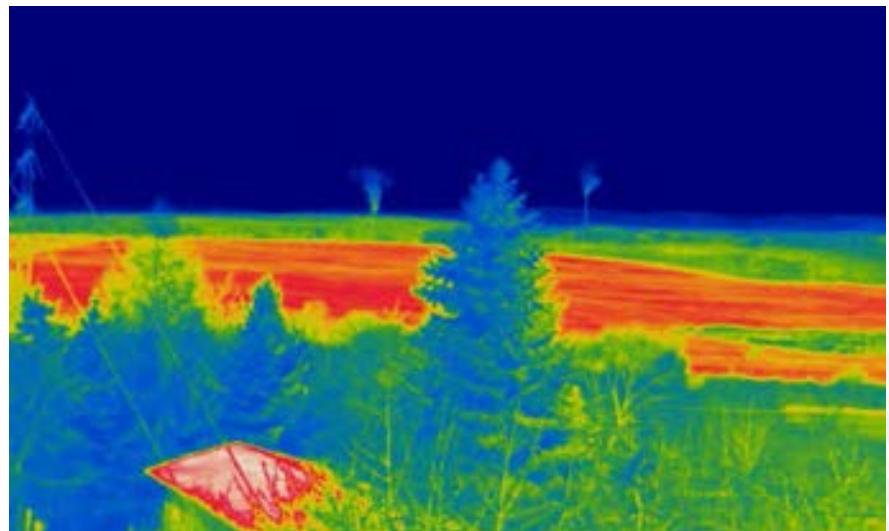
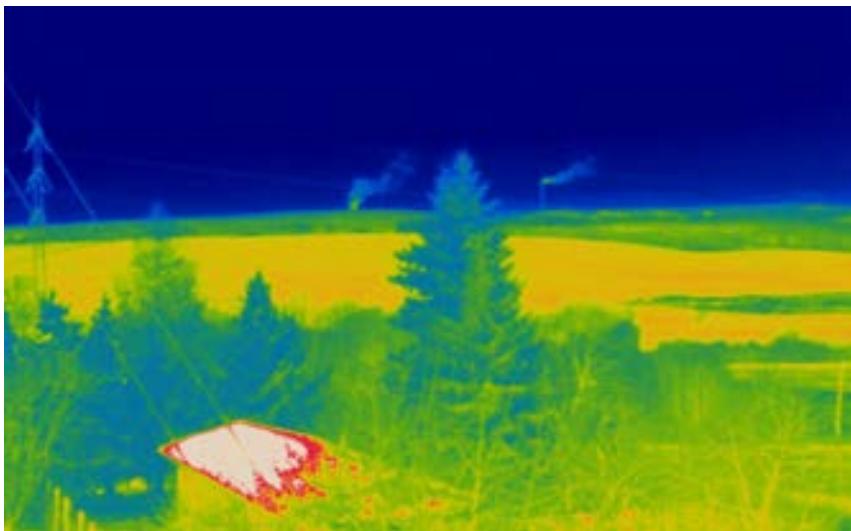
Due to the fine temperature resolution of the optris® PI 450, even veins under the skin can be seen.



Power Plant Tušimice II – Cooling towers



Power Plant Prunéřov I, II – stacks



Cairpol (FR) Light Sensors SO₂, CO₂, NO_x, NO₂ and O₃

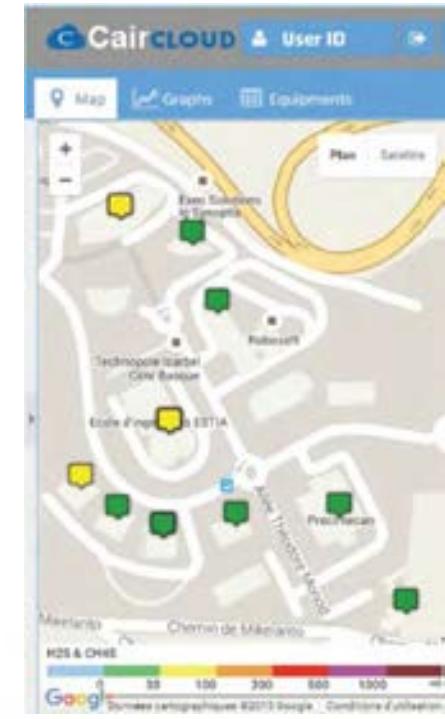
Miniature air quality monitoring sensors network

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 mbar 200 (psi 14,69 mbar 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 mbar 200 (psi 14,69 mbar 2,90)
- Electric standards: CE/UL/CSA N°61010-1; 2008 / EN 61010-1:2001

* Detailed specification per sensor on request

	Ranges :
D ₁ / NO ₂	0-250 ppb
NO ₂	0-250 ppb
CO	0-20 ppm
H ₂ S / CH ₄ S	0-1000 ppb / 0-20 ppm / 0-200 ppm
NH ₃	0-25 ppm
SO ₂	0-1000 ppb
CH ₃ O / Organic solvents	0-1000 ppb
nM VOC	0-16 ppm



Dust Particles Light Sensors



Particle Analyser (GRIMM MINI-LAS 11E, DE)

- PM10, PM2.5 and PM1
- range: from 0.25 to 32 μm
- weight: 2,1 kg

<http://wiki.grimm-aerosol.de/index.php?title=ENVIRO-11E>



Fidas Fly 200 (Palas, DE)

- Ultra-light dust monitor **Fidas Fly 100** integrated into **HORUS flight robot**
- PM10, PM4, PM2.5 and PM1
- range: from 0.18 to 18 μm
from 0.40 to 40 μm
- Weight (Fidas Fly 100): 1,4 kg

<http://www.palas.de/en/product/fidasfly200>



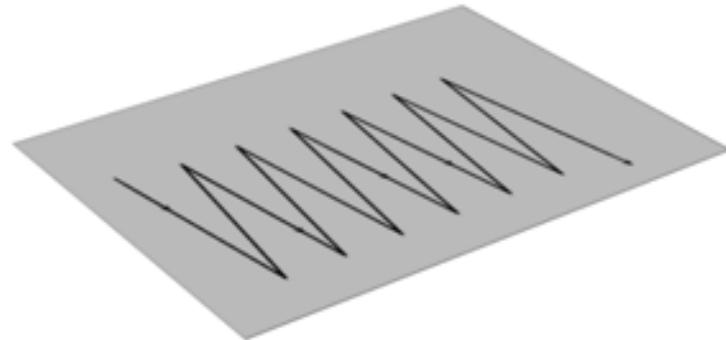
Fidas Frog (Palas, DE)

- PM10, PM4, PM2.5 and PM1
- range: from 0.18 to 40 μm
- weight: 2,1 kg

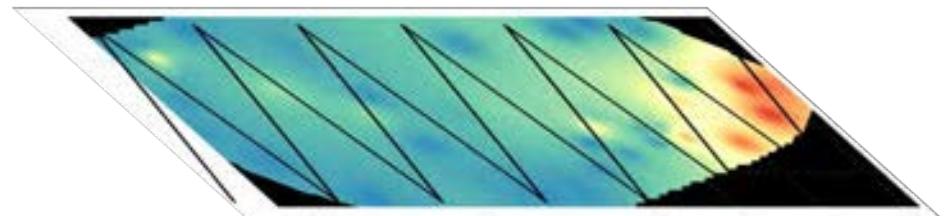
<http://www.palas.de/en/product/fidasfrog>

Flight Scenarios and Data Processing / Visualisation

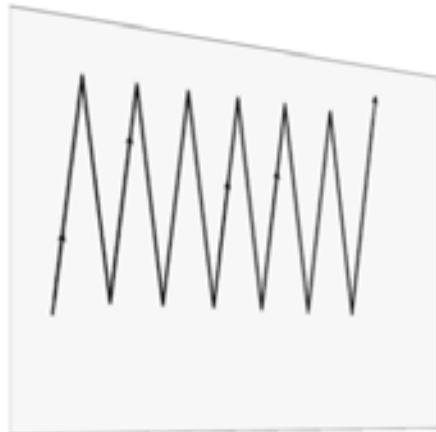
Flight in Horizontal Plane



Measured Values Interpolated



Flight in Vertical Plane



Comparison of CairClip O3 / NO₂ Sensor with Reference Measurement

- **CairClip parameters:**

- Equivalent value of O₃ + NO₂ (ppb)
- Data sampling: 1-min or 15-min
- Range: 0 - 250 ppb
- Detection limit: 20 ppb
- Repeatability in 40% of range: +/-15%
- Uncertainty: < 30%



- **Testing period:**

- At Tušimice Observatory
- 3 month, from June 2015 until September 2015
- Located at the reference height 2 m, in housing (a meteorological shelter)



Reference Measuring Method – NO₂, O₃

Automated Air Quality Monitoring Network of CHMI



TELEDYNE API
Everywhereyoulook™



Analyzers: Teledyn API (California, US)

- **O₃: T400**

Min. range: 0 - 100 ppb

Max. range 0 - 10 ppm

Detection limit: < 0.4 ppb

- **NO₂: T200**

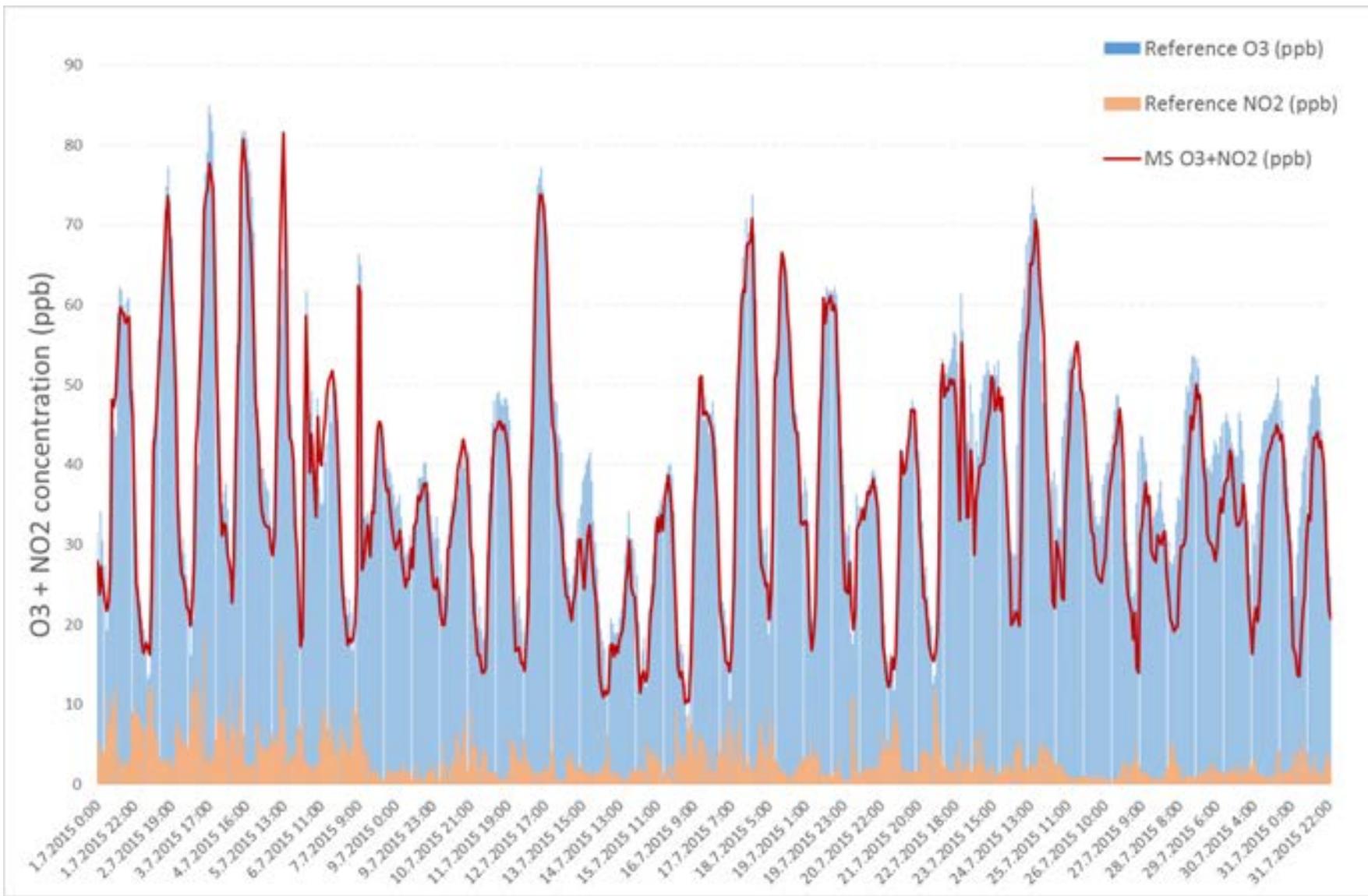
Min. range: 0 - 50 ppb

Max. range: 0 - 20 ppm

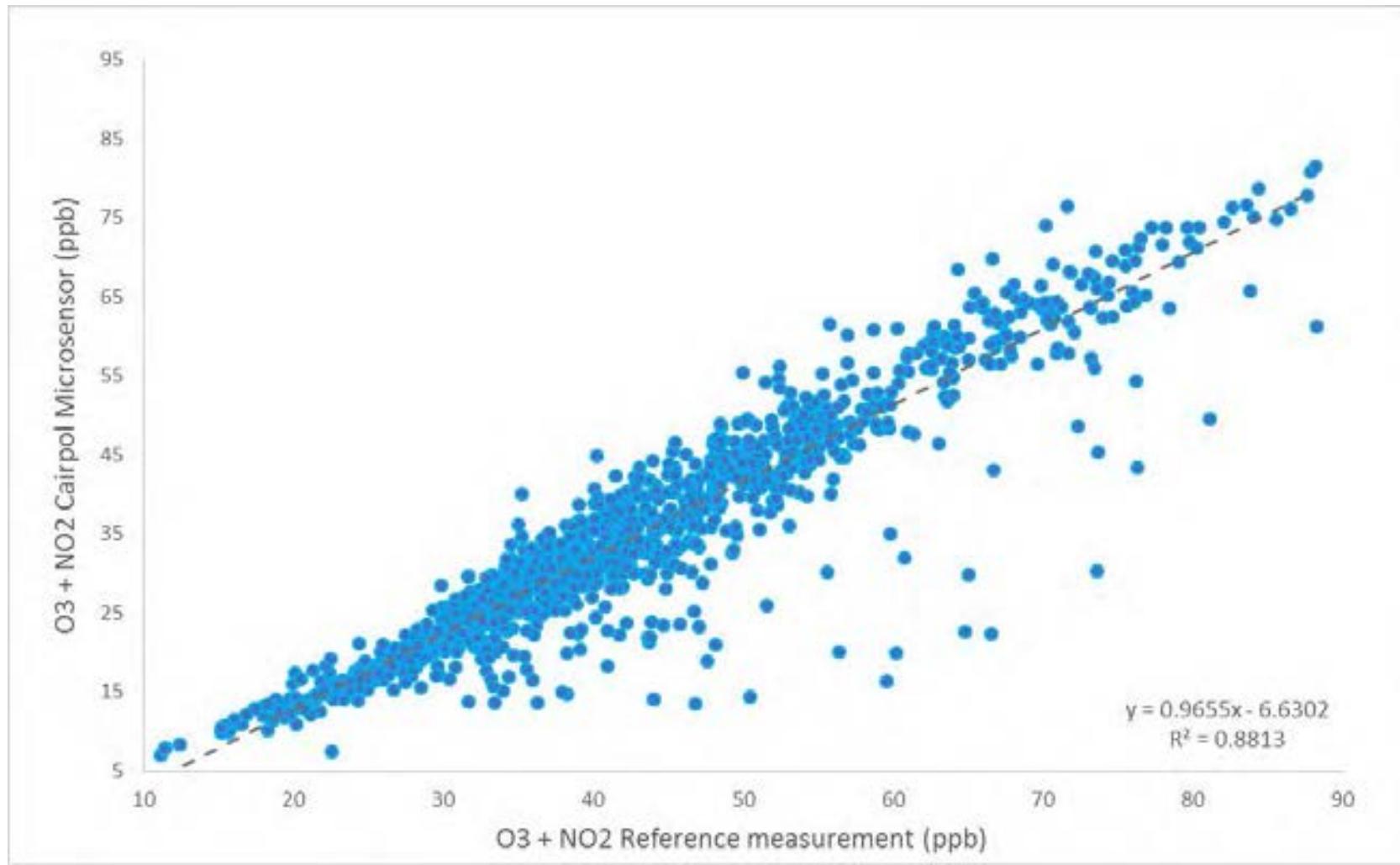
Detection limit: 0.4 ppb

MS vs. Reference Measurement O₃ + NO₂

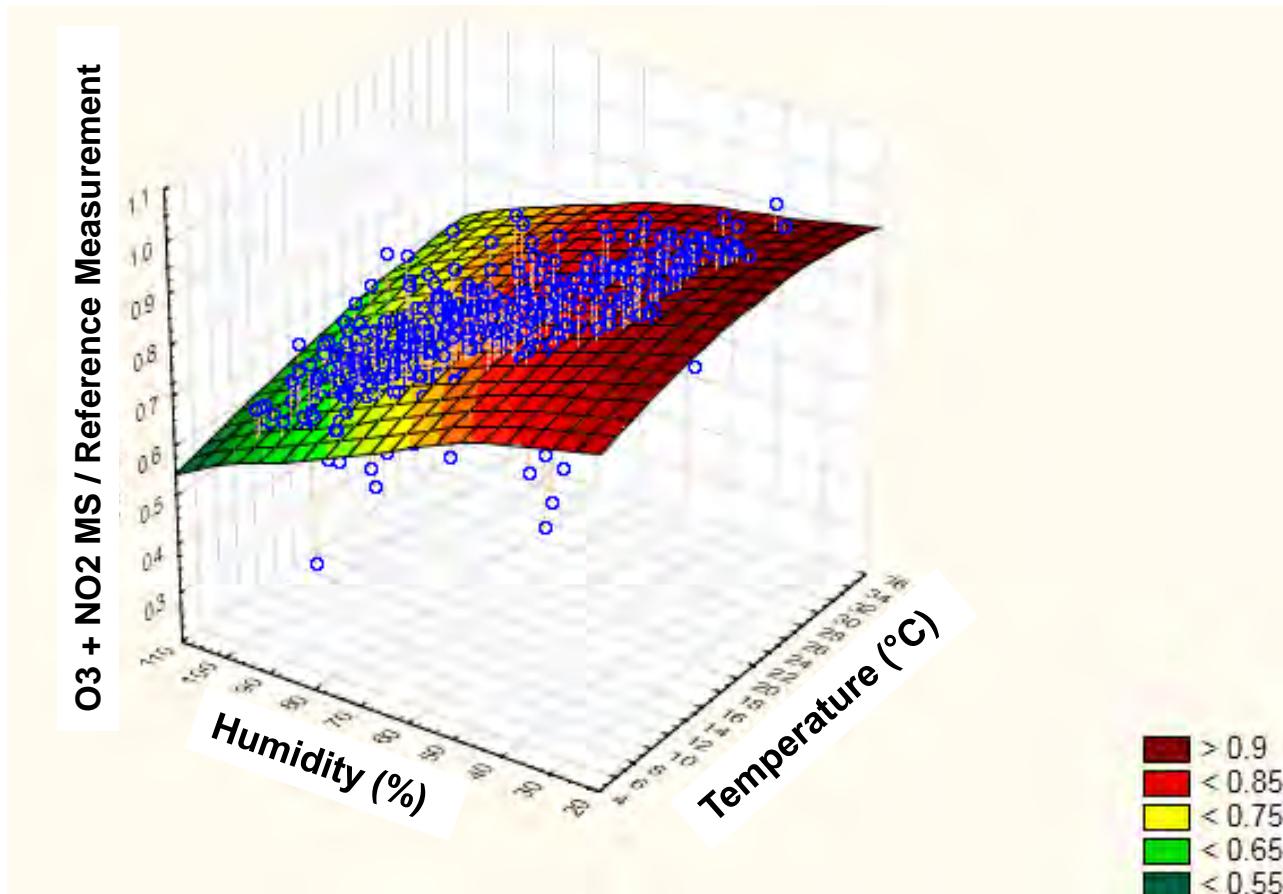
(July 2015)



Strong Correlation between MS and Reference Measurement



Influence of air temperature and humidity on measuring accuracy of MS



- The largest deviations between MS and RM in measured values at low temperature and high relative humidity

Effect of temperature and humidity

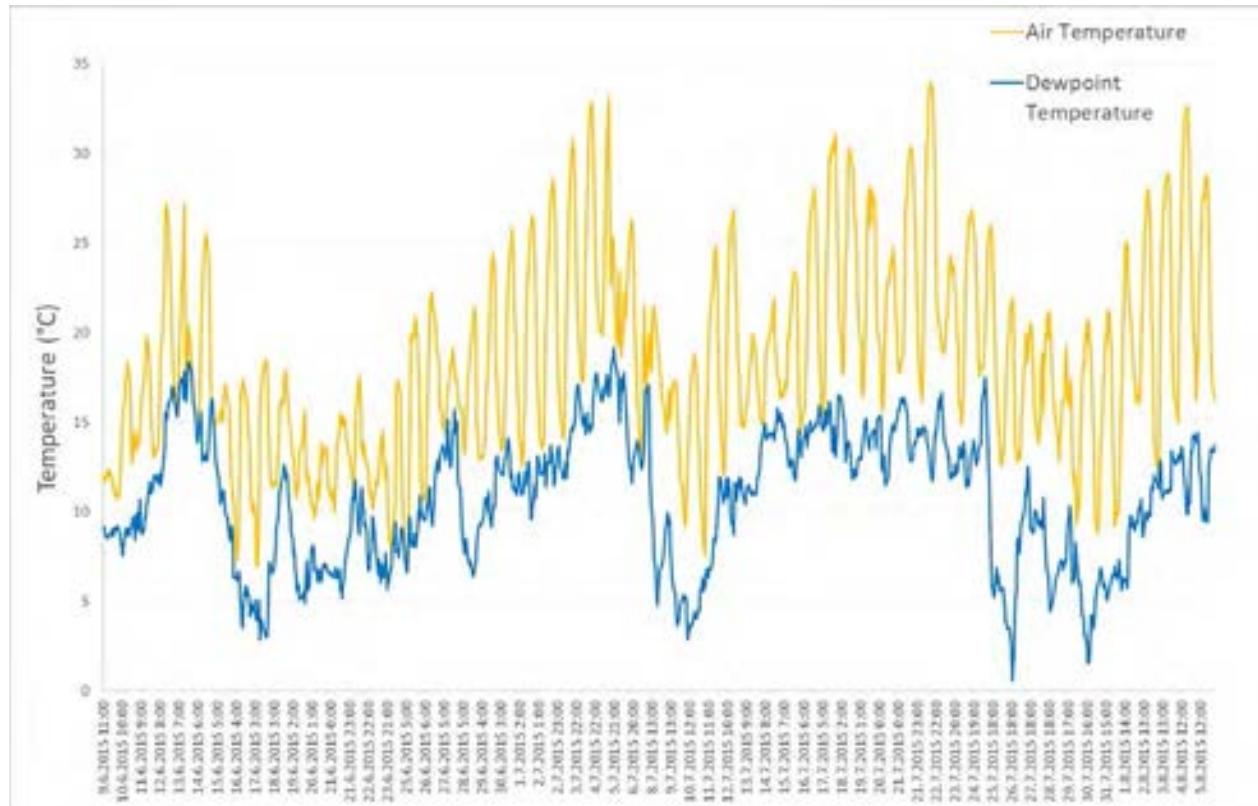
- Dewpoint temperature calculation

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

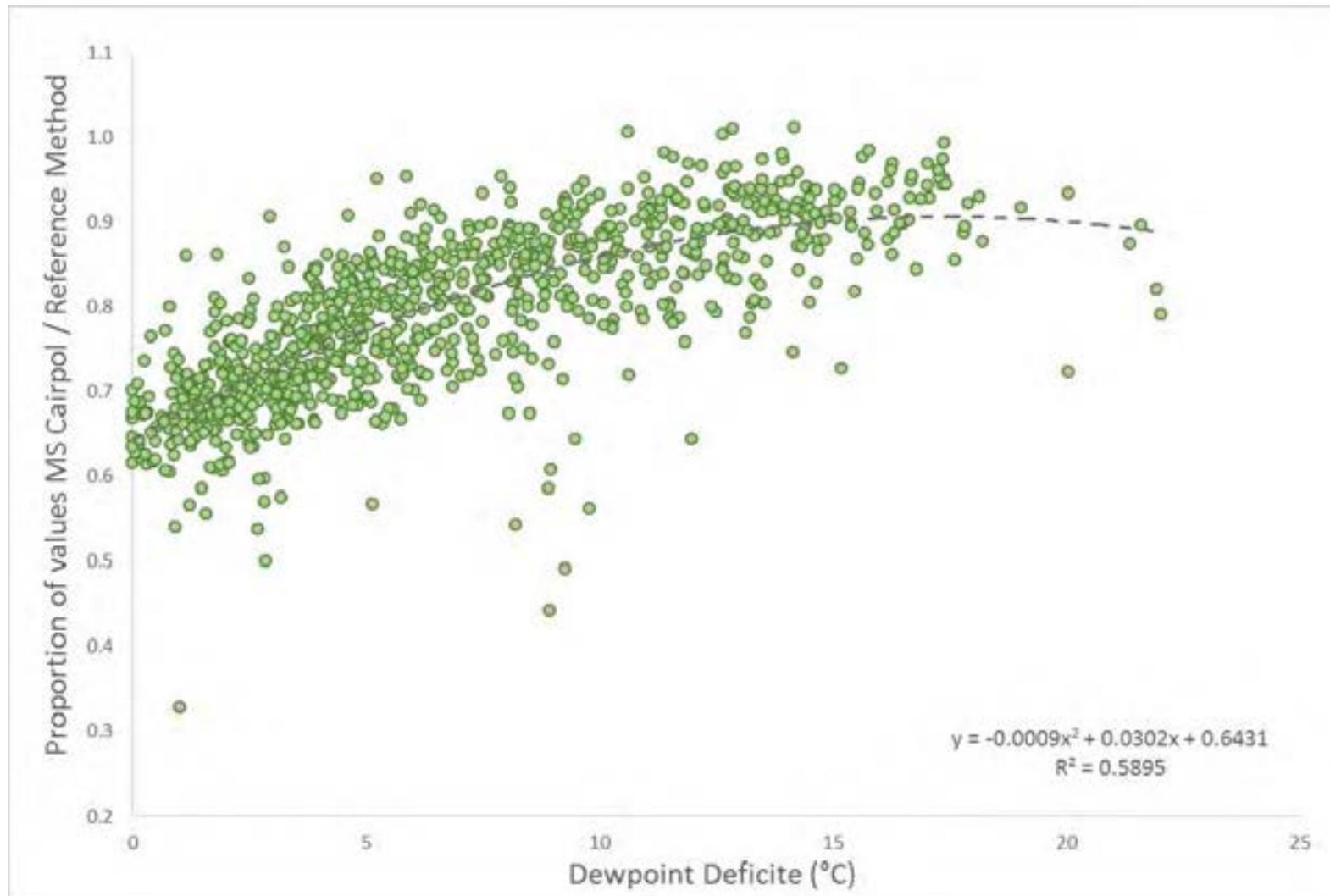
$$A = \left[\ln(RH / 100) \right] + \left[\frac{(17.502 \cdot t)}{(240.97 + t)} \right]$$

- Dewpoint deficit

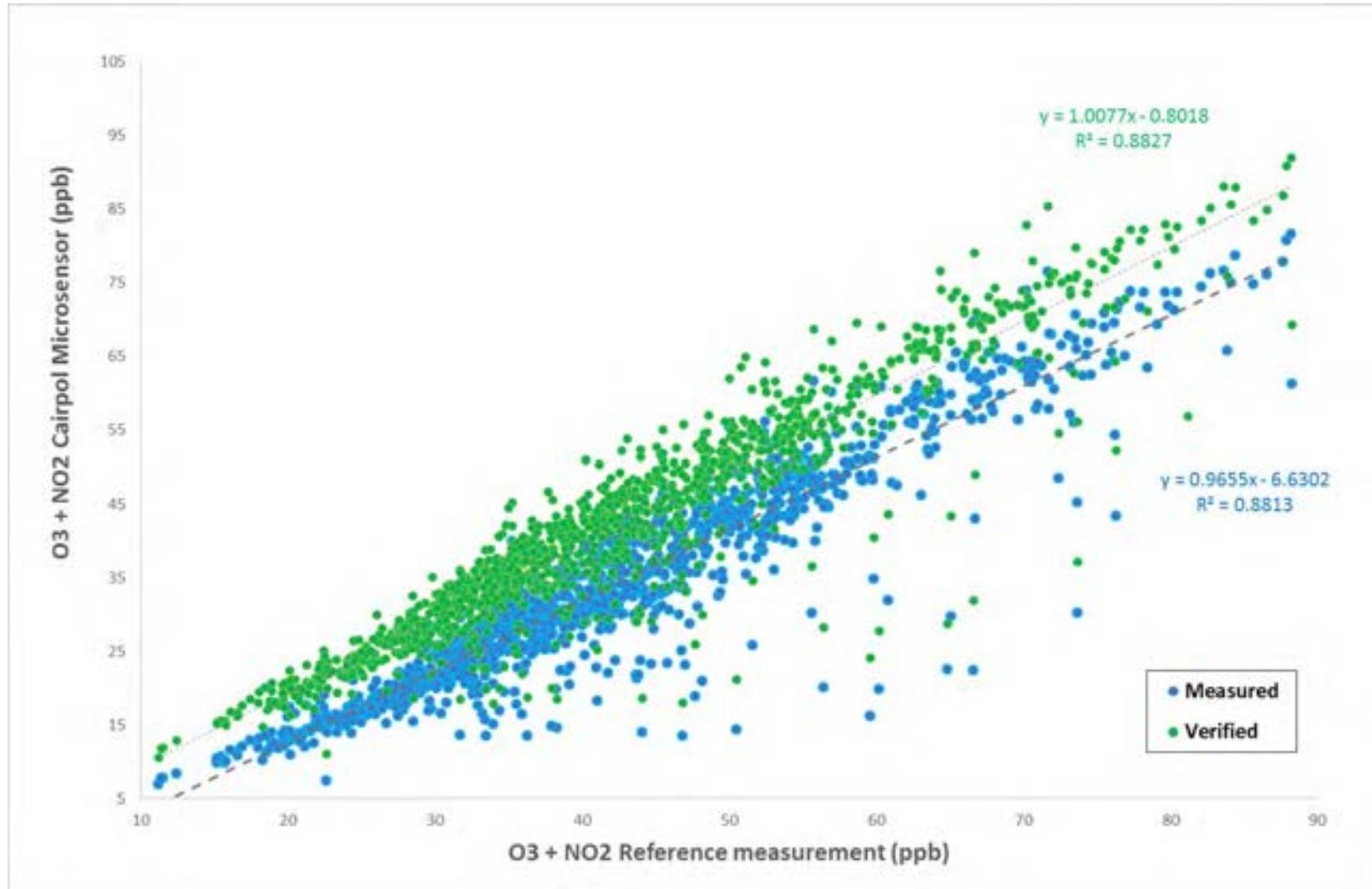
$$T_d \text{ deficit} = T - T_d$$



MS measurement quality increases with decreasing air humidity



Data verification according to Dewpoint Deficite



Summary

Comparative Measurement MS vs. RM

- Accuracy of MS measurement is lower than the accuracy of Reference Analysers
- Cairpol MS O₃ + NO₂ values are highly correlated with reference measurement of O₃ and
- Measurement quality of microsesor depends on meteorological conditions (air temperature and humidity)
- Possibility to validate data according to relevant meteorological variables



Conclusion

- Microsensors are very promising instruments in air quality research
- Connectable to mobile carriers (car, plane, drone, public transportation) => getting real-time hetero-spatial data
- Use of data in air quality modeling and hotspots identifying
- The need to know the „behaviour“ of the sensor
- The need for appropriate interpretation of measured data! (regarding to measurement quality of MS)



References

- <http://www.uav.kelcom.cz/>
- <http://www.robodrone.com/produkty-a-sluzby#robodrony>
- <http://www.palas.de/en/product/fidasfly200>
- http://www.cairpol.com/index.php?option=com_content&view=article&id=57&Itemid=166&lang=en

Thank you for your attention!



O3/NO₂

CO

AIR
POL
MINIATURE AIR QUALITY MONITORING SYSTEMS
PS49D OZ Technical Data Sheet O3-NO₂ 160812

Technical Data Sheet CairClip O₃-NO₂

(document prone to modification)

Range	0-250 ppb (0 - 240 ppb analog)
Limit of detection ^(1, 2)	20 ppb
Repeatability at zero ^(3, 4)	+/- 7 ppb
Repeatability at 40 % of range ^(3, 4)	+/- 15 %
Linearity ^(3, 5)	< 10 %
Uncertainty	< 30% ^(3, 6)
Short term zero drift ^(3, 1, 4)	< 5 ppb / 24 H
Short term span drift ^(3, 1, 4)	< 3% FS ⁽³⁾ / 24 H
Long term zero drift ^(3, 1, 4)	< 10 ppb / 1 month
Long term span drift ^(3, 1, 4)	< 2% FS ⁽³⁾ / 1 month
Rise time (T10-90) ^(3, 7)	< 90s (180s if large variation of RH)
Fall time (T10-90) ^(3, 7)	< 90s (180s if large variation of RH)
Effect of interfering species ⁽⁸⁾	Cl ₂ : around 80%
Temperature effect on sensitivity ⁽³⁾	Reduced sulphur compounds : negative interference < 0.5 % / °C
Temperature effect on zero ⁽³⁾	+/- 50 ppb maximum under operating conditions
Maximum exposure	50 ppm
Annual exposure limit (1 hour average)	780 ppm
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 ⁽⁹⁾	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

⁽¹⁾According to our operating conditions during test in laboratory: 20°C +/- 2°C / 30%RH +/- 10% / 1013 mbar +/- 3%⁽²⁾Values possibly affected by exposure to high gradients of concentration⁽³⁾In accordance with the Directive 2006/95/EC of the European Parliament and of the Council of 21 May 2006 on ambient air quality and cleaner air for Europe⁽⁴⁾Full scale continuous exposure⁽⁵⁾F2 = Full Scale⁽⁶⁾The complete discharge of a device (crosses turned off) can lead to a deterioration of its performances⁽⁷⁾Any use of the sensor not complying with the conditions specified in herein, including exposure, 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.

AIR
POL
MINIATURE AIR QUALITY MONITORING SYSTEMS
PS78D OZ Technical Data Sheet CO 230113

Technical DataSheet CairClip CO (preliminary version)

(document prone to modification)

Range	0 - 20 ppm (0 - 19 ppm analog)
Limit of detection ^(3, 8)	0.05 ppm
Repeatability at zero ^(3, 8)	+/- 0.05 ppm
Repeatability at 80 % of range ^(3, 8)	+/- 15 %
Linearity ^(3, 8)	< 10 %
Uncertainty	< 25 % ^(3, 8)
Short term zero drift ^(3, 1, 8)	< 0.2 ppm / 24 H
Short term span drift ^(3, 1, 8)	< 1 % FS ⁽³⁾ / 24 H
Long term zero drift ^(3, 1, 8)	< 0.4 ppm / 1 month
Long term span drift ^(3, 1, 8)	< 2.4 % FS ⁽³⁾ / 1 month
Rise time (T10-90) ^(3, 8)	< 60 s
Fall time (T10-90) ^(3, 8)	< 60 s
Effect of interfering species ⁽⁸⁾	H ₂ < 60%
Temperature effect on sensitivity ⁽³⁾	Long term high concentration levels (> CO) of H ₂ S, NOx, SO ₂ or acid gases may interfere the signal
Temperature effect on zero ⁽³⁾	< 1 % / °C
Maximum exposure	+/- 1 ppm maximums under operating conditions
Annual exposure limit (1 hour average)	90000 ppm
Operating conditions	-20°C to 50°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 ⁽⁹⁾	5 VDC / 200 mA (rechargeable by USB via PC or 100 V-240 V/5 V 0.8A-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
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Article

Unmanned Aircraft Systems in Remote Sensing and Scientific Research: Classification and Considerations of Use

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