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La Région
Auvergne-Rhône-Alpes

A novel recalibration technology for air quality microsensors

eLos station _ White Paper Technique 1 _ Sept 2020

Acknowledgments

eLichens thanks Atmo AuRA for the installation and maintenance of 3 eLos stations on the reference station “Caserne de Bonne” since the end of 2018.

3 eLos stations
(eLichens outdoor air quality monitoring stations)

Reference analyzers, between others:

- NOx (Chemiluminescence),
- O_3 (UV photometry)

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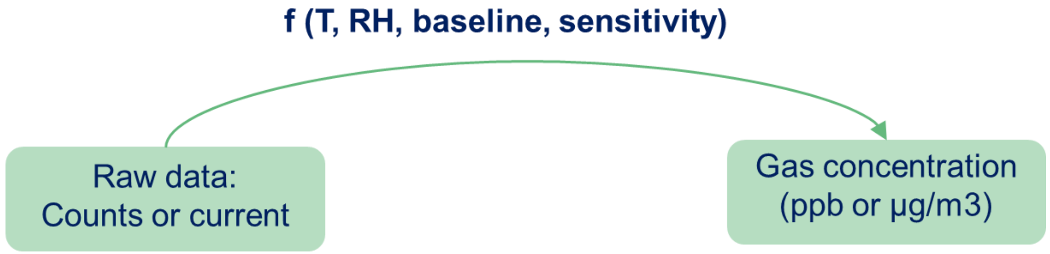
Introduction

- The raw signal from electrochemical sensors requires **calibration** to be converted to mass concentration.



- **Numerous studies** have shown that the performance of this calibration varies drastically between laboratory and real-world conditions → **difficult to predict the performance** of a sensor implanted in a ***new location and over time as environmental conditions change and sensors age***.

↓

Strong limitations in the use of sensors for monitoring outdoor air quality

No real-time processing impact for impact evaluation of an action

Needs to be compared and re-calibrated against reference instruments on a very regular basis to avoid loss of performance

No real-time assimilation in chemistry-transport models

Introduction

- eLichens offers a solution to ensure robust measurement quality based on **a real-time calibration process** for NO_2 and O_3 sensors.

- The objective of this solution is to **complete the already existing networks** of air quality reference stations which are located in large urban areas in the developed country.

- The performance of the real-time calibration process has been evaluated **over 17 months in an urban background station with 3 co-located micro-sensors.**

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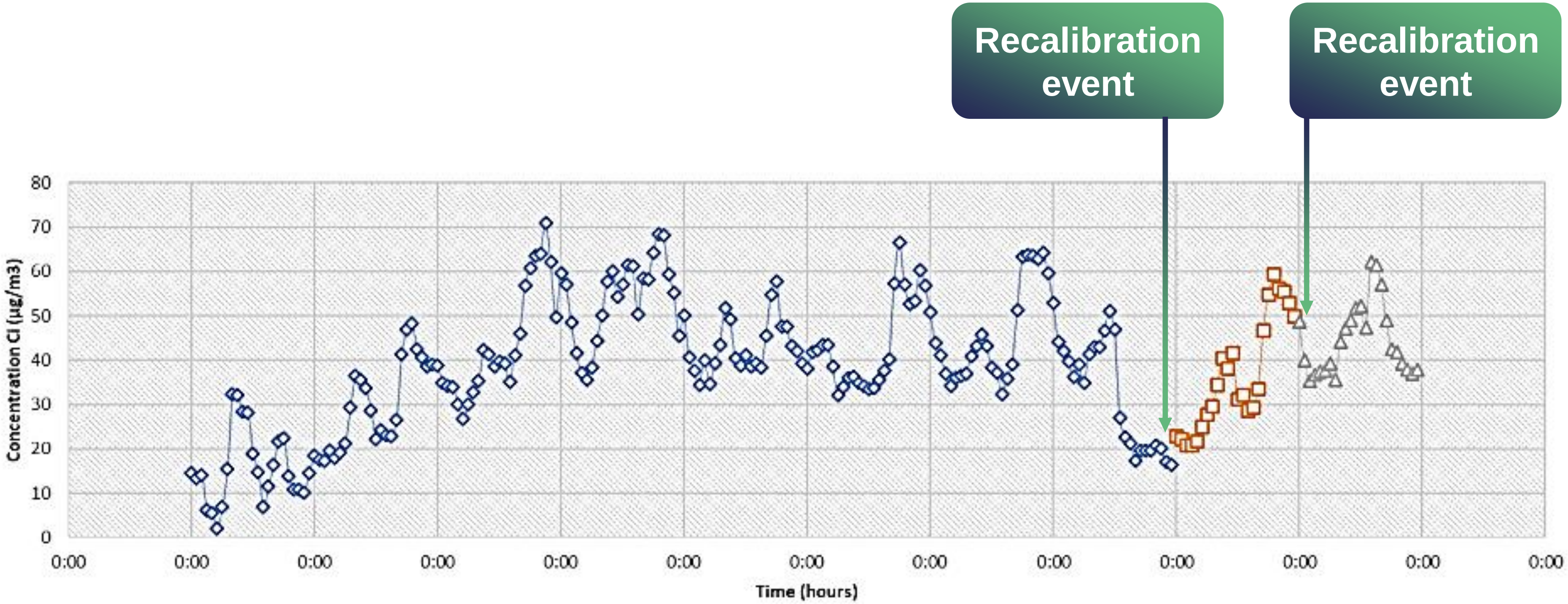
Real-time calibration process

Stations are recalibrated every day based on the last 7 days of data. This process in done in eLichens cloud.



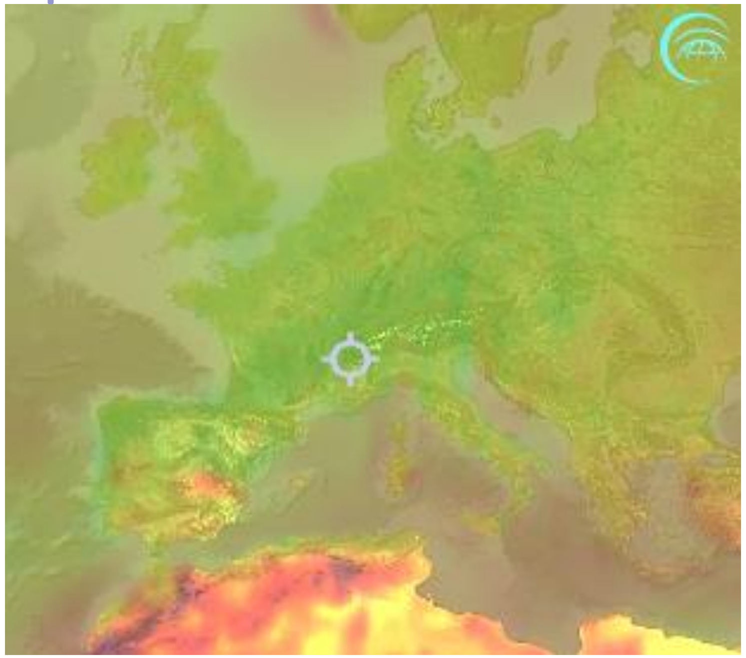
7 days of data including sensors signals, T°, H° and calibration signal computed from reference stations or Copernicus data

7 days of data including sensors signals, T°, H° and calibration signal computed from reference stations or Copernicus data

Real-time calibration process

Area without reference station
Background calibration

eLos position

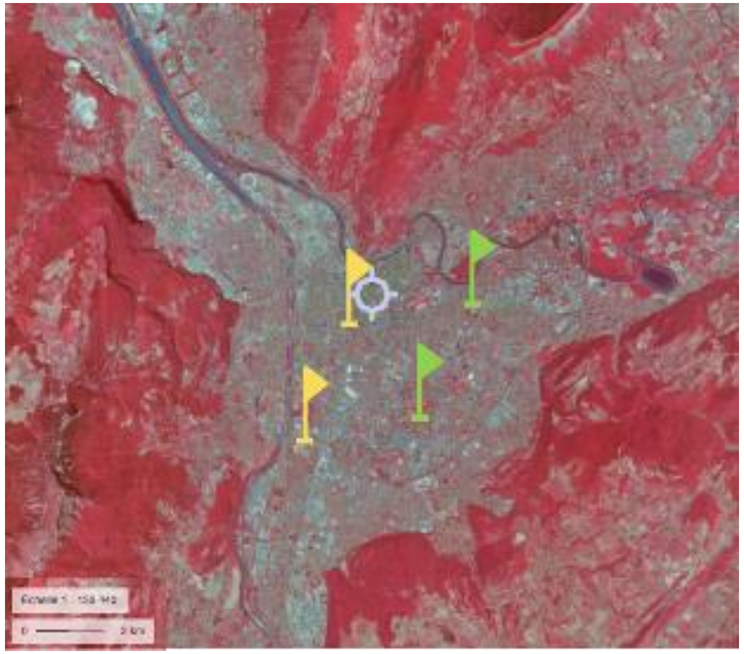


Calibration based on sensors' property and Copernicus data

Recalibration technology depends on eLos' context

T | RH | NO_2 count | O_3 count

Area with reference station
Local calibration



Calibration based on reference stations and moment when air pollution is considered homogenous over the area

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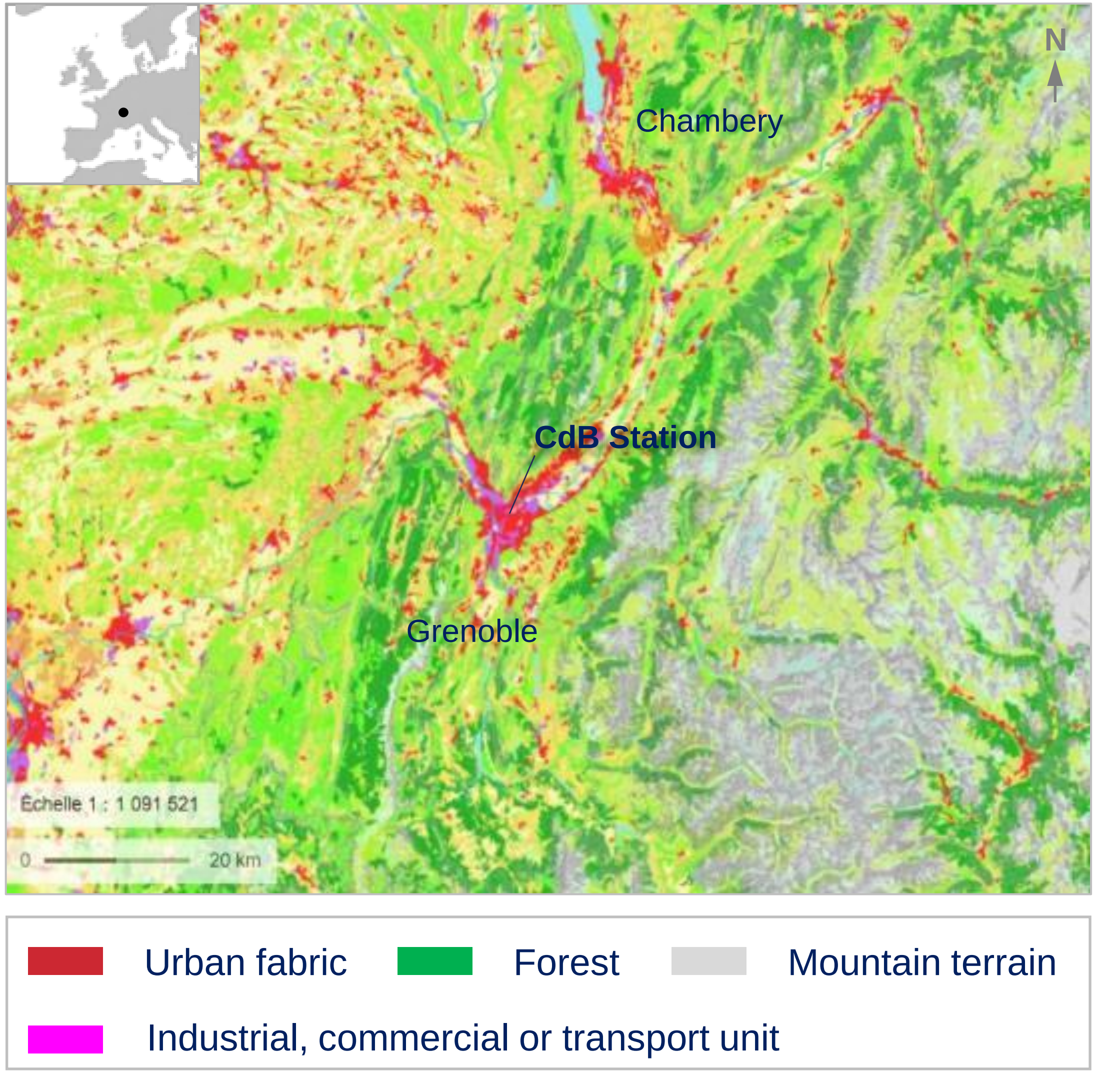
Characteristic of the measurement site



Source: EEA, Corine Land Cover 2018

- Grenoble:
  - Valley between three mountains
  - Episodes of PM_{10} pollution in winter and O_3 in summer
  - Population density: 8740 inhab/km^2

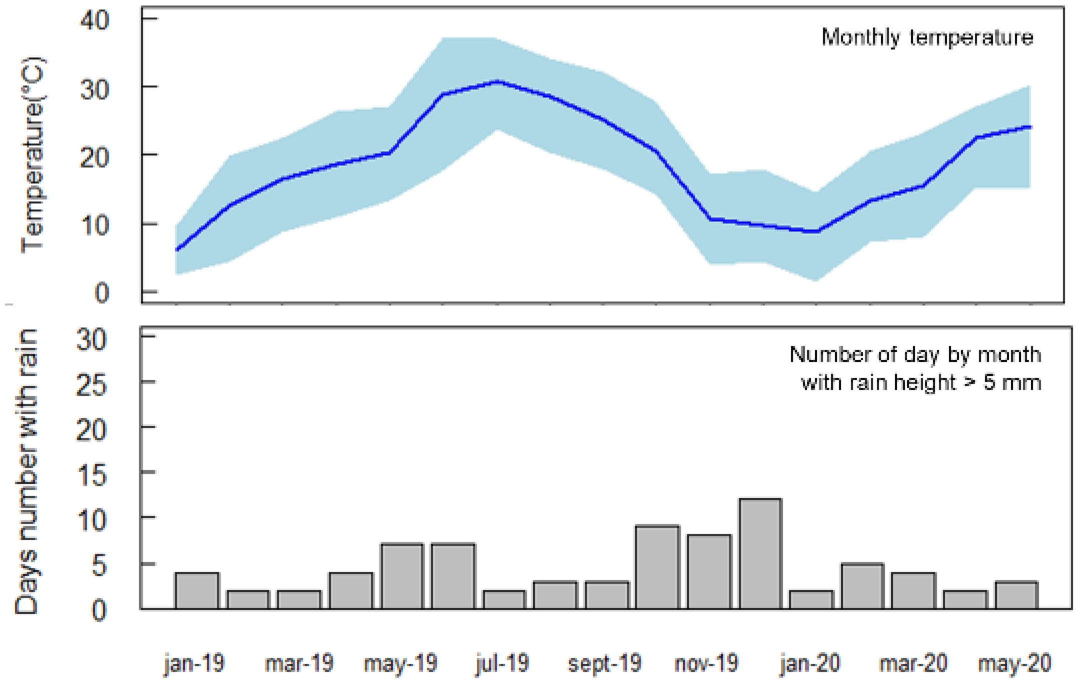
- Caserne de Bonne station:

  Urban background: representative of the average exposure of the general population. Not close by single emission source.

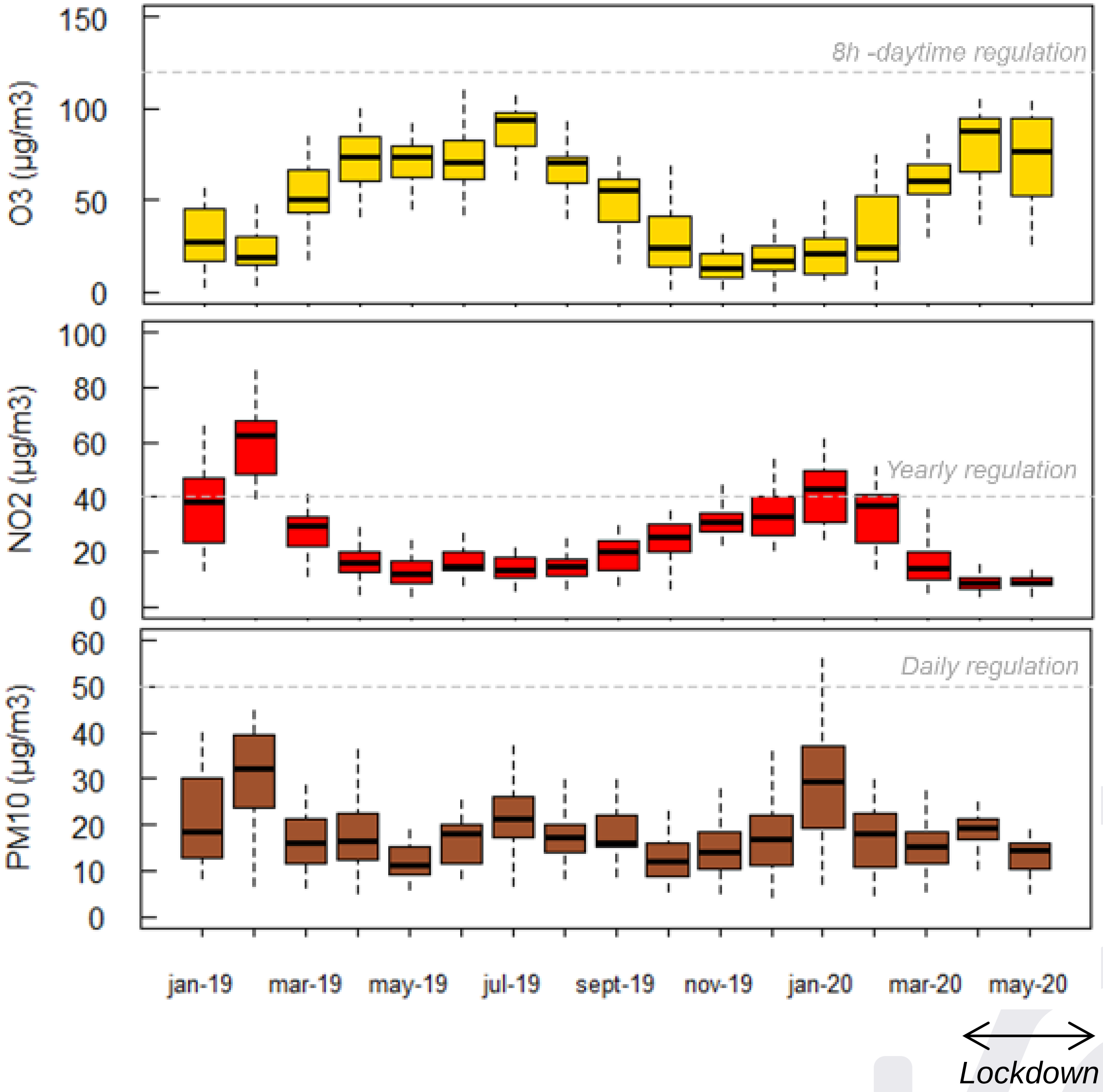
Lat: 45°11’0.024”N Long: 5°43,30.647”E Alt: 220 m

Environmental conditions during measurements

Meteorological conditions *(Météo France station_ Le Versoud)*



Air quality *(Atmo AuRA station_ Caserne de Bonne)*



- ❑ Winter 2019 colder than winter 2020 (5.9°C vs 8.7°C in Jan.), summer 2019 warm (30.8°C in Jul.)
- ❑ 2 days with PM_{10} concentration ≥ 50 µg.m^{-3}, highest concentrations of NO_2 in Feb. 2019 (60 µg.m^{-3}) and O_3 in Jul. 2019 (87 µg.m^{-3})

Test site

3 eLos stations

- Use of 3 colocalized stations (plugged into sector) with a reference station in Grenoble’s downtown

- 2 cases are considered for recalibration process technology assessment: use of 4 other reference stations in Grenoble, and without use of any reference station

- The data from reference station are not considered in anytime in the calibration process. There are only used to evaluate the performances

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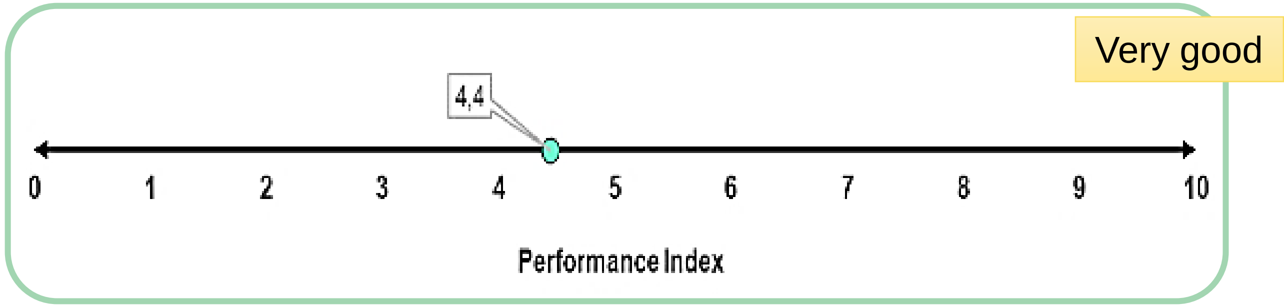
Data quality indicators

- Precision metric of French inter-comparison campaign AirLab = IPI (Integrated Performance Index)

Index between 0 and 10 which considers the different correlation coefficients (ρ,τ,κ), the root mean square error (RMSE) and two metrics to evaluate the capacity of the sensor to capture the temporal variability and orders of magnitude of the concentrations.



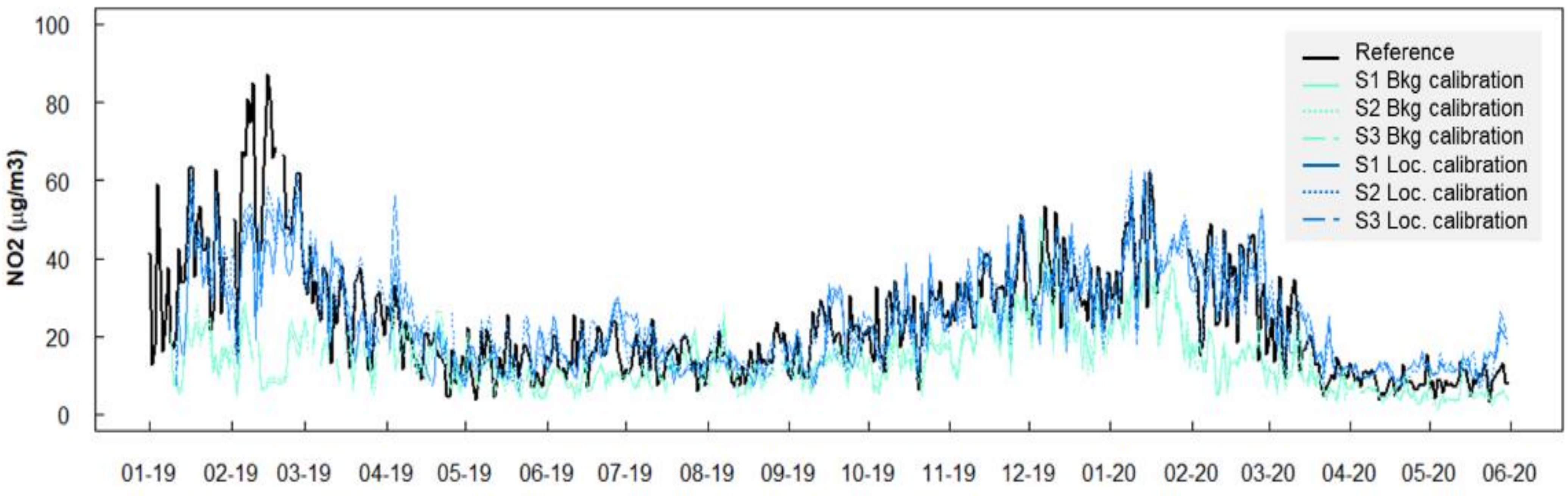
- Other statistical parameters

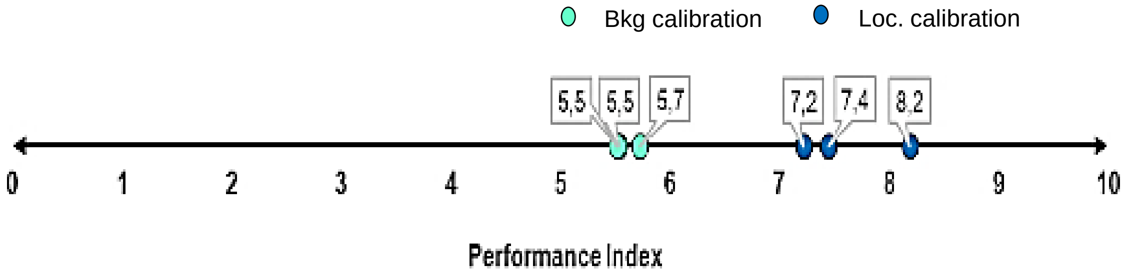
R^2	MAE ($\mu g.m^{-3}$)	MAPE (%)
Correlation coefficient of the linear regression between data stations and reference station	Mean absolute error	Mean absolute percentage error
	$\sum_{t_0}^{T} \frac{\lVert Cs_t - Cref_t \rVert}{T}$	$\frac{1}{T} \sum_{t_0}^{T} \frac{\lVert Cs_t - Cref_t \rVert}{Cref_t} * 100$

Fishbain et al. 2017. An evaluation tool kit of air quality micro-sensing units. Scien. Tot. Environ. 575, 639-648

Protocol of Microsensors Challenge 2019, AirLab (www.airlab.solutions.fr)

Evaluation of performance at daily scale

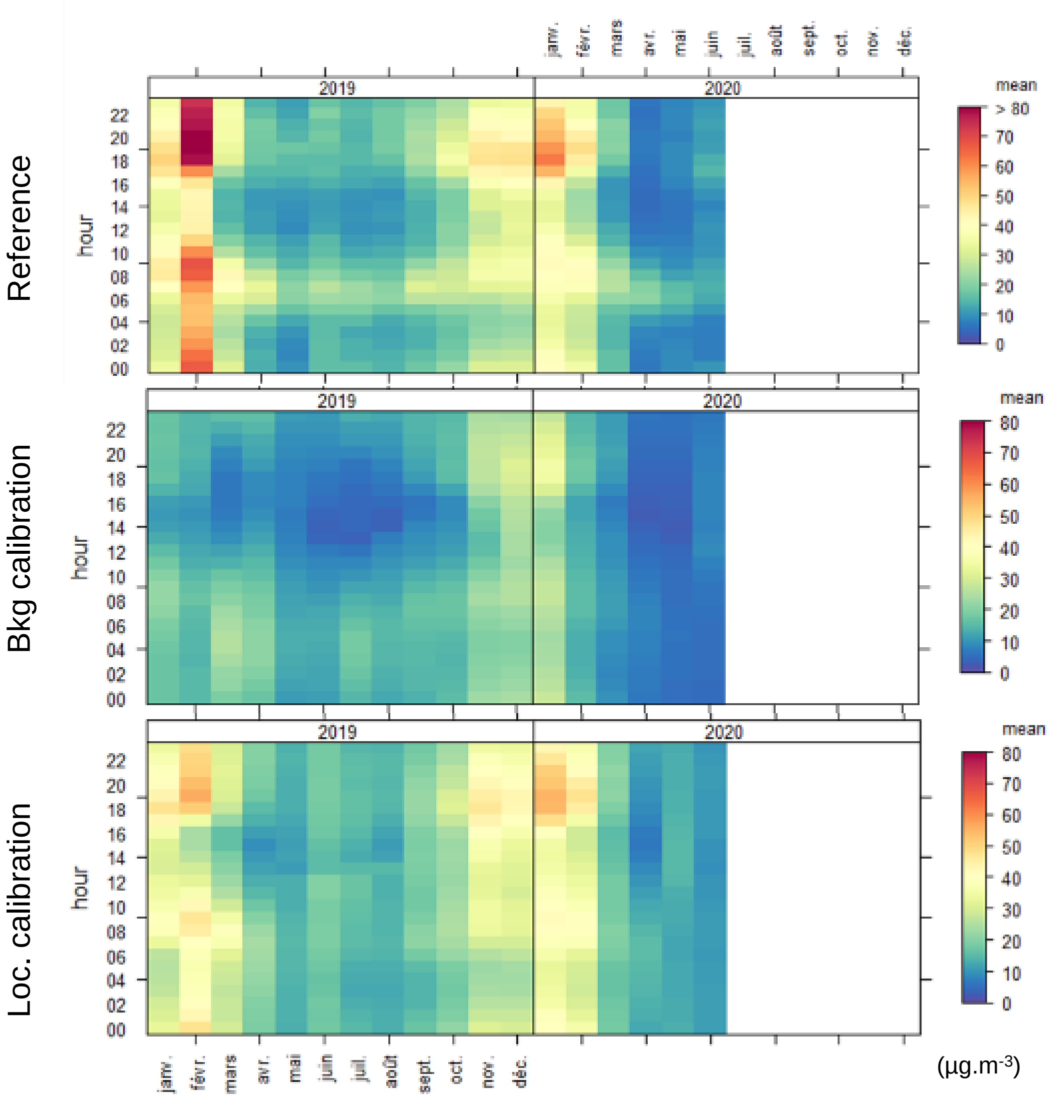




n = 532	R^2	MAE ($\mu g.m^{-3}$)	MAPE (%)
Bkg calibration	0.27-0.31	11.4 – 11.5	43 - 44
Loc. calibration	0.60-0.80	4.8 – 6.9	18 - 25

❑ High correlation and low error for NO_2 concentrations calibrated according local calibration process. As opposite, the other calibration has low performance over the whole period

Evaluation of performance at hourly scale (1/2)



Hourly averaged NO_2 concentration by month

- Presence rate: > 95% for the 3 stations

  Standard deviation between the 3 stations found inferior to NO_2 concentrations range
  Bkg calib.: 1.9 ± 2 µg.m^{-3} Loc. : 4.3 ± 4 µg.m^{-3}

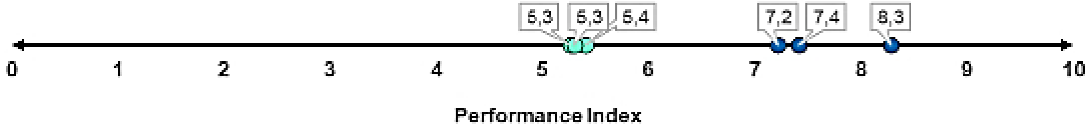
- Bkg calibration: trend only results for NO_2 on an hourly scale whatever the season → NO_2 is mainly derived from traffic sources, which can vary strongly within a grid cell from Copernicus data (res: 40 km)

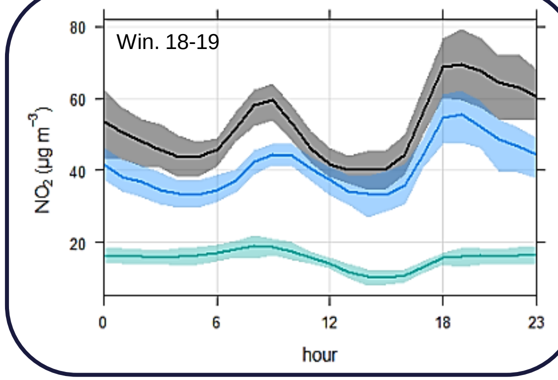
- Loc. calibration: highly correlated hourly data with low absolute error, except periods when NO_2 concentrations are low and close to the detection limit of the sensor (such lockdown period).

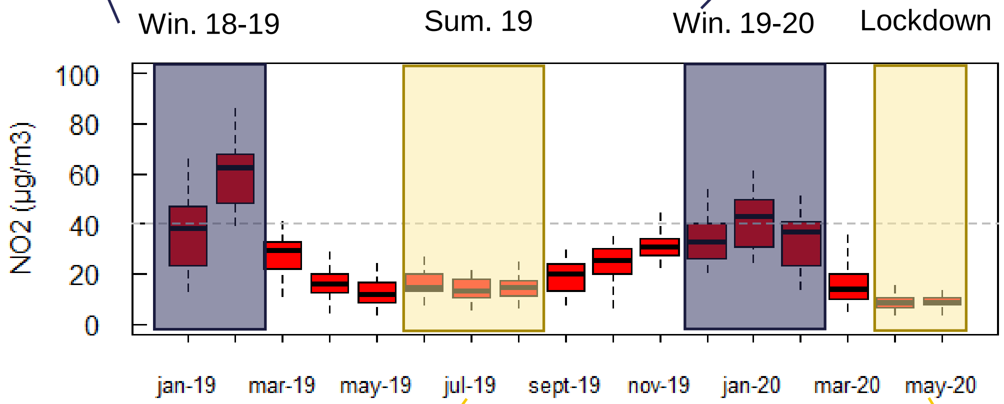
Evaluation of performance at hourly scale (2/2)

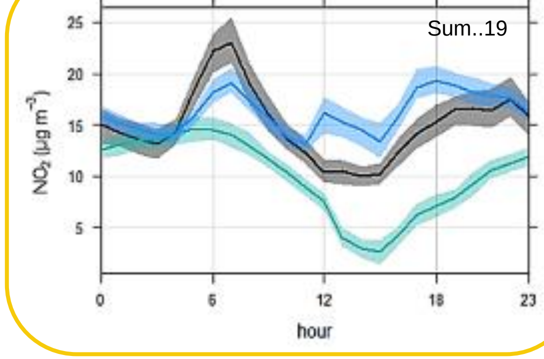
n = 1176	Mean Ref	R^2	MAE (µg.m^{-3})	MAPE (%)
Bkg calibration	52 µg.m^{-3}	< 0.1	37.1 – 38.0	66 - 69
Loc. calibration		0.55 – 0.69	14.6 – 18.1	26 - 32

n = 2184	Mean Ref	R^2	MAE (µg.m^{-3})	MAPE (%)
Bkg calibration	36 µg.m^{-3}	0.22 – 0.23	17.1 – 17.7	45 - 47
Loc. calibration		0.49 – 0.75	6.9 – 9.5	15 - 22

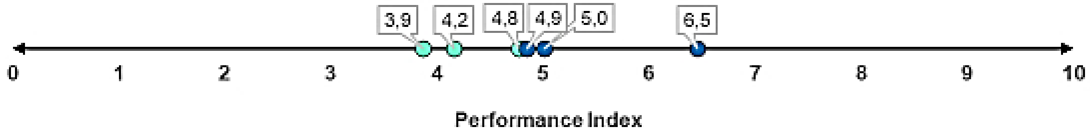




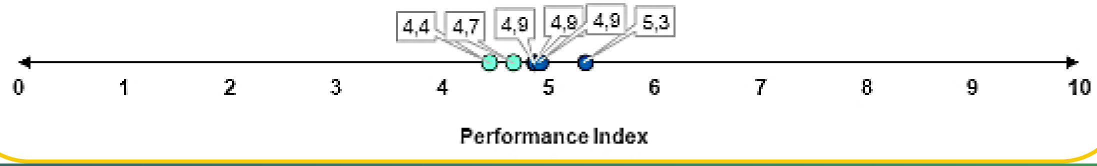




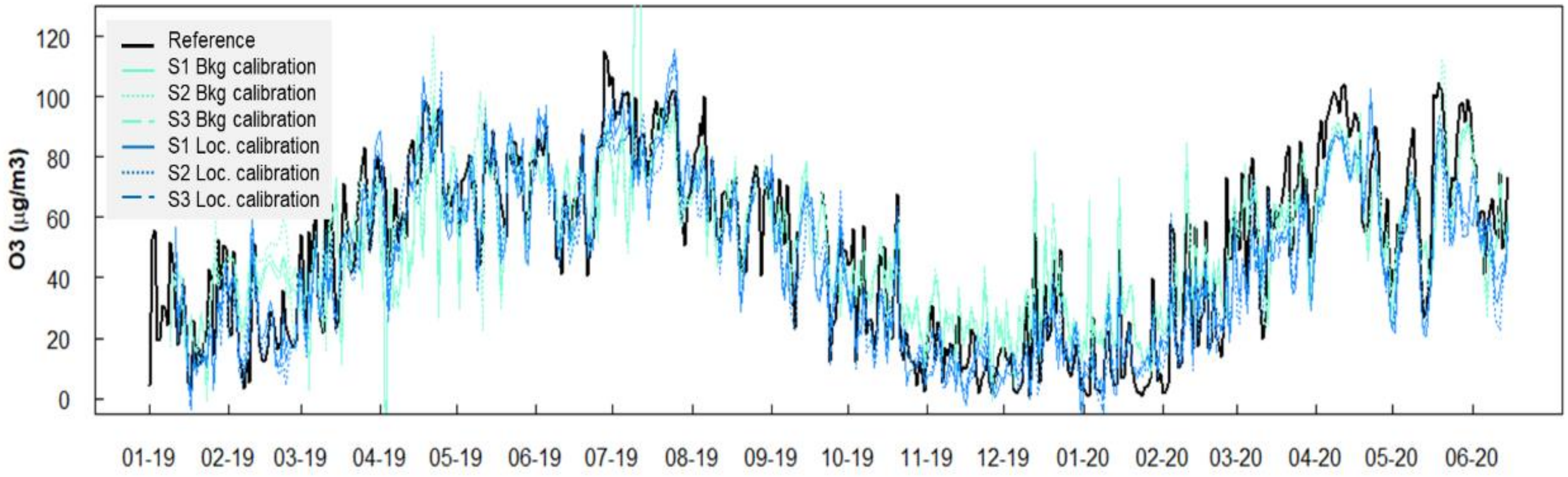
n = 2208	Mean Ref	R^2	MAE (µg.m^{-3})	MAPE (%)
Bkg calibration	15 µg.m^{-3}	≤ 0.1	7.5 – 8.1	46 - 48
Loc. calibration		0.1 – 0.33	5.6 – 7.3	31 - 40

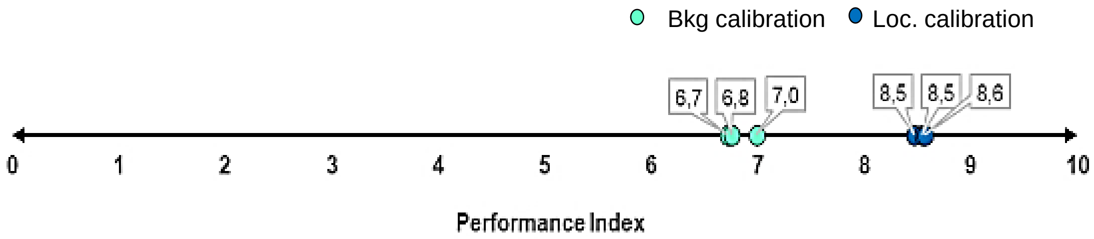


n = 1464	Mean Ref	R^2	MAE (µg.m^{-3})	MAPE (%)
Bkg calibration	9 µg.m^{-3}	0.10 – 0.18	4.5 – 4.6	46 - 48
Loc. calibration		≤ 0.10	5.2 – 5.9	51 - 62



Evaluation of performance at daily scale



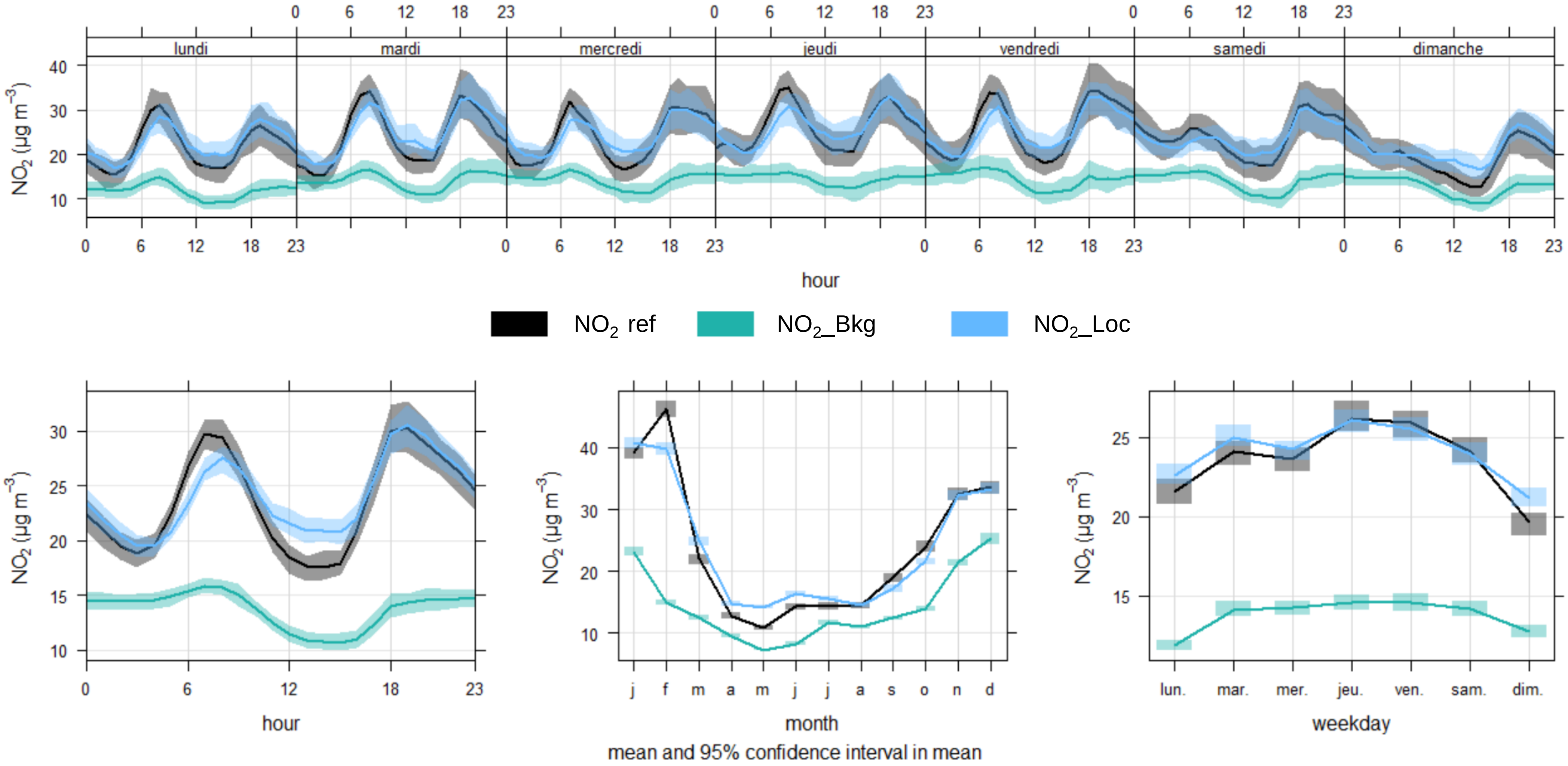


n = 532	R^2	MAE (µg.m^{-3})	MAPE (%)
Bkg calibration	0.35-0.43	14.2 – 14.5	22 - 23
Loc. calibration	0.85-0.88	9.2 – 9.7	9 - 10

- Relative high performance for the 2-calibration processes but presence of extreme values for the background calibration impacting correlation coefficients.

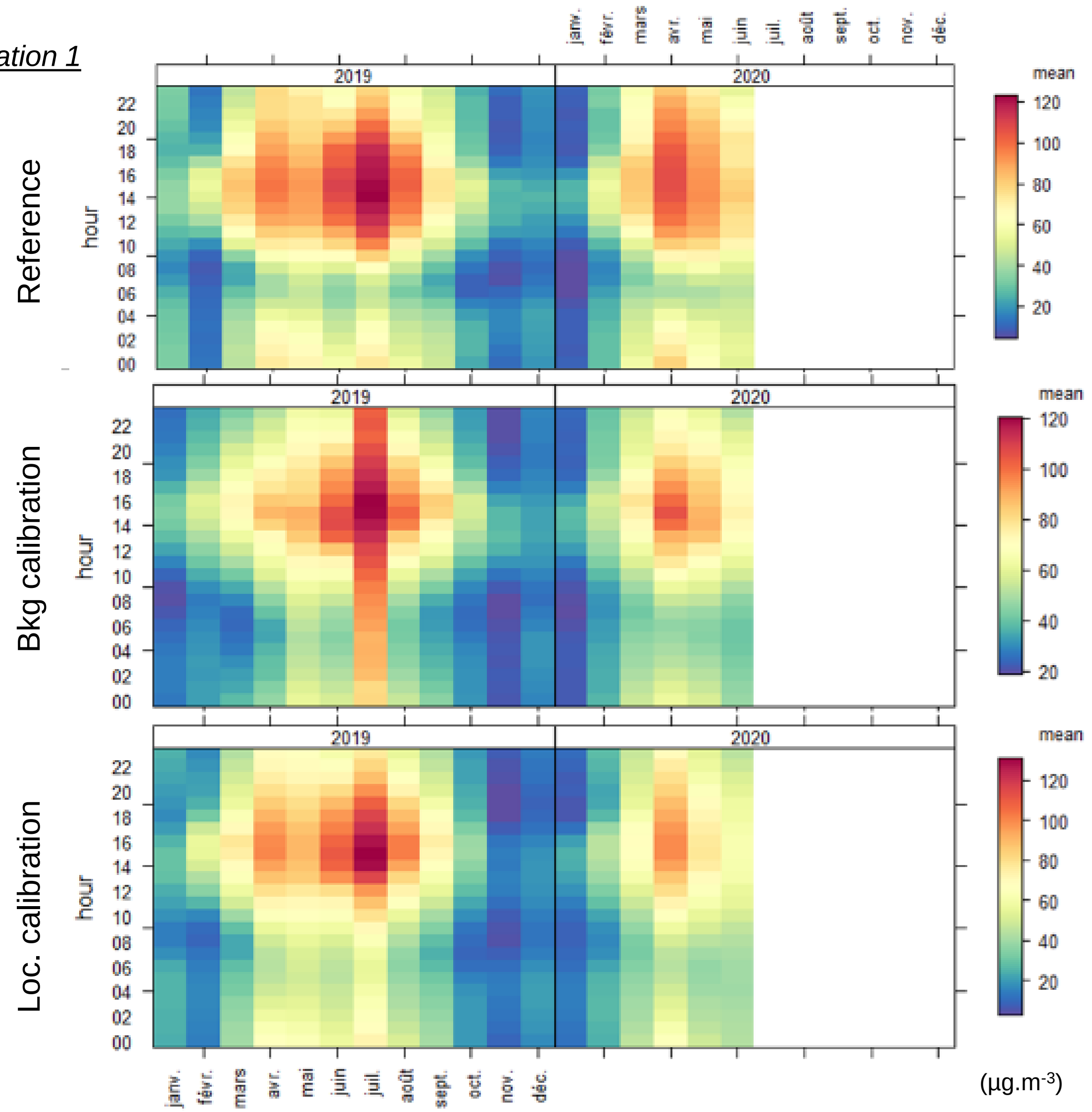
Overview of NO_2 measurements for various cycles

Illustration of the different cycles of temporal variations



Evaluation of performance at hourly scale (1/2)

Station 1



Hourly averaged O_3 concentration by month

- ❑ Presence rate: > 97% for the 3 stations

  Standard deviation between the 3 stations found inferior to O_3 concentration range
  Bkg calib.: 4.5 ± 7 µg.m^{-3} Loc. : 4.7 ± 4 µg.m^{-3}

- ❑ For both types of calibrations, daily and seasonal variations are similar to those with reference data.

Evaluation of performance at hourly scale (2/2)

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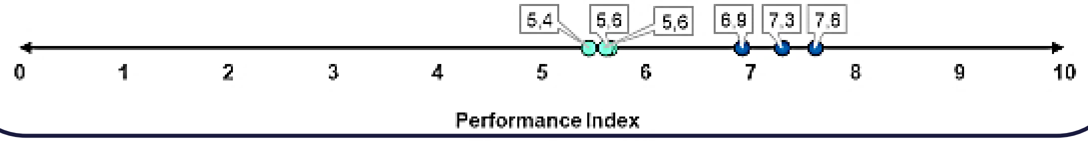
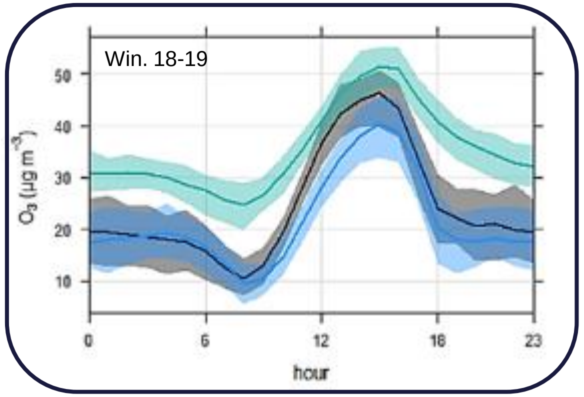
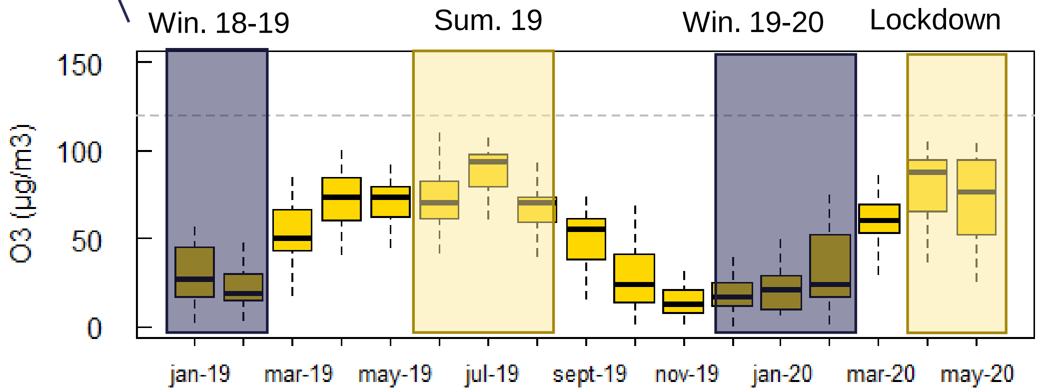
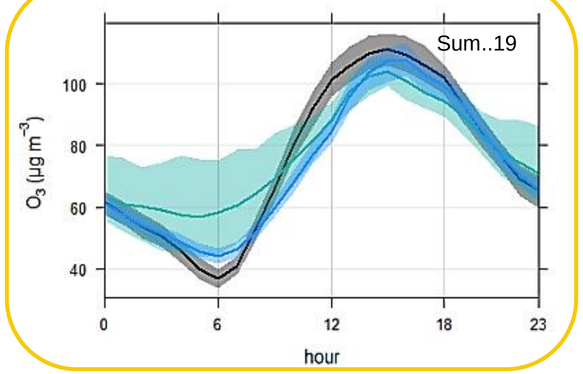
n = 1176	Mean Ref	R^2	MAE (µg.m⁻³)	MAPE (%)
Bck calibration	24 µg.m⁻³	0.20 - 0.23	19.5 – 20.8	87 - 96
Loc. calibration		0.60 – 0.73	9.3 – 11.3	39 - 46



n = 2184	Mean Ref	R^2	MAE (µg.m⁻³)	MAPE (%)
Bck calibration	13 µg.m⁻³	0.38 – 0.40	17.7 – 18.2	100 - 109
Loc. calibration		0.65 – 0.74	10.7 – 12.3	48 -52





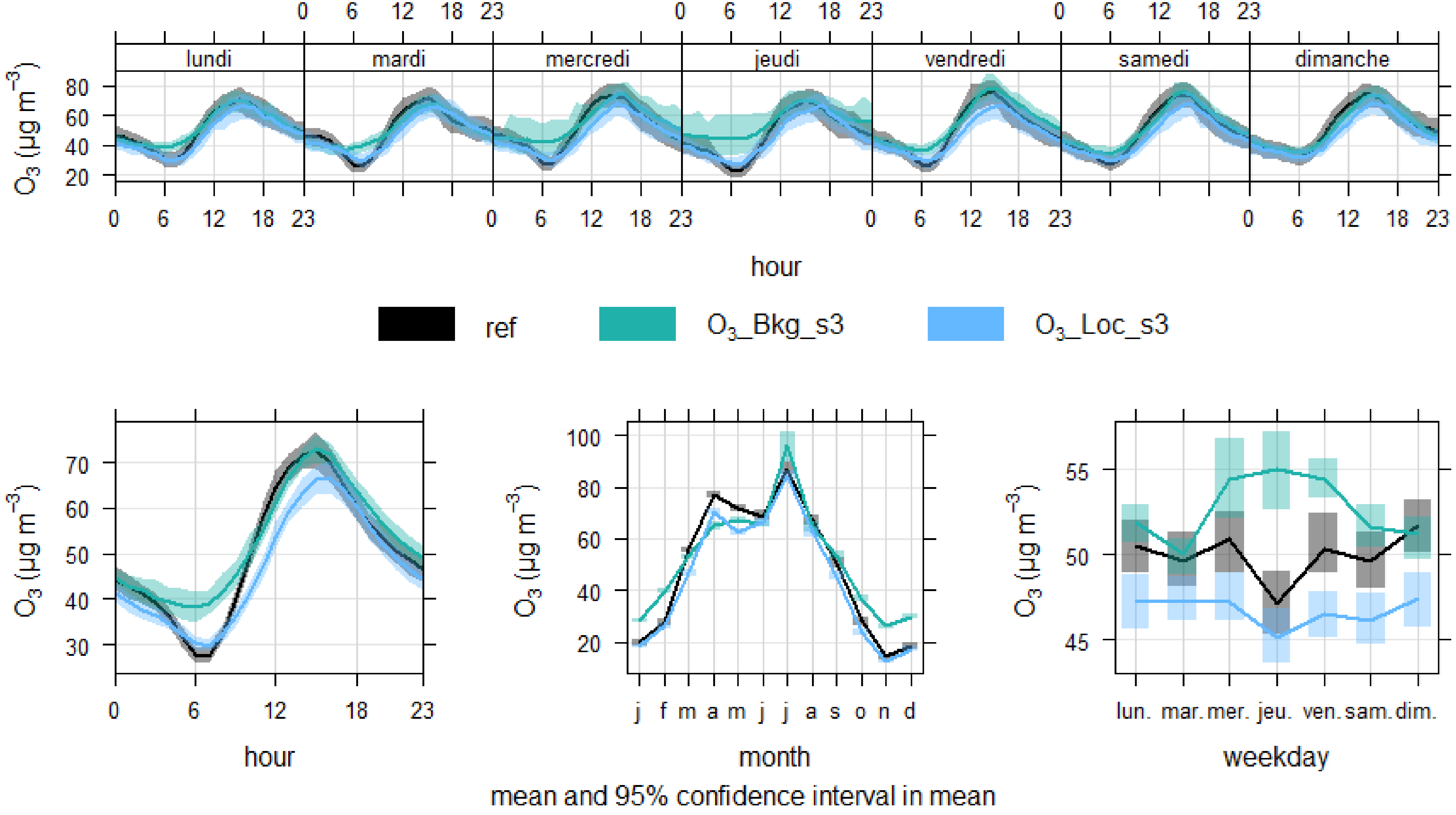


n = 2208	Mean Ref	R^2	MAE (µg.m⁻³)	MAPE (%)
Bck calibration	72 µg.m⁻³	0.12 – 0.14	20.5 – 24.0	16 - 19
Loc. calibration		0.74 – 0.81	12.2 – 14.1	14 - 16

n = 1464	Mean Ref	R^2	MAE (µg.m⁻³)	MAPE (%)
Bck calibration	76 µg.m⁻³	0.63 – 0.72	15.3 – 16.3	18 - 19
Loc. calibration		0.71 – 0.77	16.2 – 16.6	20 - 21

Overview of O_3 measurements for various cycles

Illustration of the different cycles of temporal variations



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Conclusion

- eLichens has developed and set in production a novel calibration technology for outdoor air quality stations. This technology is protected with several patents.

- The solution has been tested over 17 months in Grenoble's downtown and compared to reference station measurements. Validation campaign demonstrates very good performance for both NO_2 and O_3 sensors over the period, in particular in the case of an existing reference stations network.

Technology is already integrated in eLos product and available. eLos works either as a stand-alone product which could extend, at reduced cost, reference stations network or combined with cloud applications of real-time air quality mapping and data mining for air quality analysis.

Contact: pierre.jallon@elichens.com

See you soon!

Want to know **more** ?

Please **contact us** at **info@elichens.com**

www.elichens.com