ELICHENS

La Région Auvergne-Rhône-Alpes

A novel recalibration technology for air quality microsensors

Technical White Paper – October 2020

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)

Acknowledgments

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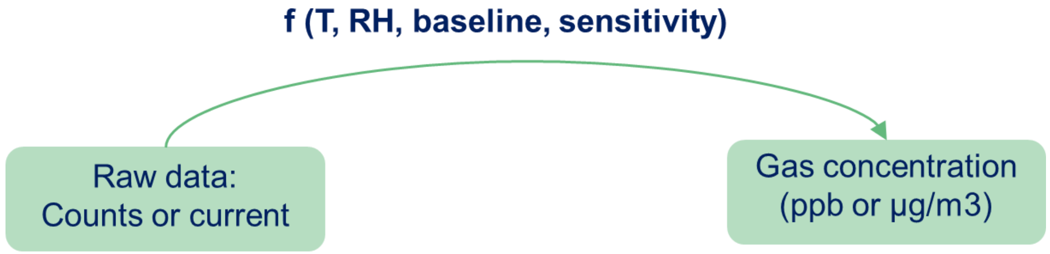
Introduction

- 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 when the sensor is 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 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

Objective

- 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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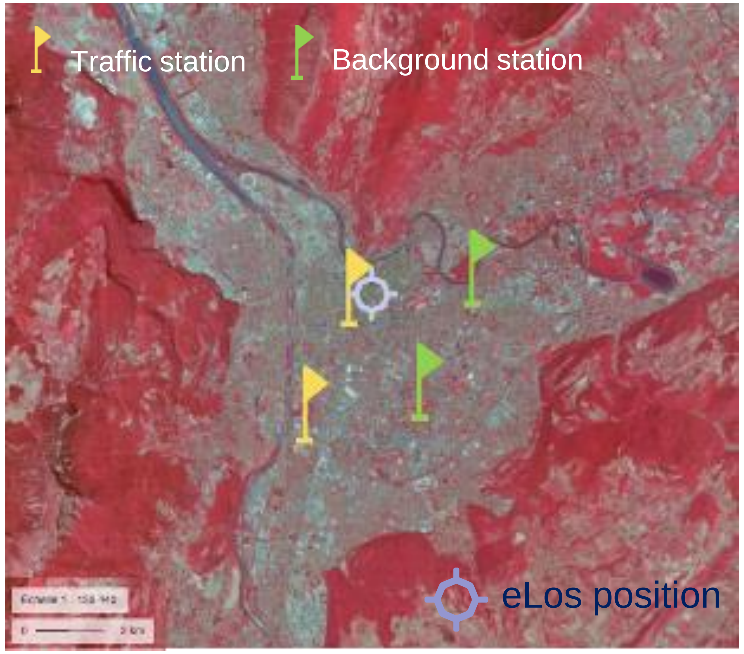
eLichens' real-time calibration process

Area with reference station

Hyperlocal calibration

Recalibration based on concentration of reference stations when air pollution is considered homogenous over the area



Automatic update of calibration parameters* according on eLos' context

T | RH | NO_2 count | O_3 count

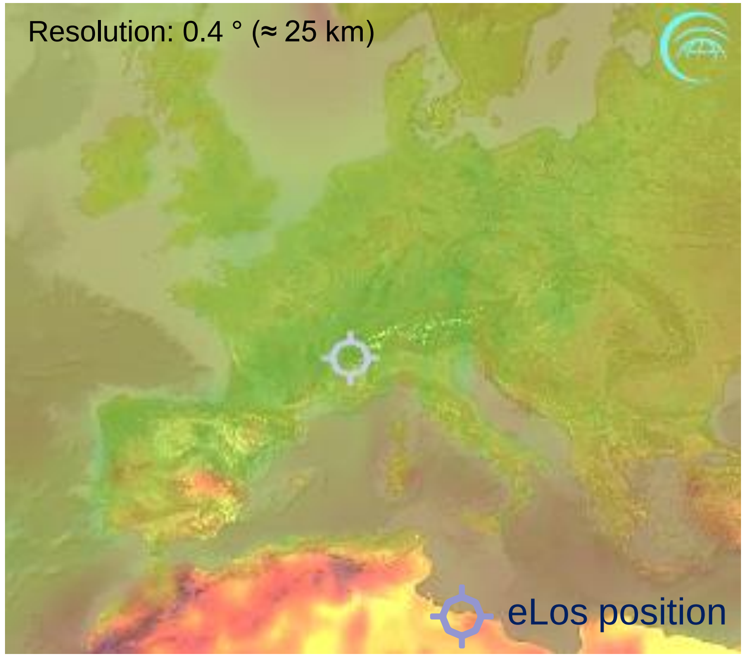
**correction factors of T and RH, offset and sensitivity parameters*

Example for eLos technology assessment

Area without reference station

Large scale calibration

Recalibration based on Copernicus data and sensors' property



eLichens' real-time calibration process

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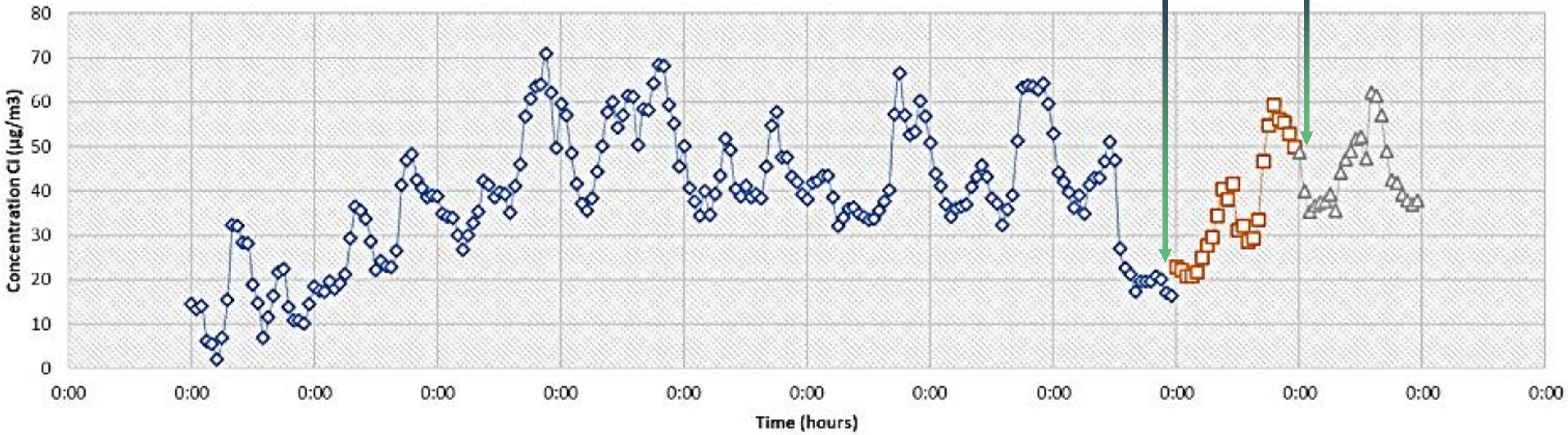
Recalibration event

Recalibration event

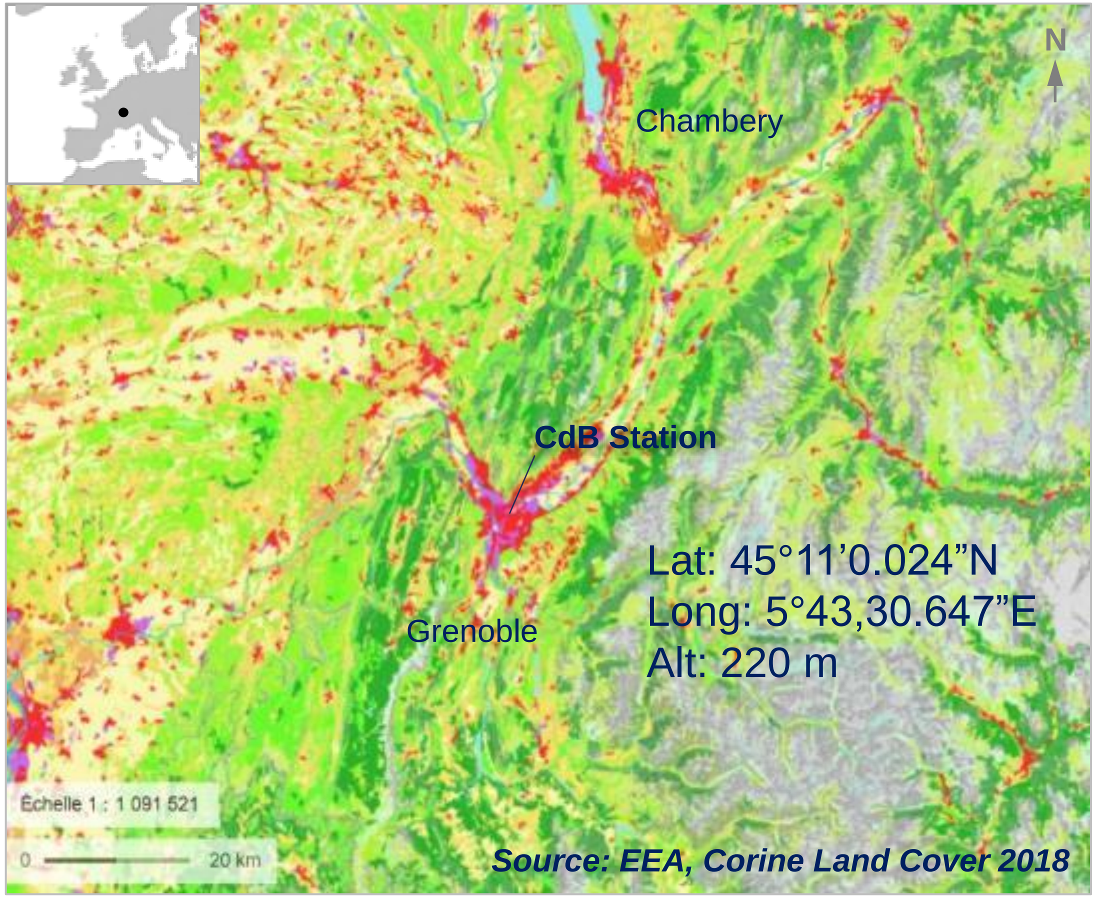
Stations are recalibrated every day based on the last 7 days of data. This process in done in eLichens cloud.



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

Measurement site for eLos performance assessment



Urban fabric | Forest | Mountain terrain
Industrial, commercial or transport unit

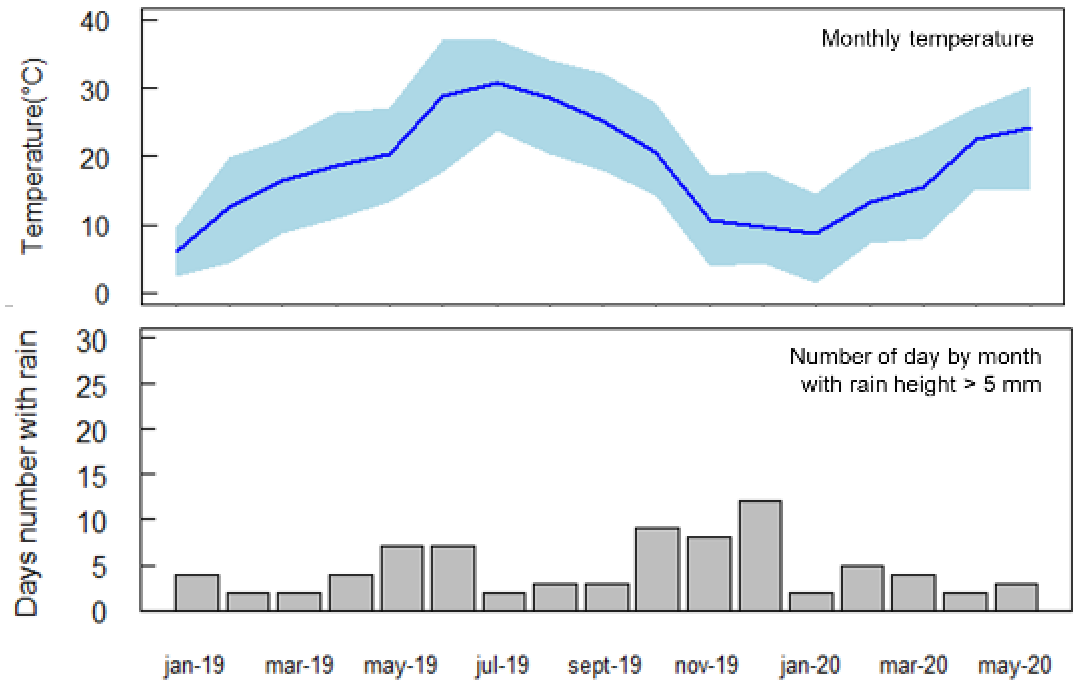
- Grenoble:
  - Valley between three mountains
  - Episodes of PM_{10} pollution in winter and O_3 in summer
  - Population density: 8740 inhab/km^2
- Caserne de Bonne station (reference station)

  Urban background: located away from emission point sources (such high traffic road)
- Period for eLos performance assessment:

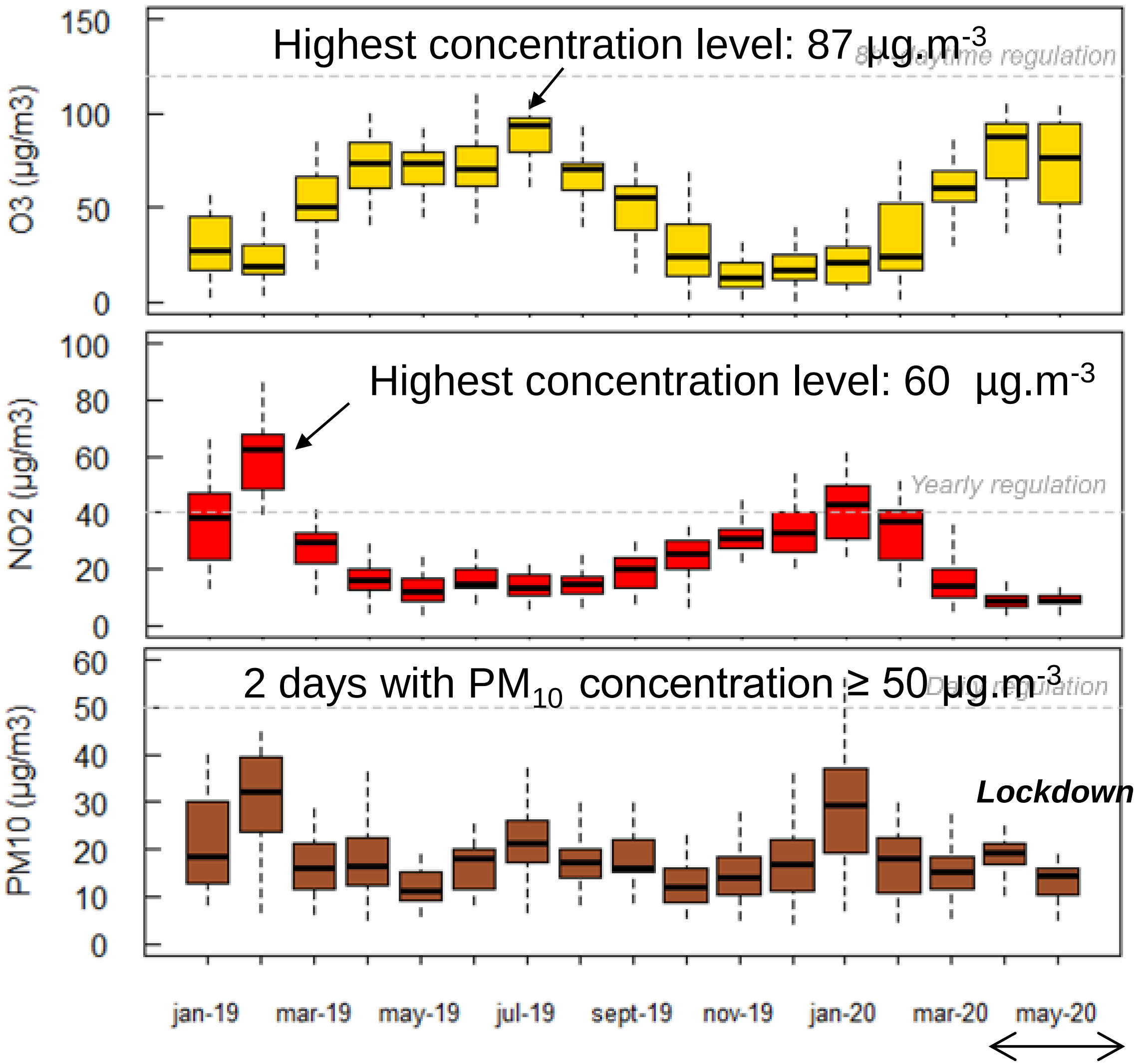
  01/01/2019 to 31/05/2020
- Colocalization of 3 eLos stations

Meteorological context

Meteorological conditions *(Météo France station_ Le Versoud)*



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



- ❑ Temperature: 5.9°C in winter 2019 , 8.7°C in winter 2020 and 30.8°C in summer 2019

Assessment method

Objective of the performance evaluation

- Analyze the completeness of eLos measurements over 17 months
- Analyze the repeatability of eLos measurements recalibrated according to the hyperlocal or large-scale method
- Assess how eLos recalibrated measurements from both methods agree with reference measurements.

Method

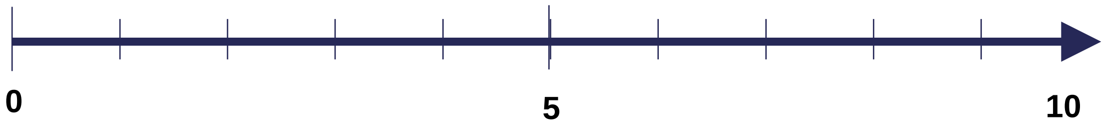
- Calculation of the presence rate of raw measurements of the 3 eLos stations.
- Both recalibration methods were applied to the 17-month measures. The data from Caserne de Bonne reference station are not considered at all in the calibration process
- Repeatability indicator: standard deviation between the 3 eLos stations
- Comparison of temporal cycles between reference and eLos measurements
- Performance indicator of measurement for trend studies (**daily scale**) and for detailed, fine-scale studies (**hourly scale in summer and winter** where NO_2 and O_3 concentrations are the lowest or highest)

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.

10 = perfect match between reference and station measurements



- 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
	$\sum_{t_0}^{T} \frac{\|Cs_t - Cref_t\|}{T}$	$\frac{1}{T}\sum_{t_0}^{T} \frac{\|Cs_t - Cref_t\|}{Cref_t} * 100$

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)

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In brief

LS= large scale
HL= hyperlocal

- Over 17 months, the O_3 and NO_2 measurements of eLos are **almost complete** and **very repeatable** (very small difference between the 3 stations)
- The **seasonal and hourly cycles of concentration correspond** to those with reference measurements with some differences for NO_2 and O_3 when LS calibration is applied (case of measurements in a city without a reference station)
- With the **HL calibration**, a **very high agreement** of the **daily and hourly concentrations** is found with the reference measurements for O_3 whatever the concentration level and for NO_2 when the concentrations are not close to the detection limit of the sensor (10 µg.m^{-3})
- With **LS calibration**, **daily and hourly O_3 concentrations** are in **good agreement** with the reference measurements. **NO_2 measurements** are underestimated but can be used for **trend analysis**.

Overview of NO_2 measurements

LS= large scale
HL= hyperlocal

- **Presence rate:**

  > 95% for the 3 stations over 17 months

- **Quality of repeatability:**

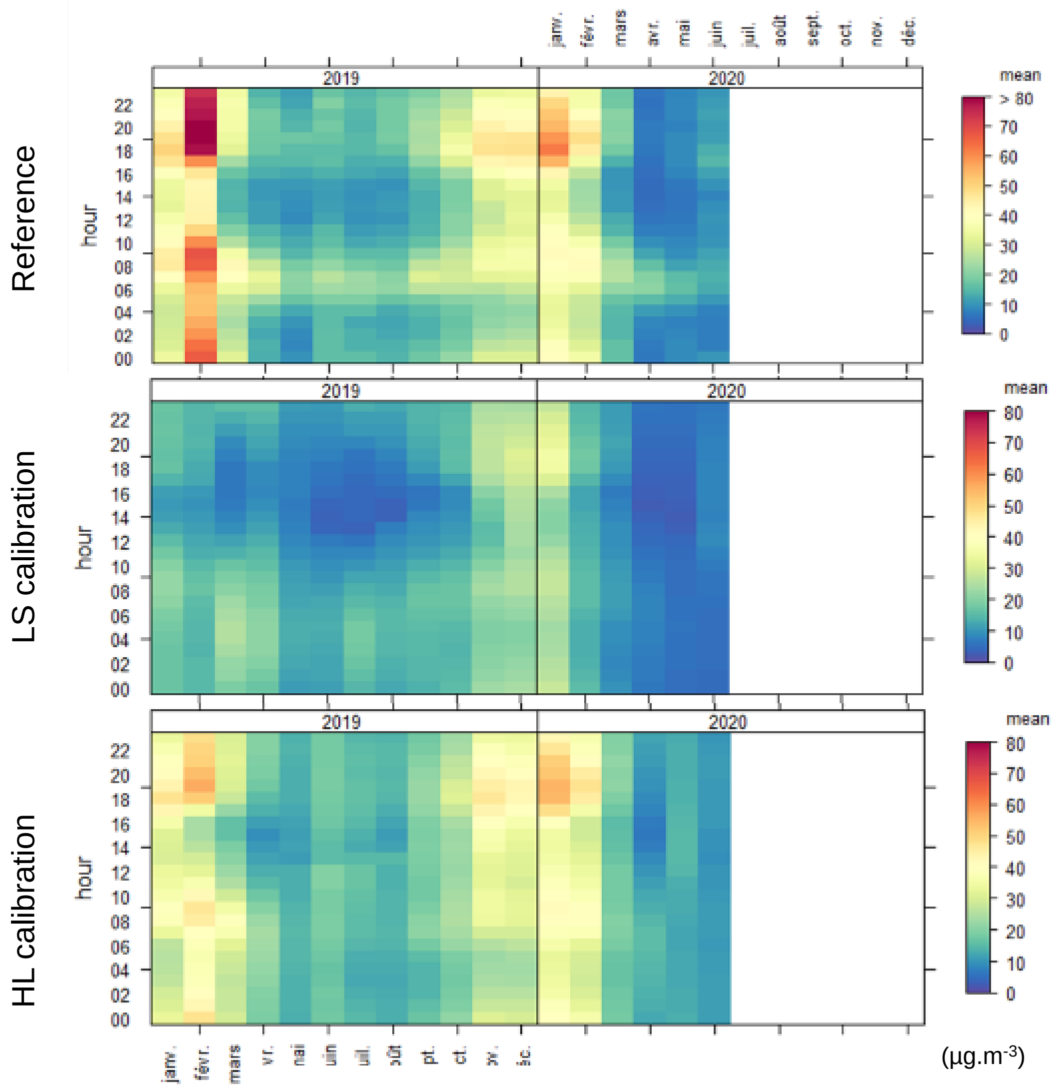
  standard deviation between the 3 stations:

  LS calibration: 1.9 ± 2 $\mu g.m^{-3}$

  HL calibration. : 4.3 ± 4 $\mu g.m^{-3}$

- **On a general overview:**

  with LS calibration, NO_2 measurements are underestimated compared to reference measurements while with HL calibration, measurements are very slightly underestimated



Hourly averaged NO_2 concentration by month

Comparison of NO_2 temporal cycles

LS= large scale
HL= hyperlocal

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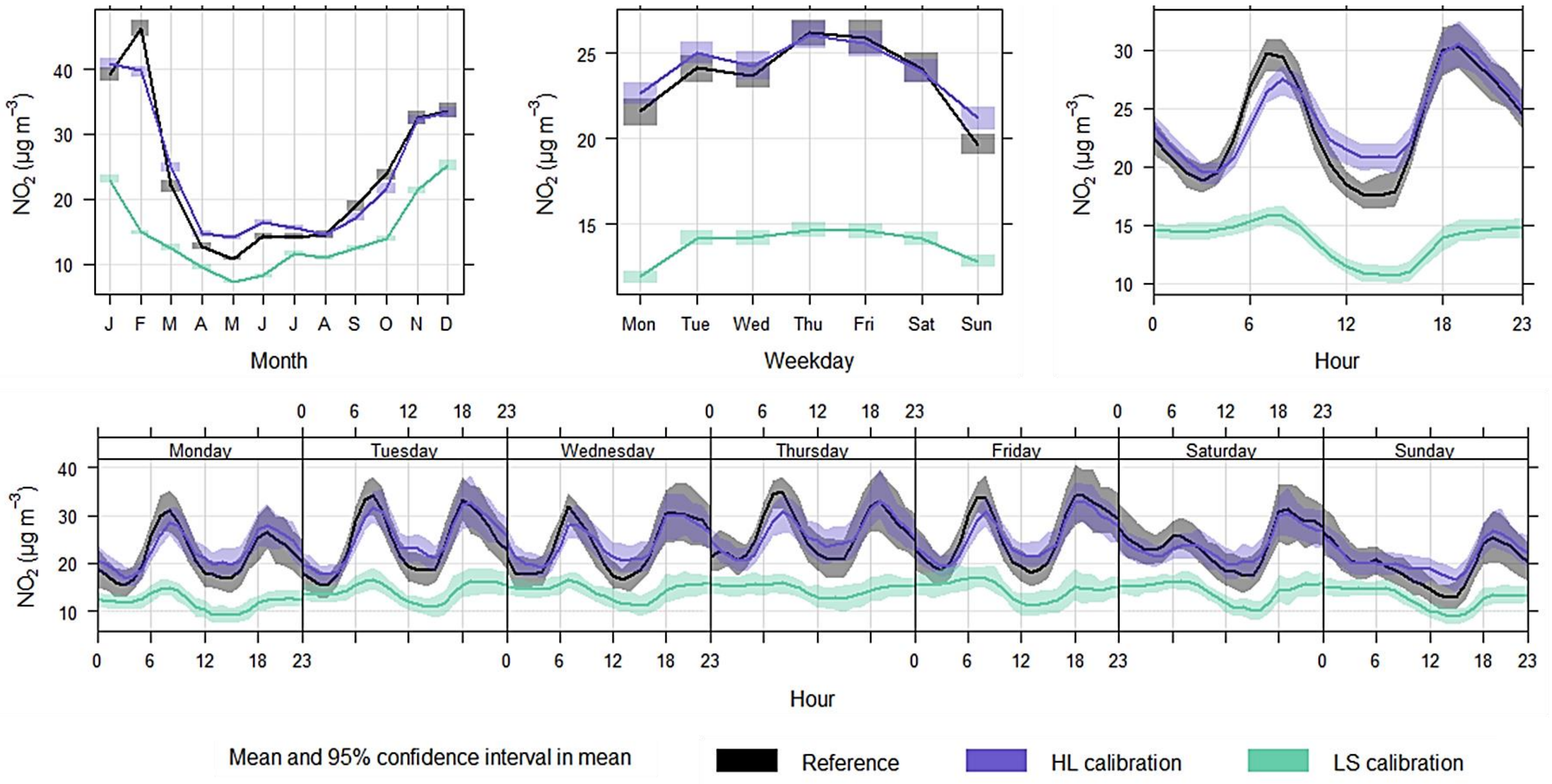
- The seasonal and hourly cycles of NO_2 concentration are found, although underestimated with LS calibration



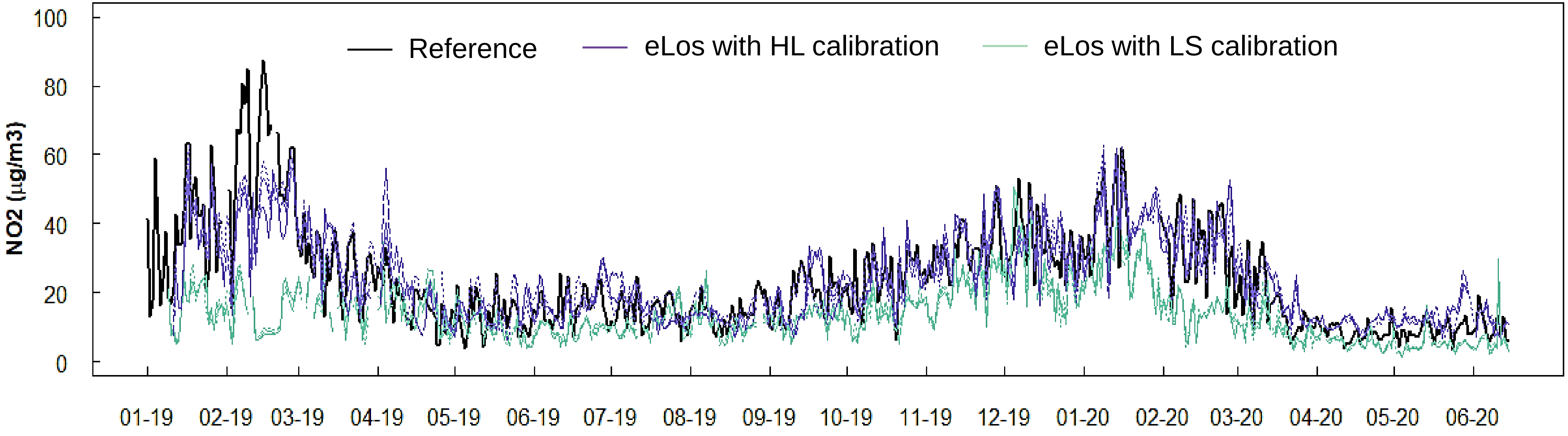
NO2 overview | NO2 temporal cycle | NO2 daily scale | NO2 hourly scale

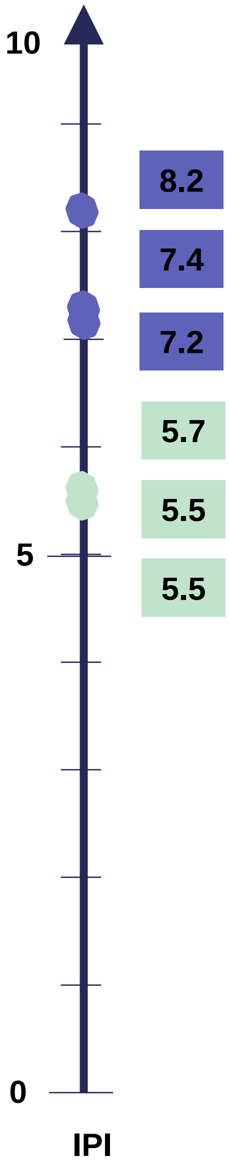
Evaluation of performance at daily scale

LS= large scale
HL= hyperlocal

- Very high degree of agreement between reference and eLos with HL calibration measurements: high IPI and correlation, low error.
- Lower agreement with LS calibration because traffic-related NO_2 concentrations are more variable and higher in the city than in the surrounding area. The large scale of Copernicus data (≈25 km) does not reflect this.

Nb. Data	Mean ref.	Calibration	R^2	MAE ($\mu g.m^{-3}$)	MAPE (%)
532	24 ($\mu g.m^{-3}$)	HL	0.60 – 0.80	4.6 – 6.9	18 – 25
		LS	0.27 – 0.31	11.4 – 11.5	43 – 44

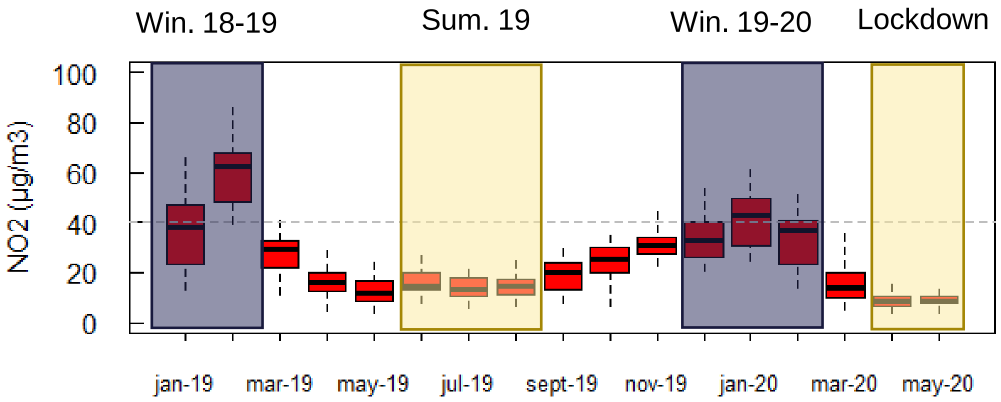




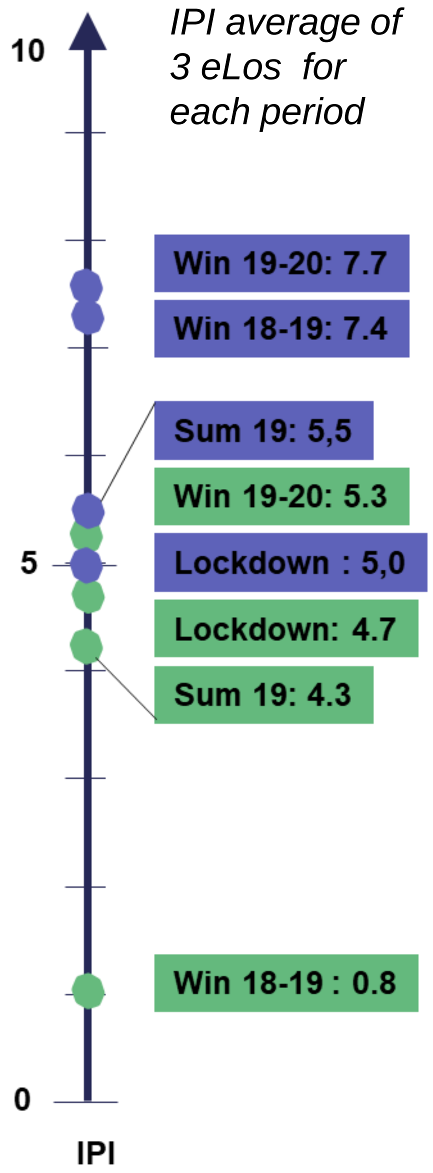
Evaluation of performance at hourly scale

LS= large scale
HL= hyperlocal

- High degree of agreement with HL calibration in winter periods when concentrations are high.
- Lower agreement for periods with low concentration (close to detection limit) and with LS calibration



	Nb. data	Mean ref.	Calibration	R^2	MAE (µg.m⁻³)	MAPE (%)
Win. 18-19	1176	52 (µg.m⁻³)	HL	0.55 – 0.69	14.6 – 18.1	26 – 32
			LS	< 0.1	37.1 – 38;0	66 – 69
Sum. 19	2206	15 (µg.m⁻³)	HL	0.1 – 0.33	5.6 – 7.3	31 – 40
			LS	< 0.1	7.5 – 8.1	46 – 48
Win. 19-20	2184	36 (µg.m⁻³)	HL	0.49 – 0.75	6.9 – 9.5	15 – 22
			LS	0.22 – 0.23	17.1 – 17.7	45 – 47
Lockdown	1464	9 (µg.m⁻³)	HL	0.1 – 0.18	4.5 – 4.6	46 – 48
			LS	< 0.1	5.2 – 5.9	51 – 62



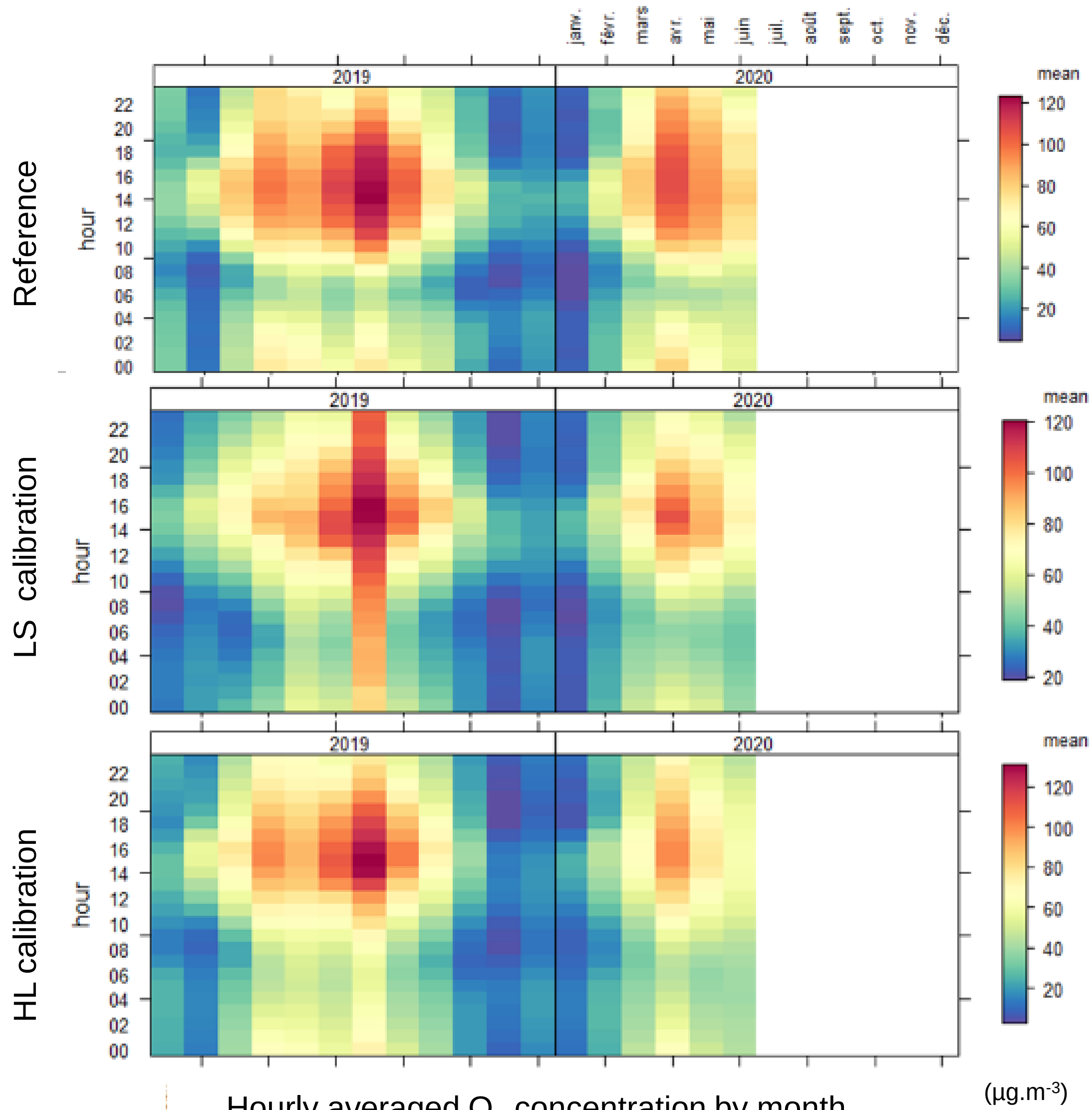
Overview of O_3 measurements

LS= large scale
HL= hyperlocal

- **Presence rate:**
  > 97% for the 3 stations over 17 months

- **Quality of repeatability:**
  standard deviation between the 3 stations:
  LS calibration: 4.5 ± 7 $\mu g.m^{-3}$
  HL calibration. : 4.7 ± 4 $\mu g.m^{-3}$

- **On a general overview:**
  O_3 measurements with HL and LS calibration are similar to reference measurements. With LS calibration, measurements are slightly overestimated .



Hourly averaged O_3 concentration by month

O3 overview | O3 temporal cycle | O3 daily scale | O3 hourly scale

Comparison of O_3 temporal cycles

LS= large scale
HL= hyperlocal

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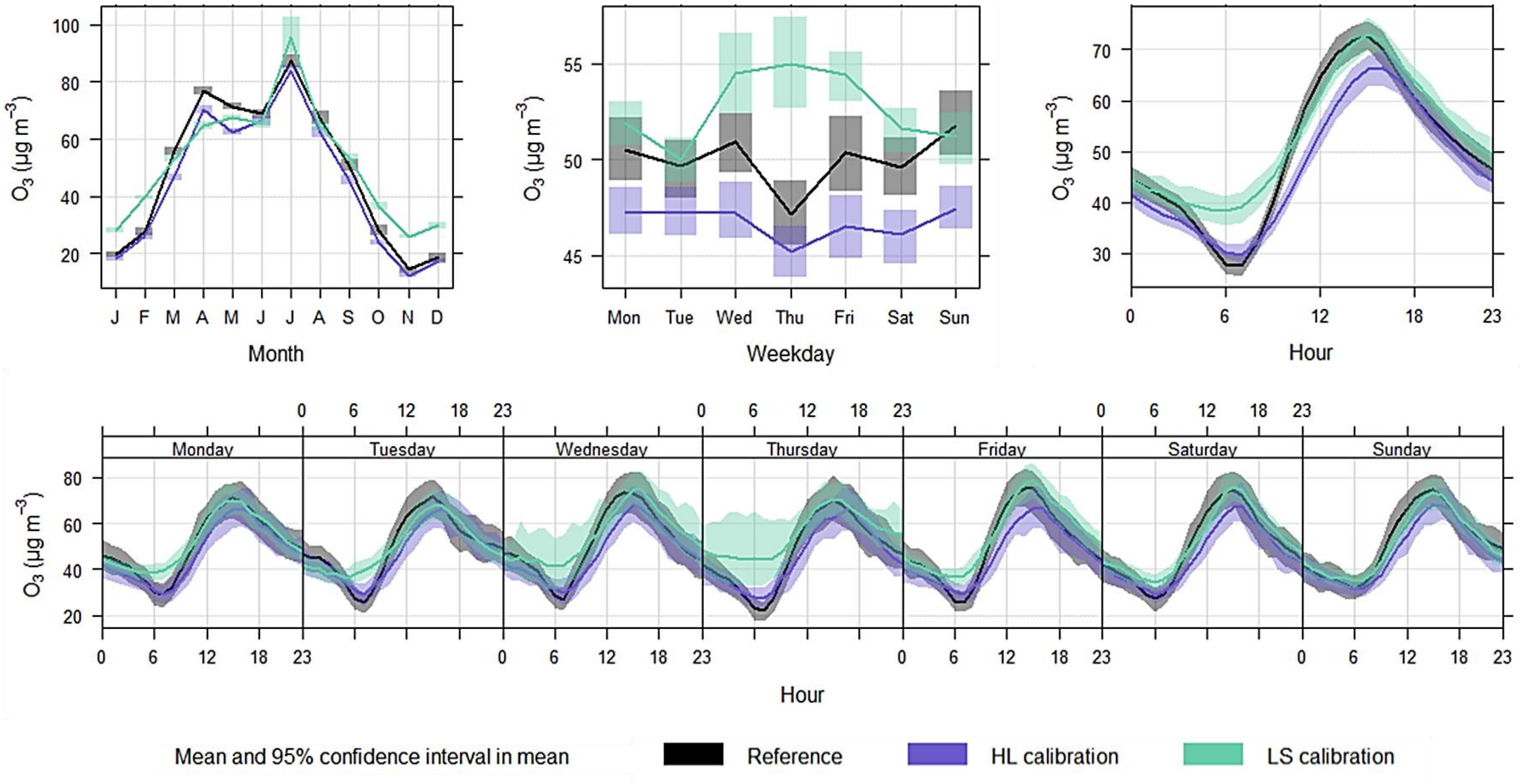
- The seasonal and hourly cycles of O_3 concentration are globally found, although overestimates are observed with the LS calibration.



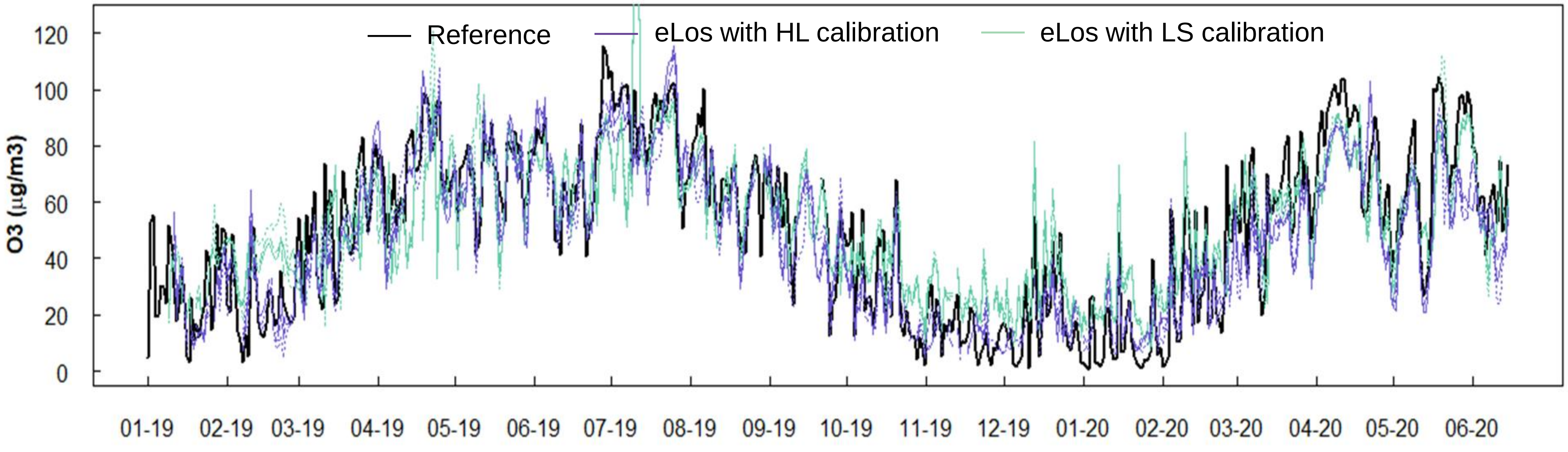
O3 overview | O3 temporal cycle | O3 daily scale | O3 hourly scale

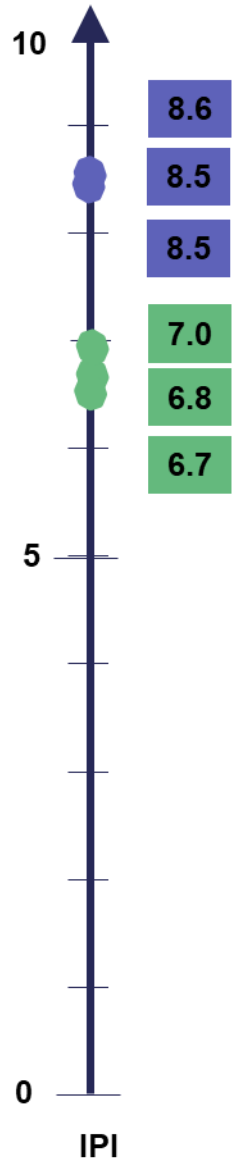
Evaluation of performance at daily scale

LS= large scale
HL= hyperlocal

- Very high degree of agreement between reference and eLos with HL calibration and high with LS calibration. For this calibration, correlation are lower due to few days with high difference between reference and eLos recalibrated measurements.

Nb. Data	Mean ref.	Calibration	R^2	MAE ($\mu g.m^{-3}$)	MAPE (%)
532	50 ($\mu g.m^{-3}$)	HL	0.85 – 0.88	9.2 – 9.7	9– 10
		LS	0.35 – 0.43	14.2 – 14.5	22 – 23



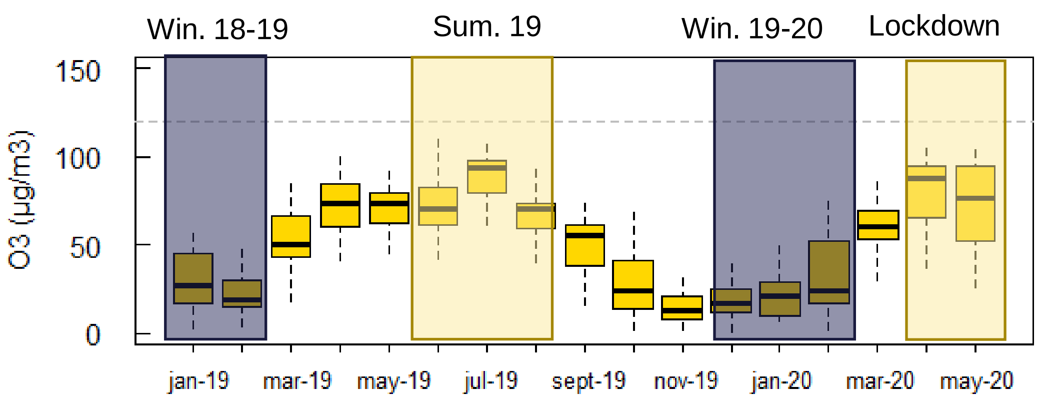


O3 overview | O3 temporal cycle | O3 daily scale | O3 hourly scale

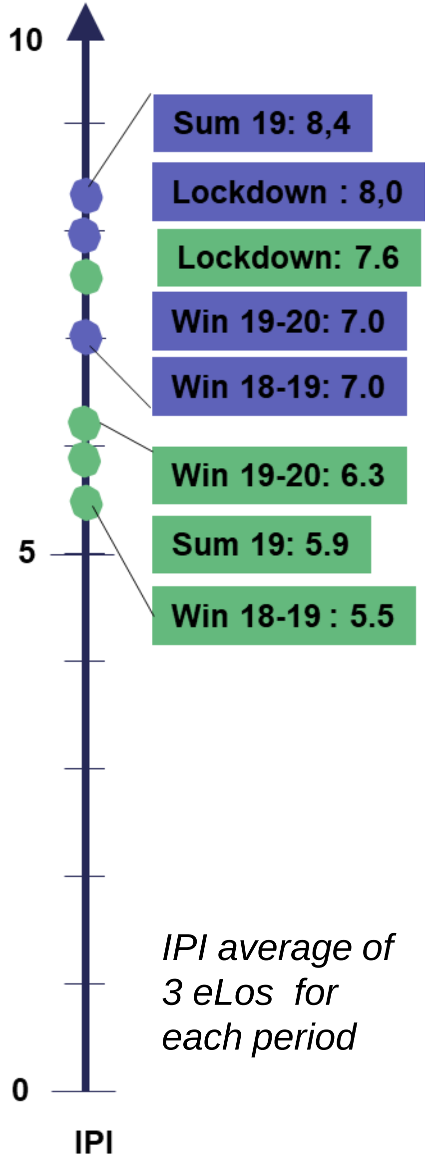
Evaluation of performance at hourly scale

LS= large scale
HL= hyperlocal

- Very high degree of agreement with HL calibration for all periods, even with low concentration
- High degree of agreement with LS calibration but error are slightly higher, and correlation are lower due to few days with high difference with reference.



	Nb. Data	Mean ref.	Calibration	R^2	MAE ($\mu g.m^{-3}$)	MAPE (%)
Win. 18-19	1176	24 ($\mu g.m^{-3}$)	HL	0.60 – 0.73	9.3 – 11.3	39 – 46
			LS	0.20 – 0.23	19.5 – 20.8	87 – 96
Sum. 19	2206	72 ($\mu g.m^{-3}$)	HL	0.74 – 0.81	12.2 – 14.1	14 – 16
			LS	0.12 – 0.14	20.5 – 24	16 – 19
Win. 19-20	2184	13 ($\mu g.m^{-3}$)	HL	0.65 – 0.74	10.7 – 12.3	48 – 52
			LS	0.38 – 0.40	17.7 – 18.2	100 – 109
Lockdown	1464	76 ($\mu g.m^{-3}$)	HL	0.71 – 0.77	16.2 – 16.6	20 – 21
			LS	0.63 – 0.72	15.3 – 16.3	18 – 19



IPI average of 3 eLos for each period

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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: marc.attia@elichens.com

See you soon!

Want to know **more** ?

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

www.elichens.com