Multi-sensor devices to monitor urban air quality as a support for the official network: development, selection and calibration

Falzone C. – Uliège – UR SPHERE, Sensing of Atmospheres and Monitoring (SAM)
Lenartz F. – ISSeP – Official Walloon Air Quality Department
Romain AC. – Uliège – UR SPHERE, Sensing of Atmospheres and Monitoring (SAM)

Objectives

- Development of low-cost sensor systems (LCSS) for air quality monitoring
- Calibration campaign collocated with an official monitoring station
- Evaluation of different calibration approaches

Campaign

Herstal – Belgium

- Official air quality monitoring station (Urban background station)
- Continuous measurement
  - NO – APNA 370 HORIBA ® (chemiluminescence)
  - NO_2 - APNA 370 HORIBA ® (chemiluminescence)
  - O_3 – APOA 370 HORIBA ® (UV absorption)
  - PM_{10} and $PM_{2.5}$ – EDM180 GRIMM ® (light scattering)
- Campaign
  - Calibration period: from 26-03-2024 to 31-05-2024 (47d)
  - Validation period: from 01-06-2024 to 30-06-2024 (30d)
  - The ranges of the calibrations cover the ranges of the validation (except temperature and O_3)
  - Data: average on 30 minutes (based on 6-s/10-s measurement)

	Period	Min	q0.25	q0.5	Mean	q0.75	Max	NA's
Relative humidity - (%)	Cal.	28	61	84	77.9	98	98	458
	Val.	*26*	*53*	*81*	*74.1*	*98*	*98*	*211*
Temperature - (°C)	Cal.	-0.5	9	12.7	12.6	15.7	27.5	458
	Val.	*7.8*	*13.6*	*16.1*	*16.8*	*19.3*	*30*	*211*
Precipitation - (mm)	Cal.	0	0	0	0.1	0	21.4	10
	Val.	*0*	*0*	*0*	*0.1*	*0*	*9.6*	*1*
NO - (ppb)	Cal.	0	0.8	0.8	2.1	2.4	43.3	83
	Val.	*0*	*0.8*	*0.8*	*2.1*	*2*	*32.1*	*78*
NO_2 - (ppb)	Cal.	0.5	3.7	5.8	6.8	8.9	33.4	83
	Val.	*0.5*	*3.1*	*5.2*	*6.6*	*8.9*	*33.4*	*78*
O_3 - (ppb)	Cal.	0	21.5	30.6	29.3	37.6	66.1	84
	Val.	*1.5*	*19.5*	*28.6*	*30.2*	*39.6*	*78.1*	*76*
$PM_{2.5}$ - (µg/m^3)	Cal.	0	0	2.7	5.3	6.5	60.7	13
	Val.	*0*	*2.7*	*6.5*	*7.3*	*11.4*	*31.7*	*4*
PM_{10} - (µg/m^3)	Cal.	0	4	8	12.8	18	258	13
	Val.	*0*	*9*	*17*	*19.3*	*25*	*157*	*4*

Campaign
LCSS

Electrochemical sensors: Alphasense ® for NO, NO_2, O_3

Optical sensors: Sensirion ® SPS30 for $PM_{2.5}$, PM_{10}

Probe: temperature and humidity

Data acquisition: 1 minute on SD-card and on cloud (Grafana)

No pump: natural air flow

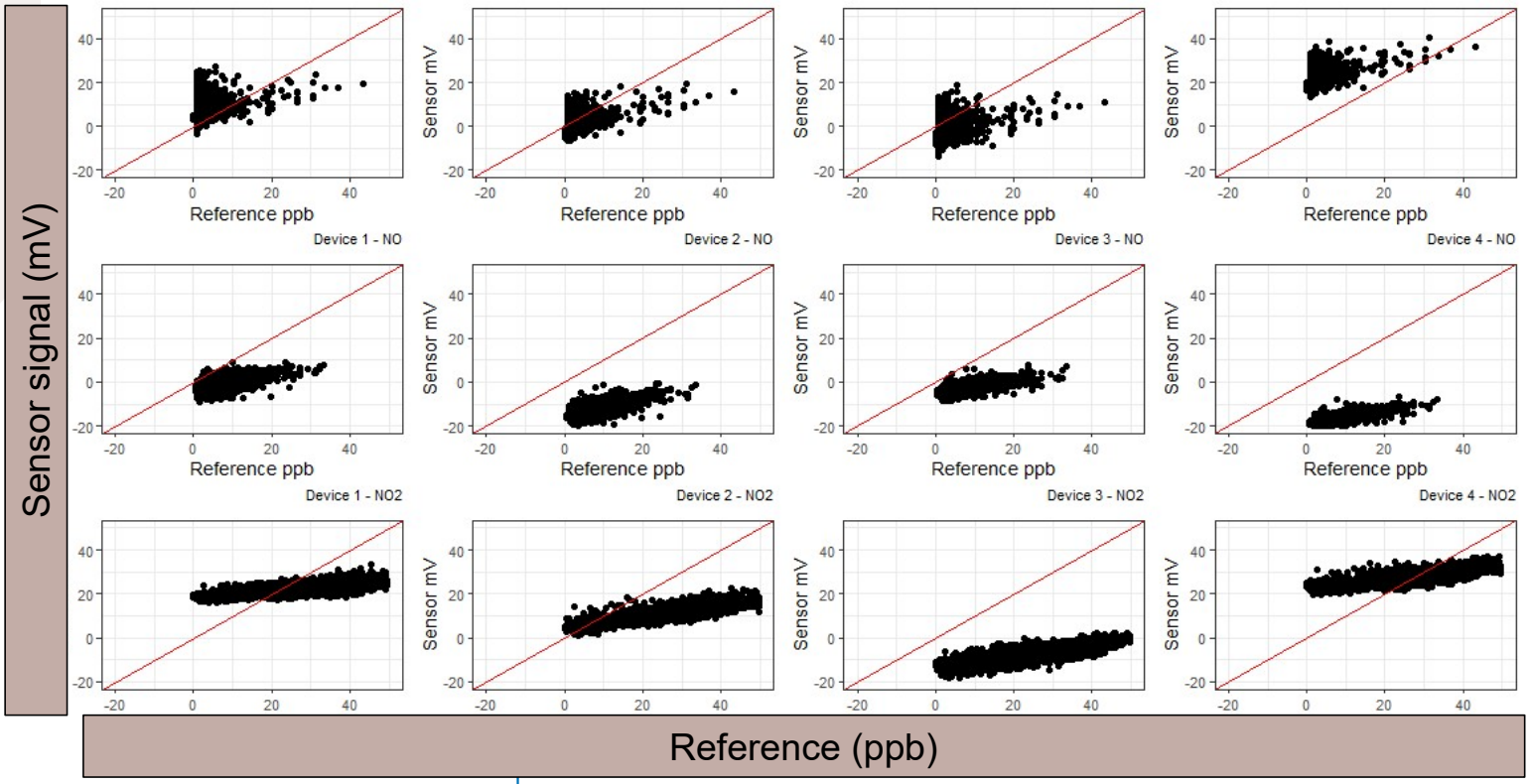
ECT

Saïga

	ECT	Saïga
Number of LCSS	4	1
EC sensors series	B4	A4
EC sensor	WE and AE	WE signal (voltage difference |b| the working and the counter electrode)
Communication	Wifi / LTE (4G)	LTE (4G)
Power supply	12V	Photovoltaic panel (12-18V)

Gas sensors Results – ECT

Raw data



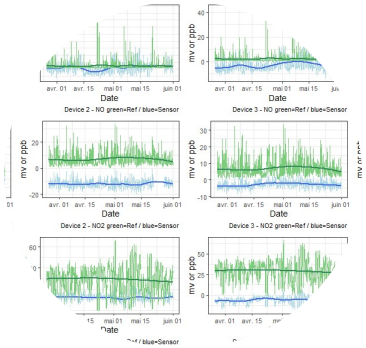
Verification

- Sensors drift
- Effect of temperature and humidity

Gas sensors Results – ECT

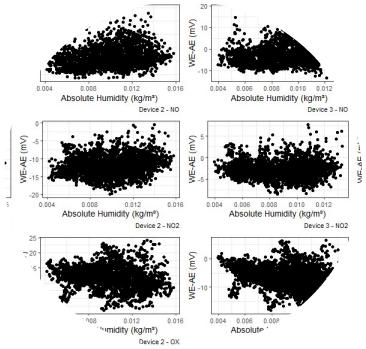
Influence

During this short period (2 months)



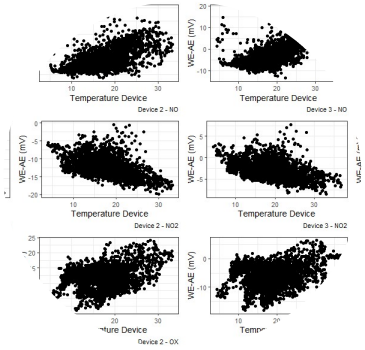
Drift

NO



Absolute Humidity

NO



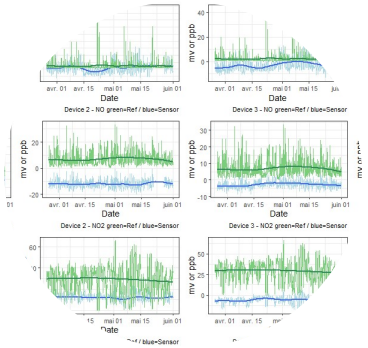
Temperature

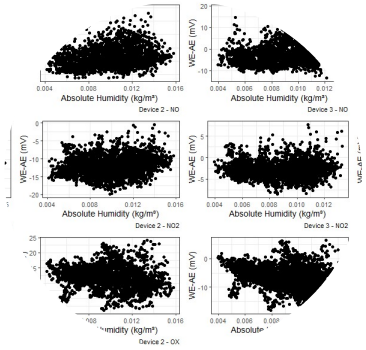
YES

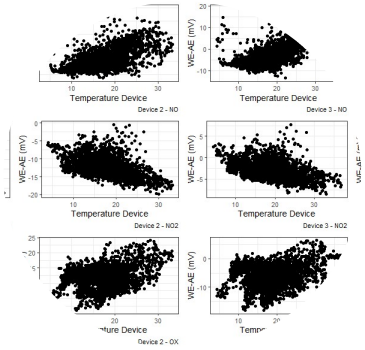
Gas sensors Results – ECT

Influence

During this short period (2 months)







Drift	Humidity	Temperature
NO	NO	YES

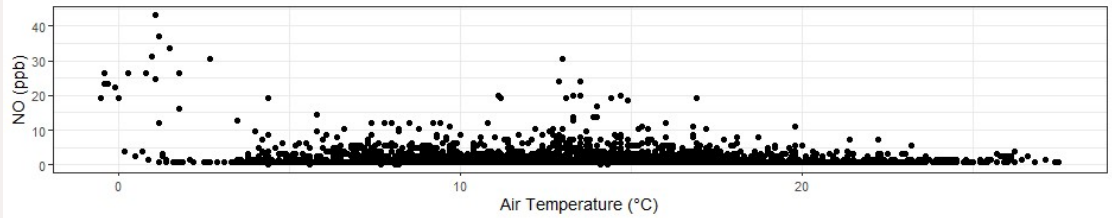
Is the sensor or the pollutant influenced by the temperature?

Gas sensors Results – ECT

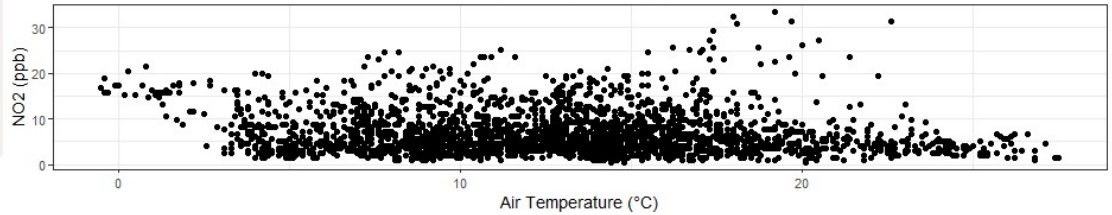
Influence

Concentrations from official station

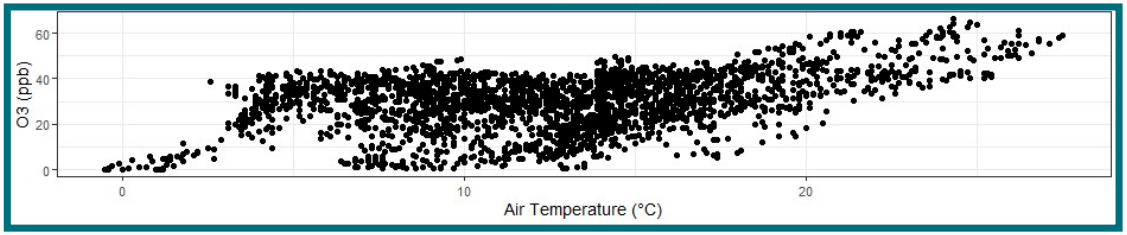
NO

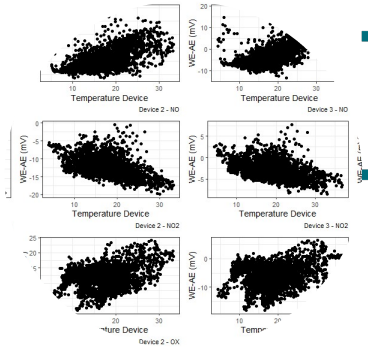


NO_2



O_3





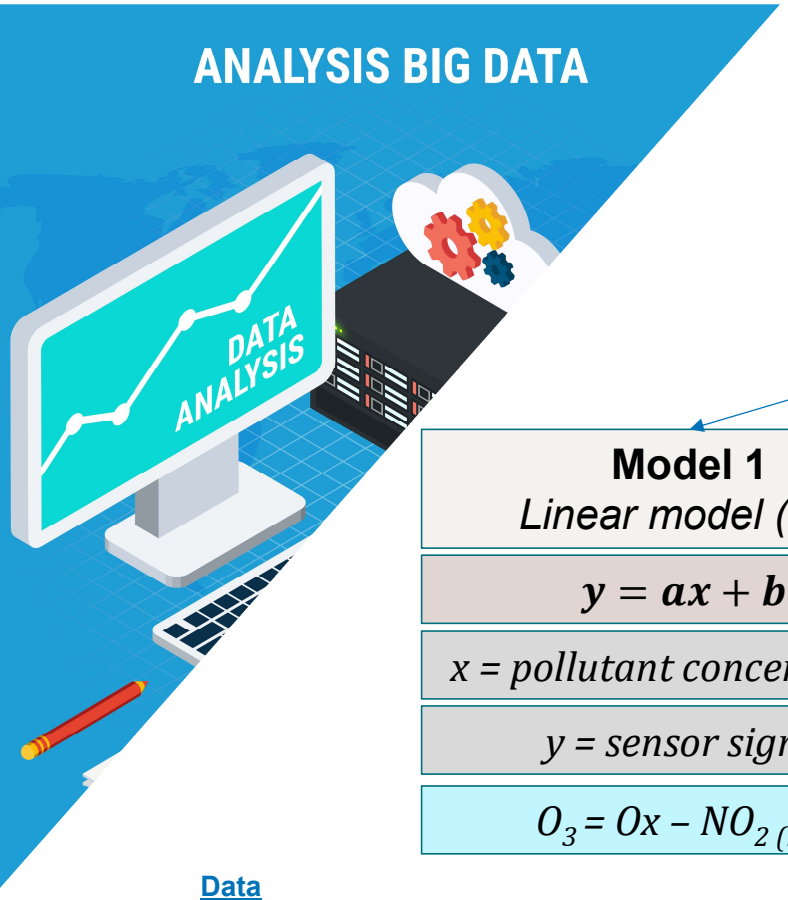
Temperature

YES

NO and NO_2 concentrations no affected by temperature.

↳Sensor influenced by temperature

O_3 affected by temperature



Gas sensors Results - ECT
Calibration models

LIÈGE université Arlon Campus Environnement

ISSeP Institut scientifique de service public

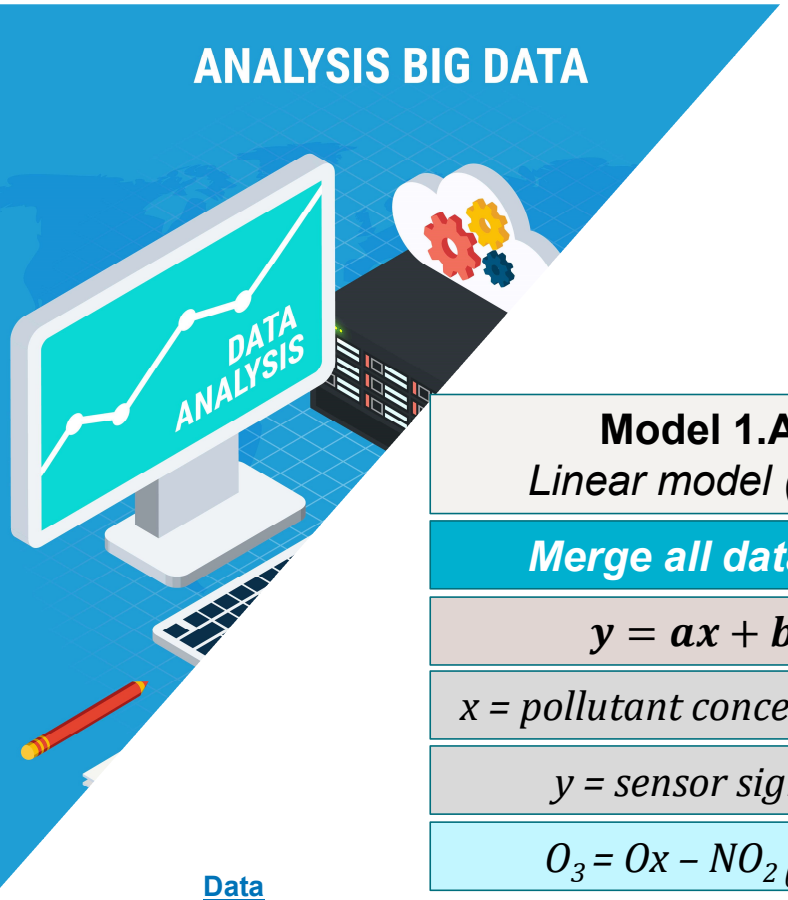
Individual calibration dataset

Model 1 *Linear model (LM)*	**Model 2** *Linear model (LM)*	**Model 3** *Multi-Linear model*
$y = ax + b$	$y = ax_t + b$	$y = ax_t + bx_{ref} + c$
x = pollutant concentration	x_t = temperature	x_t = temperature
y = sensor signal	y = sensor signal	x_{ref} = pollutant concentration
$O_3 = Ox - NO_{2\ (raw)}$	$y' = ax_{ref} + b$	y = sensor signal
	x_{ref} = pollutant concentration	$O_3 = Ox - NO_{2\ (raw)}$
	y' = sensor signal corrected	
	$O_3 = Ox - NO_{2\ (T\ corrected)}$	

Data
- 4 sensors for each pollutant
- Sensor values WE and AE (mV)
- Reference values expressed (ppb)
- Temperature (°C)

Cross validation
K fold = 10

S.A.M.

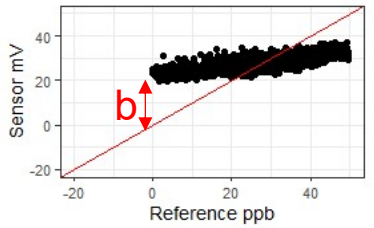


Gas sensors Results - ECT
Calibration models

Model 1.A *Linear model (LM)*
Merge all dataset
$y = ax + b$
x = *pollutant concentration*
y = *sensor signal*
$O_3 = Ox - NO_{2\ (raw)}$

Model 2.A *Linear model (LM)*
Individual dataset
$y = ax_t + b$
x_t = *temperature*
y = *sensor signal*
Merge all dataset
$y' = ax_{ref} + b$
x_{ref} = *pollutant concentration*
y' = *sensor signal corrected*
$O_3 = Ox - NO_{2\ (T\ corrected)}$

Model 3.A *Multi-Linear model*
Merge all dataset
$y = ax_t + bx_{ref} + c$
x_t = *temperature*
x_{ref} = *pollutant concentration*
y = *sensor signal*
$O_3 = Ox - NO_{2\ (raw)} + b$



Data
- 4 sensors for each pollutant
- Sensor values WE and AE (mV)
- Reference values expressed (ppb)
- Temperature (°C)

Cross validation
K fold = 10

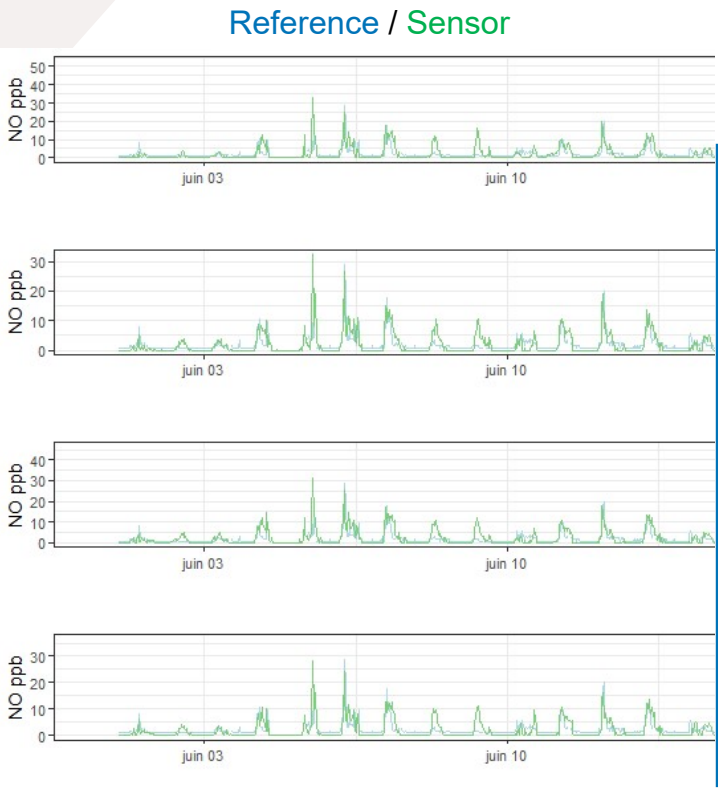
Alternative
All dataset by pollutant merge in one

Gas sensors Results - ECT

Validation period – best models

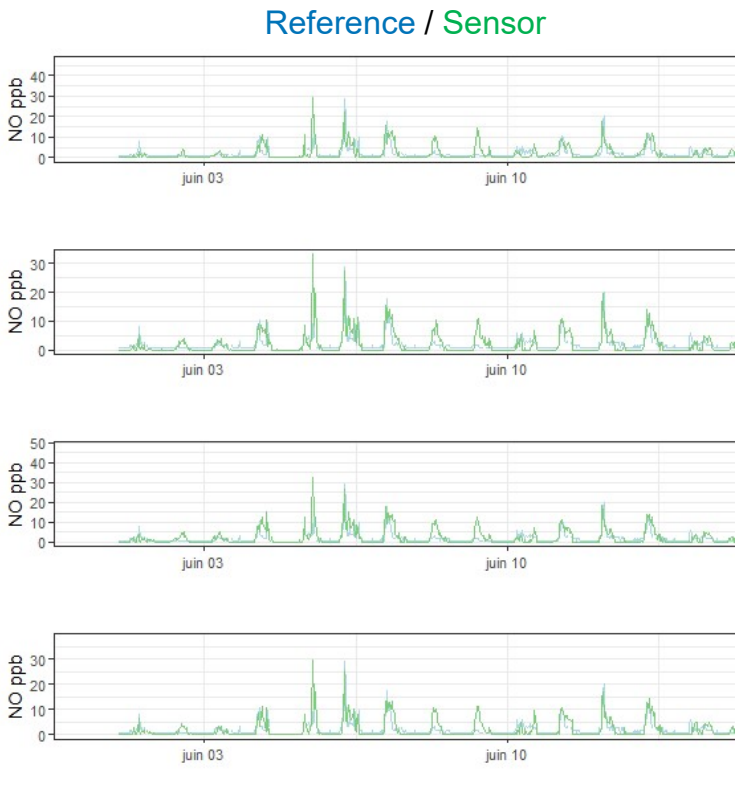
NO - Model 2 (T correction – IDS)*

Sensor 1	R^2	0.36
	LIN	0.51
	MAE	2.3
	RMSE	4.28
Sensor 2	R^2	0.41
	LIN	0.61
	MAE	1.83
	RMSE	2.96
Sensor 3	R^2	0.42
	LIN	0.59
	MAE	2.03
	RMSE	3.48
Sensor 4	R^2	0.45
	LIN	0.64
	MAE	1.9
	RMSE	3.12



NO - Model 2.A (T correction – ADS*)

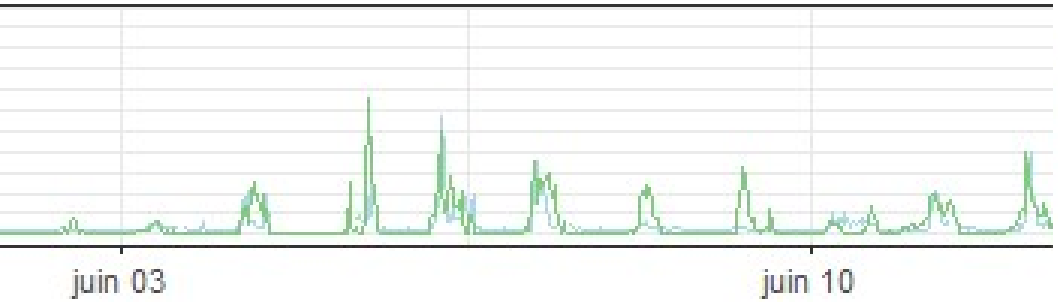
R^2	0.37
LIN	0.54
MAE	2.12
RMSE	3.82
R^2	0.41
LIN	0.6
MAE	1.87
RMSE	3.03
R^2	0.42
LIN	0.58
MAE	2.08
RMSE	3.61
R^2	0.45
LIN	0.63
MAE	1.96
RMSE	3.24

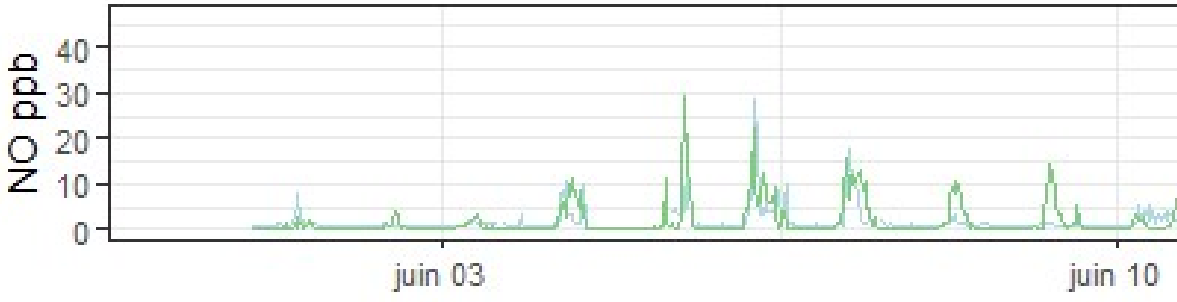


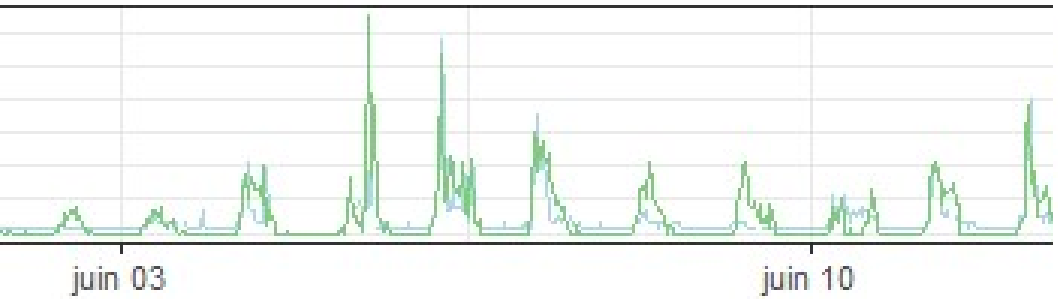
*IDS=Individual dataset ; ADS=All dataset

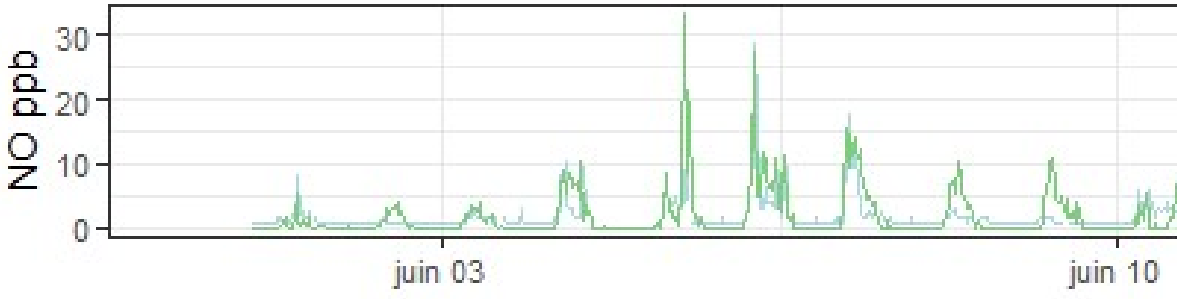
Gas sensors Results - ECT

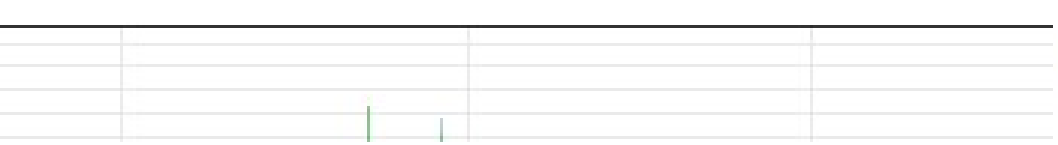
Validation period – best models











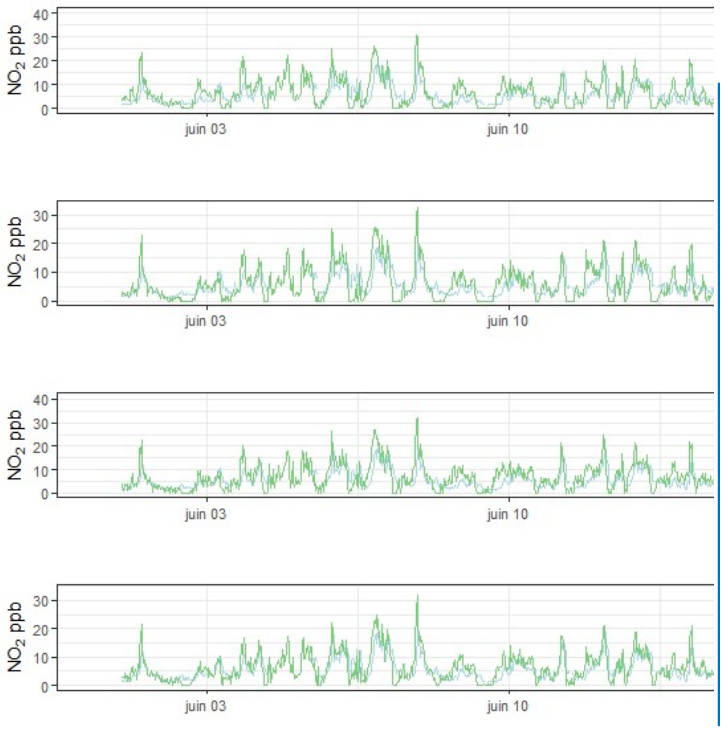
Gas sensors Results - ECT

Validation period – best models

NO_2 - Model 2 (T correction – IDS)*

Sensor 1	R^2	0.38
	LIN	0.54
	MAE	4.5
	RMSE	6.04
Sensor 2	R^2	0.45
	LIN	0.6
	MAE	3.58
	RMSE	4.89
Sensor 3	R^2	0.43
	LIN	0.59
	MAE	3.92
	RMSE	5.41
Sensor 4	R^2	0.57
	LIN	0.71
	MAE	3.08
	RMSE	4.21

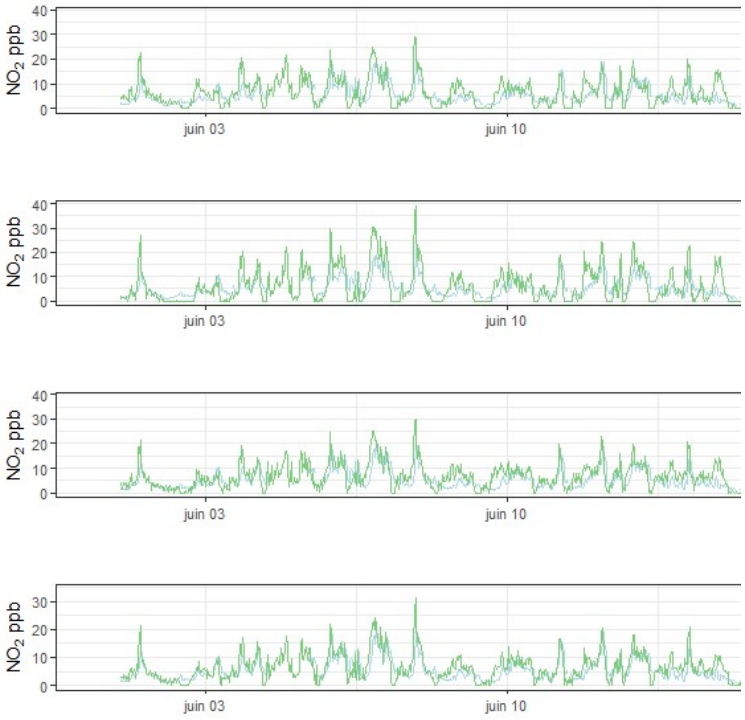
Reference / Sensor



NO_2 – Model 2.A (T correction – ADS)*

	R^2	0.38
	LIN	0.55
	MAE	4.3
	RMSE	5.77
	R^2	0.45
	LIN	0.53
	MAE	4.35
	RMSE	6.1
	R^2	0.43
	LIN	0.6
	MAE	3.71
	RMSE	5.08
	R^2	0.58
	LIN	0.71
	MAE	3.07
	RMSE	4.2

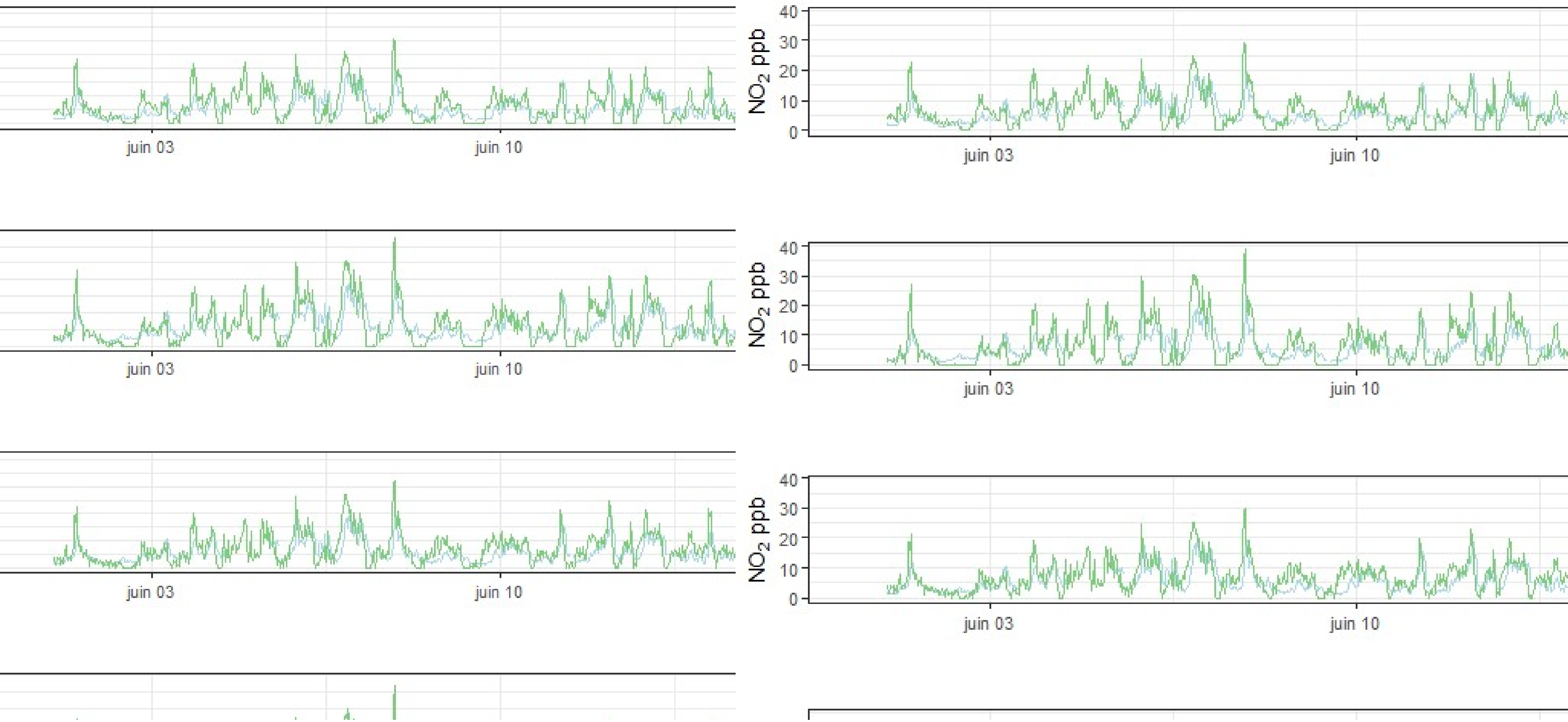
Reference / Sensor



*IDS=Individual dataset ; ADS=All dataset

Gas sensors Results - ECT

Validation period – best models



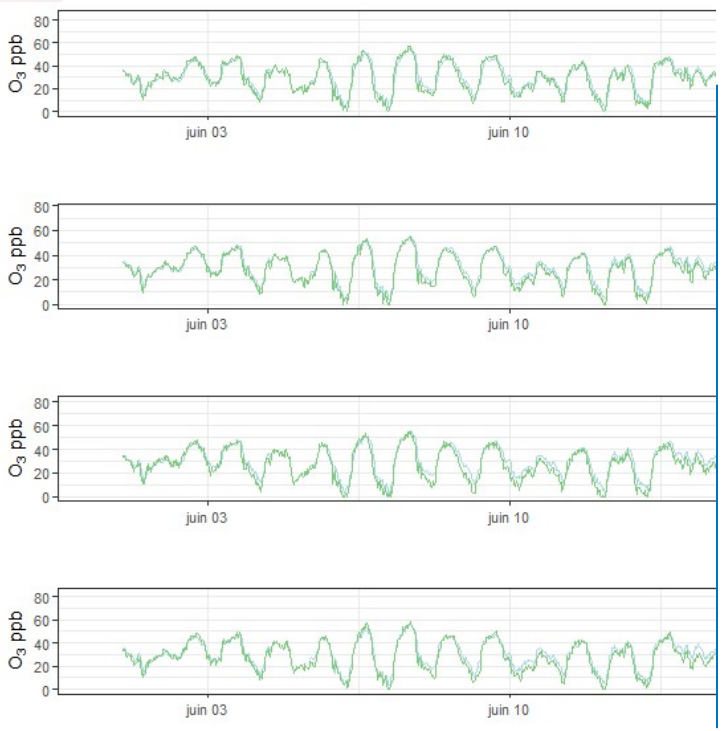
Gas sensors Results - ECT

Validation period – best models

O_3 - Model 3 (T in the model – IDS*)

Sensor 1	R^2	0.92
	LIN	0.95
	MAE	3.89
	RMSE	5.13
Sensor 2	R^2	0.94
	LIN	0.96
	MAE	3.07
	RMSE	4
Sensor 3	R^2	0.93
	LIN	0.94
	MAE	4.43
	RMSE	5.57
Sensor 4	R^2	0.95
	LIN	0.96
	MAE	3.69
	RMSE	4.6

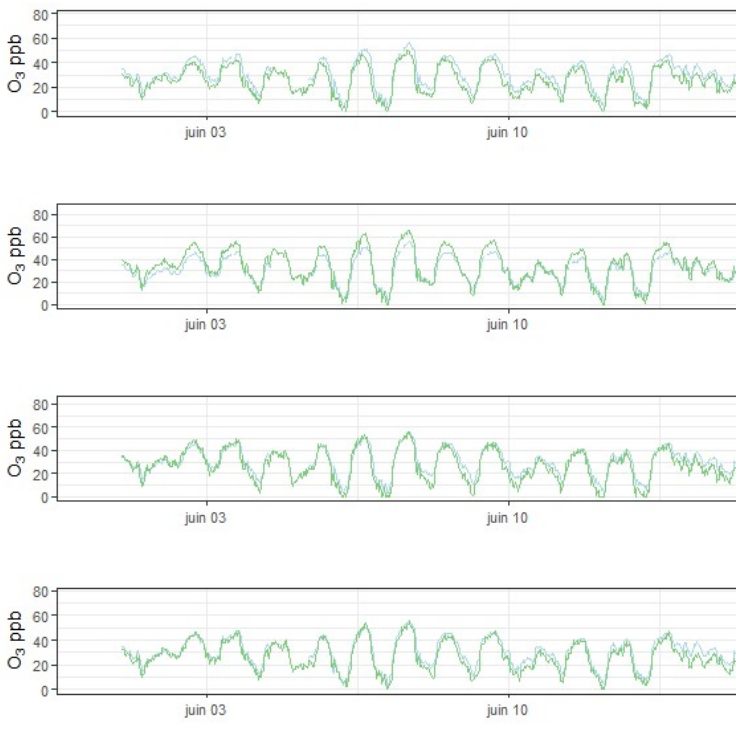
Reference / Sensor



O_3 - Model 3.A (T in the model – ADS*)

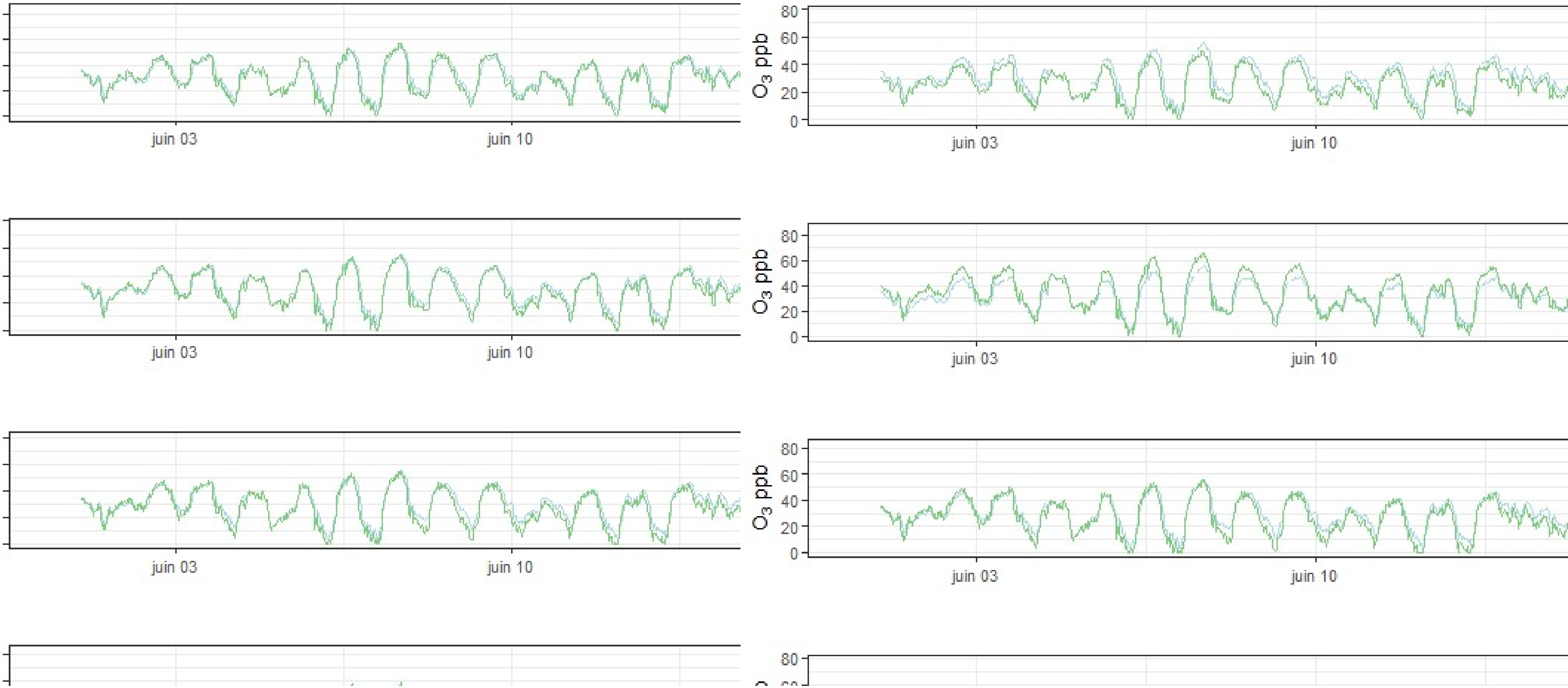
	R^2	0.92
	LIN	0.95
	MAE	3.89
	RMSE	5.13
	R^2	0.94
	LIN	0.96
	MAE	3.07
	RMSE	4
	R^2	0.93
	LIN	0.94
	MAE	4.43
	RMSE	5.57
	R^2	0.95
	LIN	0.96
	MAE	3.69
	RMSE	4.6

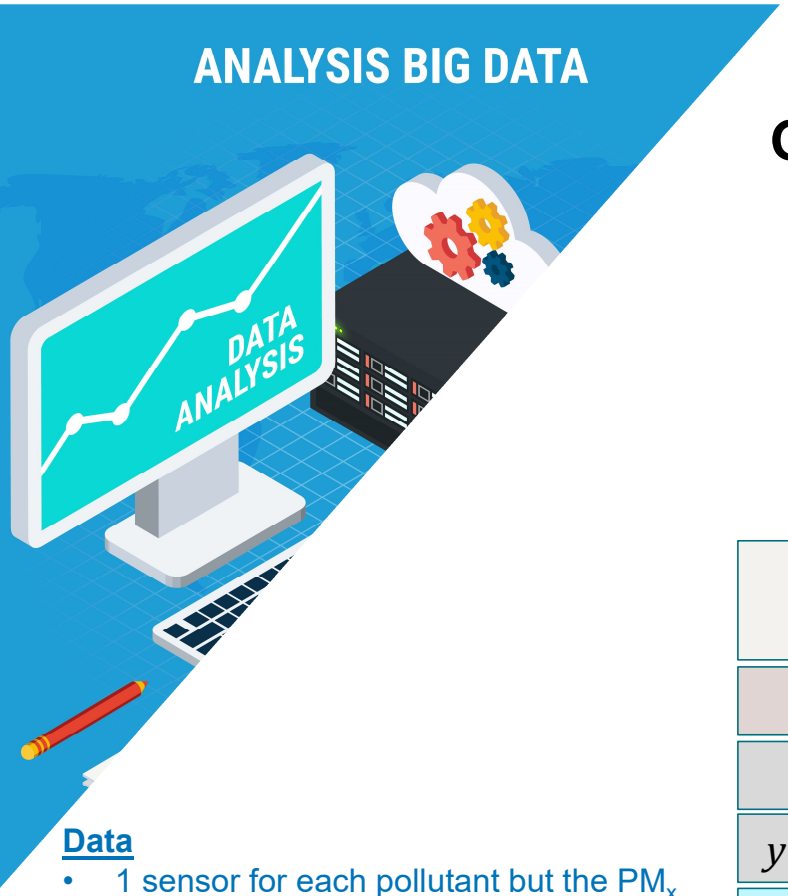
Reference / Sensor



*IDS=Individual dataset ; ADS=All dataset

Gas sensors Results - ECT
Validation period – best models





Gas sensors Results – Saïga (ISSeP)

Calibration models

Individual calibration dataset

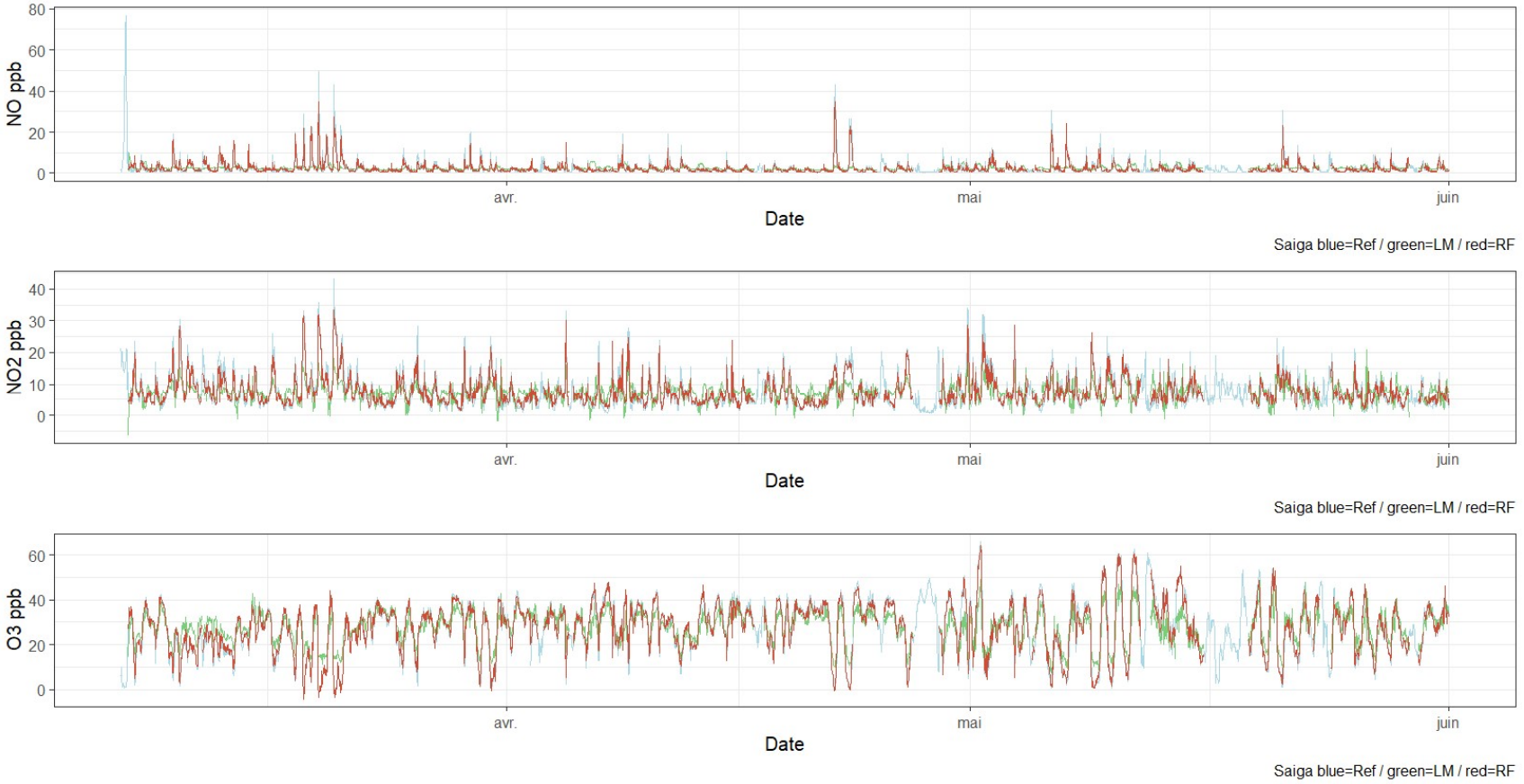
Model 1 *Linear model (LM)*	**Model 2** *Random Forest (RF)*
$y = ax + b$	**50 trees**
x = sensor signal	x_{sensor} = sensor signal
y = pollutant concentration	x_t = temperature
$O_3 = Ox - NO_{2\ (raw)}$	x_{RH} = relative humidity
	y = pollutant concentration
	$O_3 = Ox - NO_{2\ (raw)}$

Data

- 1 sensor for each pollutant but the PM_x that provides both $PM_{2.5}$ and PM_{10}
- Sensor raw values (WE-CE)
- No use of the AE
- Reference values expressed in µg/m³
  Temperature expressed in °C
- Relative humidity expressed in %

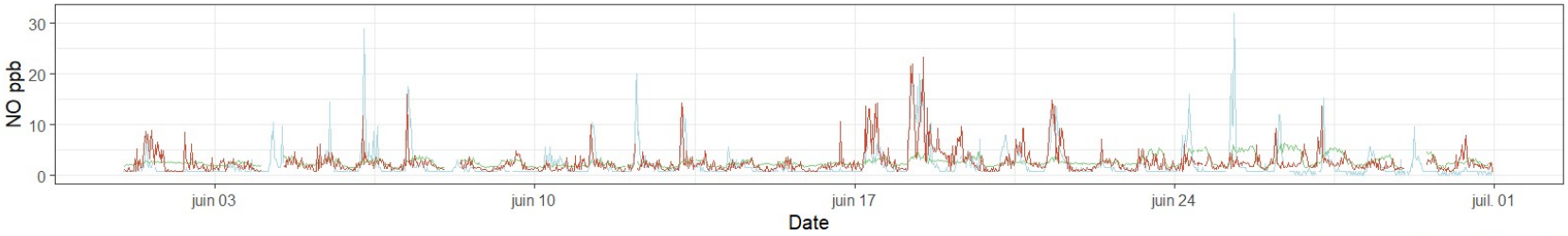
Gas sensors Results – Saïga (ISSeP)
Calibration models

Random forest fit very well on the calibration dataset



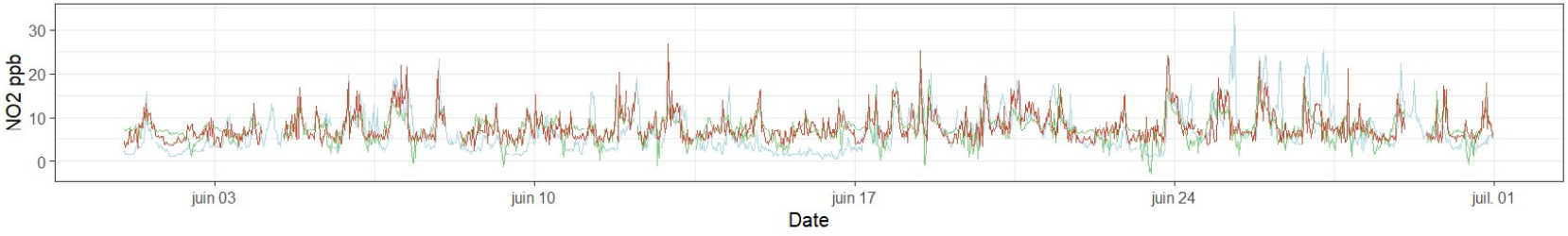
Gas sensors Results – Saïga (ISSeP)
Validation period – best models

NO sensor	LM	RF
R^2	0.07	0.22
LIN	0.14	0.44
MAE	2.47	2.11
RMSE	3.79	3.62



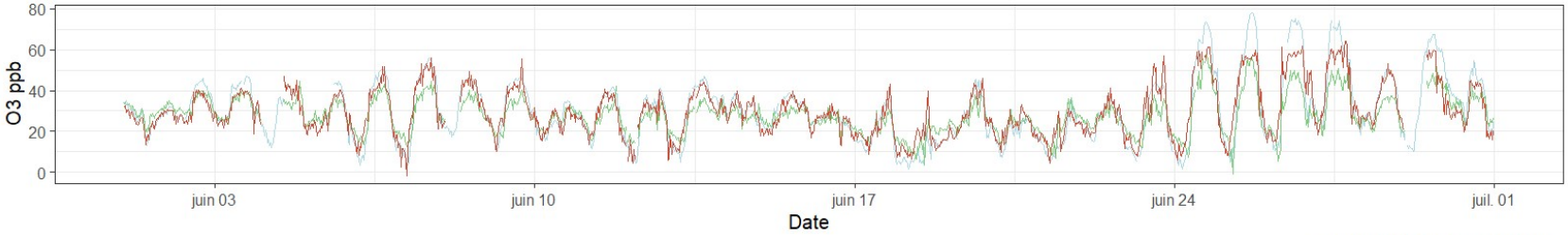
Saiga blue=Ref / green=LM / red=RF

NO_2 sensor	LM	RF
R^2	0.17	0.22
LIN	0.38	0.43
MAE	6.77	6.30
RMSE	8.69	8.55

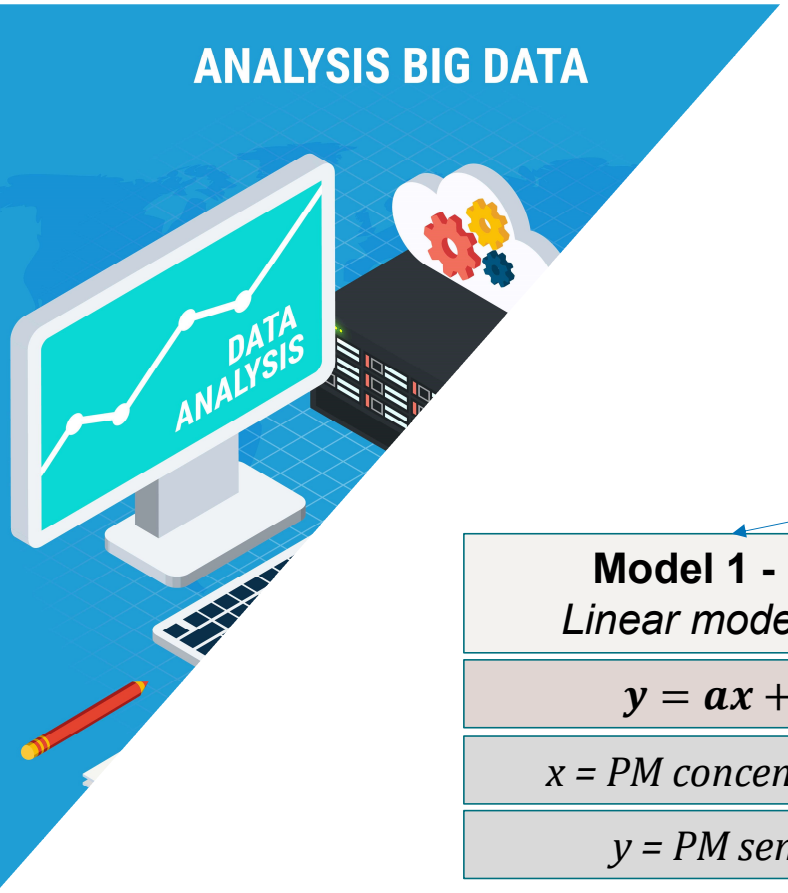


Saiga blue=Ref / green=LM / red=RF

O_3 sensor	LM	RF
R^2	0.88	0.86
LIN	0.79	0.90
MAE	13.21	9.31
RMSE	17.06	12.67



Saiga blue=Ref / green=LM / red=RF

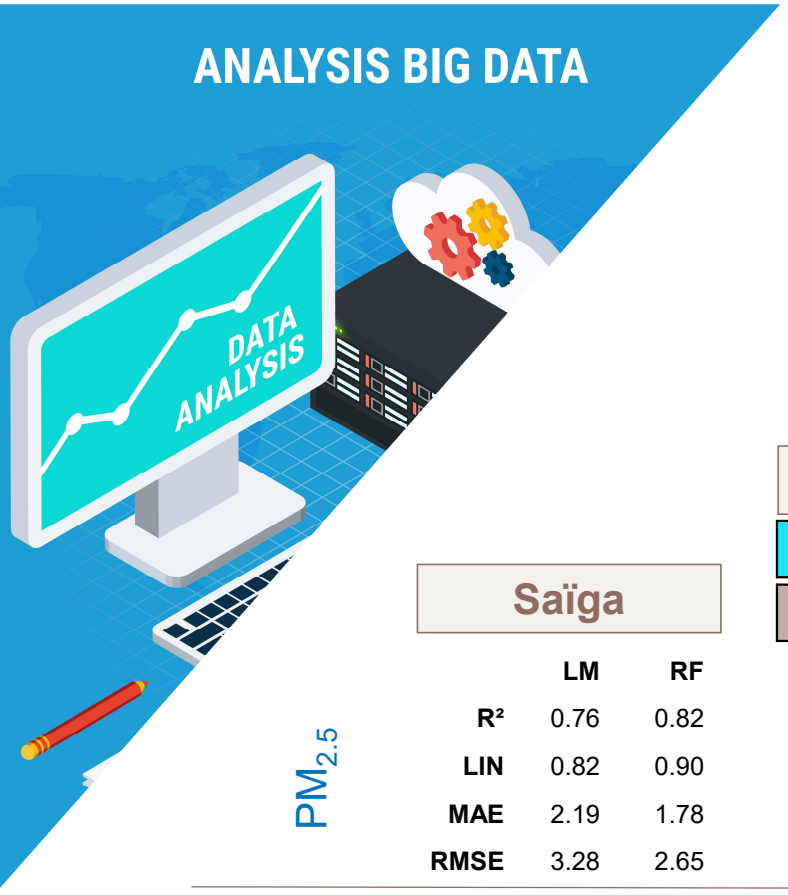


Optical sensors Results ECT & Saïga

Calibration models

Individual calibration dataset

Model 1 - ECT *Linear model (LM)*	**Model 1 - Saïga** *Linear model (LM)*	**Model 2 - Saïga** *Random Forest (RF)*
$y = ax + b$	$y = ax + b$	***50 trees***
x = *PM concentration*	x = *PM sensor*	x_{sensor} = *PM sensor*
y = *PM sensor*	y = *PM concentration*	x_t = *temperature*
		x_{RH} = *relative humidity*
		y = *PM concentration*



Optical sensors Results
ECT & Saïga
Validation

LIÈGE université
Arlon Campus Environnement

ISSeP
Institut scientifique de service public

		Saïga		ECT							
				+1		+2		+3		+4	
				Device 2		Device 4		Device 3		Device 1	
		LM	RF		LM		LM		LM		LM
$PM_{2.5}$	R^2	0.76	0.82	R^2	0.8	R^2	0.79	R^2	0.78	R^2	0.75
	LIN	0.82	0.90	LIN	0.82	LIN	0.8	LIN	0.81	LIN	0.8
	MAE	2.19	1.78	MAE	2.27	MAE	2.37	MAE	2.34	MAE	2.5
	RMSE	3.28	2.65	RMSE	3.34	RMSE	3.51	RMSE	3.48	RMSE	3.63
		LM	RF		LM		LM		LM		LM
PM_{10}	R^2	0.13	032	R^2	0.18	R^2	0.19	R^2	0.18	R^2	0.19
	LIN	0.18	0.48	LIN	0.23	LIN	0.14	LIN	0.14	LIN	0.13
	MAE	9.70	7.66	MAE	10.28	MAE	14.49	MAE	13.7	MAE	15.06
	RMSE	17.05	14.30	RMSE	16.29	RMSE	20.61	RMSE	80.05	RMSE	20.98

Air flow

S.A.M.

Conclusions

Gas sensors

- Temperature:
  - Correction is mandatory
  - T is a variable of the model for O_3
- A single equation for all LCSS seems promising
- RF seems promising during the calibration period but not for generalization (other conditions)
- A4 series sensors perform not as well as the B4 series

Optical sensors

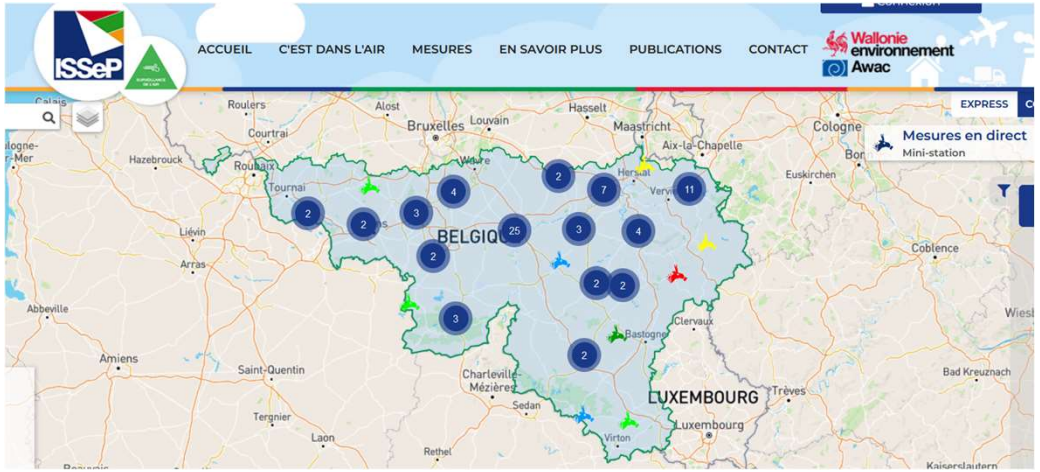
- Better results for $PM_{2.5}$ than for PM_{10},
- SPS30 is adequate for the monitoring of $PM_{2.5}$ in suburban environments.
- Particles measurement is a function of height.

On-going

- Evaluation of the robustness of the calibration models over various environments

  locations, station types, seasons

- On going data treatment from other LCSS (Winsense ®, metal oxide sensors SGX)
- On-going on-site installation in Walloon region (ISSeP)



https://wallonair.be

Thank you for your attention
Questions ?

CONTACTS

Falzone C. – Uliège – UR SPHERE, Sensing of Atmospheres and Monitoring (SAM)
cfalzone@uliege.be

Lenartz F. – ISSeP – Air Quality Department
f.lenartz@issep.be

Romain AC. – Uliège – UR SPHERE, Sensing of Atmospheres and Monitoring (SAM)
acromain@uliege.be