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Air Quality and MObility

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Report on deployment of best practices

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Author(s): François Bodin (UR1), Laurent Morin (UR1), Manuel Chevé (Air Breizh), Simon Leray (Air Breizh), Maël Jan (Air Breizh), David Lavoué (Air Breizh).

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<tr><td rowspan="4">Authorship</td><td>Written by:</td><td>François Bodin (UR1)</td></tr>
<tr><td>Contributors:</td><td>François Bodin (UR1)
Laurent Morin (UR1)
Manuel Chevé (Air Breizh)
Simon Leray (Air Breizh)
Maël Jan (Air Breizh)
David Lavoué (Air Breizh)</td></tr>
<tr><td>Reviewed by:</td><td>Corentin Lefèvre (Néovia Innovation)</td></tr>
<tr><td>Approved by:</td><td>TB / MB</td></tr>
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* - The dissemination level are indicated as follows: **PU** – Public, **CO** – Confidential, only for members of the consortium (including the Commission Services) **CL** – Classified, as referred to in Commission Decision 2991/844/EC.

Document Status Sheet

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0.1	31/10/2020	Draft V1	
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References and Applicable Documents

[1] https://www.openstreetmap.org

[2] http://www.addair.fr/product/analyseur-temps-reel-portable-poussieres-fidas-frog/

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List of Acronyms and Abbreviations

Below is an extensive the List of Acronyms used in previous deliverables. Please add additional ones specific to this deliverable and delete unrelated ones.

API	Application Programming Interface
AQMO	Air Quality and MObility
BAM	Beta Attenuation Monitor
CARA	*CARActérisation chimique des particules* - Chemical characterisation of particles
HPC	High Performance Computing
IDRIS	Institute for Development and Resources in Intensive Scientific Computing
IoT	Internet of Things
LCSQA	*Laboratoire Central de Surveillance de la Qualité de l'Air* – Central Laboratory for Air Quality Monitoring
LoRa	Long Range
MQTT	Message Queuing Telemetry Transport
NUC	Next Unit of Computing
PM	Particulate Matter
R&D	Research and Development
SDN	Software Defined Network
TPM	Trusted Platform Module
VPN	Virtual Private Network
ZRR	*Zone à Régime Restrictif* – Restricted Area

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Table of contents

Table of Figures

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Table of Tables

Introduction

This report develops the best practices learnt during the implementation of the AQMO project. The first part of the document describes the analysis performed to understand the results obtained from the micro-sensors used by the project while the second part focuses on the AQMO technology integration process.

1 Comparison between micro-sensors and regulatory instruments for the AQMO project

1.1 Introduction

The effect of Particulates Matter (PM) are well-known regarding their negative impact on the human health. Mostly in cities, transportation sector is one of the main important PM emitting contributors. Current regulation requires conducting long-term measurements with reference instruments. However, for the past few years, air quality monitoring agencies have started to complement their networks of reference instruments with additional micro-sensors. One of the main advantage of these micro-sensors is there price – varying from a few hundreds to a few thousands of euros – e.g one order of magnitude less expensive than the reference instruments.

Measurements from micro-sensors can provide detailed spatial and temporal air quality data to complete existing operational monitoring network. Current studies are focusing on developing methods to assimilate pollutant concentrations measured by micro-sensors into air quality models (Lyon School of Engineering[1]).

However, the results obtained from previous inter-comparison experiments with reference instruments have indicated that sensors are not as accurate and as precise as regulatory equipment.

The AQMO project uses micro-sensors installed as mobile units on the Rennes Metropolis bus network. As the official body in charge of air quality monitoring for the French Brittany region, Air Breizh decided to test several micro-sensors to:

- Measure hourly concentrations
- Check their ability to capture pollution events
- Characterize the sensors' functioning in real-life conditions
- Quantify deviation from reference observations

1.2 Experimental Design

Air Breizh installed several types of sensors at two operational sites during an extended period of time in order to analyze their data against reference measurements as well as to compare sensors' results between each other.

[1] *Ecole Centrale de Lyon*

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1.2.1 Measurement Sites

The objective of our study is to compare micro-sensors with reference instruments installed at two air quality stations in the city of Rennes. The first station is an urban background station located in a small park along Pays-Bas Avenue, the second one is a traffic station located along the René Laënnec Boulevard (Figure 1).

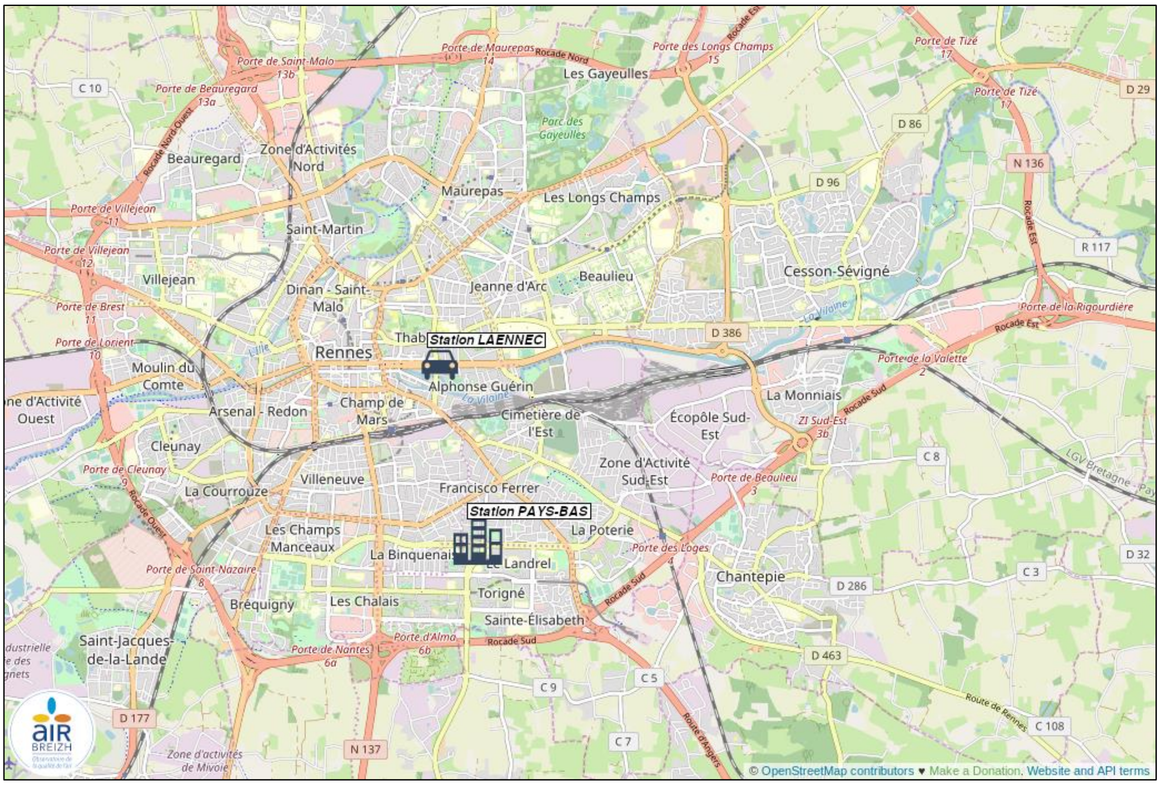

Figure 1 - The two continuous air quality monitoring stations (Pays-Bas, Laënnec) operated by Air Breizh and selected as reference sites for the AQMO study[2]

Maintenance duties for these stations requires the intervention of the city technical services, which, under normal circumstances, is a seamless task. This was however affected by the restrictions' measures adopted in response to the Covid-19 pandemic.

These stations were chose as experience sites for the micro-sensors as they allow the temporary installation of weather-proof measuring equipment by relying on masts or existing shelters.

1.2.2 Pays-Bas station measurement site

The urban background station Pays-Bas in Rennes is part of the French measurement network CARA (in French : "*Caractérisation chimique des particules*[3]"). CARA's objective is to determine the main sources of ambient particles under normal conditions and during

[2] Copyright OpenStreetMap – Contribution from AirBreizh
[3] Chemical characterisation of particles

pollution episodes. For this purpose, the CARA sites integrate various types of instruments to measure PM concentrations and composition.

Pays-Bas station is equipped with a FIDAS sensor to measure ambient levels in PM_1, $PM_{2.5}$, PM_{10} and total PM. It has mainly been used to experiment how to plug and get data from sensors. In the next sections, all mentioned data have been collected from sensors deployed at road-side air quality station Laënnec (also in Rennes).

1.2.3 Laënnec measurement site

Laënnec is a road-side air quality station. This implies the use of certified techniques for PM PM, especially including a Beta Attenuation Monitor (BAM) which measures properties of PM directly related to its mass.

Figure 2 - Location of the street-side cabin sheltering the measurement instruments (indicated by the yellow circle) on René Laënnec boulevard in downtown Rennes

Figure 3 - BAM instrument at Laënnec

A weather shelter has been specifically installed at this station in order to accommodate micro-sensors (or other equipment) not originally designed to support weather's conditions.

The Laënnec station has been the main station used for AQMO's calibrations experiments.

1.3 Technical specifications of the micro-sensors

We conducted an evaluation of various micro-sensors against traditional monitoring equipment. PM micro-sensors infer PM mass by detecting particles by number.

1.3.1 Micro-sensors used apart from AQMO

SDS011

Although the SDS011 sensors are not formally used in the frame of the AQMO project, Air Breizh conducted experiments on these sensors to increase internal basic electronic and engineering skills that has been used for AQMO. More specifically, this system needs to be entirely built from bare components (PM sensor, Temperature and humidity sensor, controller). The acquired experience has proven to be important for the implementation of the AQMO project.

Figure 4 - Detail of one initial SDS011 sensor box (left), three of them in the meteorological shelter at Laënnec station (center), New experimental package (right) with two associated sensors to be able to evaluate bias

New SDS011 packaging prototype shown in figure 6 (right picture) have been deployed for unit tests during 2020 summer and one of them at station Laënnec, the 11th of November. This kind of packaging is more basic than the AQMO one (with OPC-N3 sensors) as they contain only pollutant, moisture and temperature data acquisition through Wi-Fi transmission capabilities, e.g without all computing and connectivity capabilities (edge computing) that Rennes 1 University has integrated in the AQMO mobile unit.

Atmotrack

Atmotrack is an 'out-of-the-box' system developed by a French startup based in Nantes and named '42 Factory'.

In France, Atmotrack is known as one of the first air quality micro-sensors' fleet deployment firm. The company provides "easy-to-use" packaged micros-sensors and an API to collect data from the sensors. Contrary to SDS011 system, Atmotrack system is ready to plug and

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has not to be assembled. The counterpart is that Atmotrack relies on a leasing model, e.g their sensors are rented.

Figure 5 - Atmotrack at Laënnec station and detail of one of them

1.3.2 Alphasense OPC-N3

OPC-N3 is the identified PM sensor to equip buses in AQMO project. In the same way as SDS011, it needs to be included in a fully DIY built package. In the case of the AQMO project, packaged box and architecture (electronic and embedded program) has been developed by Rennes 1 University. On its side, Air Breizh has worked on a specific ‘Raspberry Pi’ package and has collaborated with Rennes 1 University to collect the air quality monitoring data at station Laënnec in order to evaluate the results of the sensors used in the project.

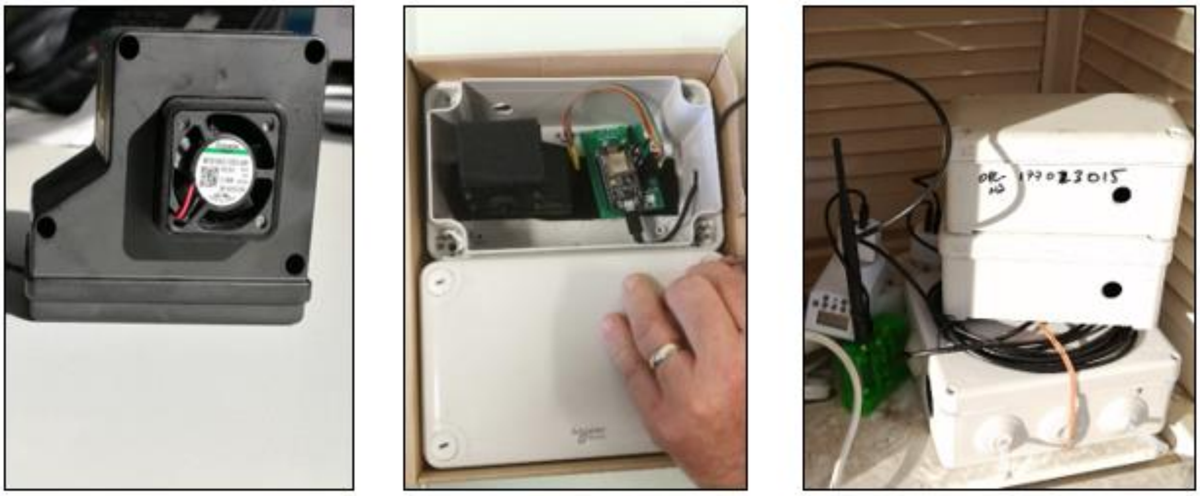

Figure 6 - Detail of one Alphasenses OPC-N3 sensors (left), detail of IRISA packaging (right) and two OPC-N3 in their box at Laënnec station (center)

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1.3.3 FIDAS Frog

Fidas Frog is a handled instrument from Addair[4] designed to offer an easy way to get real-time PM measurements. It is used, in particular, in French car industry to evaluate PM levels inside vehicle cabin. Fidas Frog is mainly dedicated to indoor and workplaces measurement, even if outdoor use is also mentioned by PALAS[5]. Air Breizh had tested Fidas Frog instrument on operational conditions in 2020 during a study focus on air quality in the landfill center of Saint-Brieuc Armor Agglomération[6].

Figure 7 - Fidas Frog sensor

[4] http://www.addair.fr/product/analyseur-temps-reel-portable-poussieres-fidas-frog/

[5] https://www.palas.de/en/product/fidasfrog

[6] not published yet

1.4 Experimental Setup

The table below (table 1) gives the main information about the micro-sensors used.

Sensor model	SDS011	Atmotrack	OPC-N3	Fidas Frog
Manufacturer	Nova Fitness	42 Factory (integrator)	Alphasense	Addair
Approximate price (€)	40€	260 € (Monthly rental)	500€	-
Dimensions (mm)	71x70x23	140x140x46.5	75x60x63.5	240x150x100
Weight (g)	50	500	105	2100
Power supply voltage	5	DC 12	DC 4.8 to 5.2	Lithium battery + AC/DC 220
Working current (A)	0.22	1	0.18	
Detectable size range (µm)	0.3- 10	0.3 - 1.0 1.0 - 2.5 2.5 - 10	0.5 to 40	
Estimated PM concentration	$PM_{2.5}$ / PM_{10}	PM_1 / $PM_{2.5}$ / PM_{10}	PM1 / $PM_{2.5}$ / PM_{10}	PM1 / $PM_{2.5}$ / PM_4 /PM_{10}
Concentration Range (µg/m³)	0-999.9	0 - 500	0-2000	0-10000
Identifiers	532146 (#1) 77899817 (#2) 7789987 (#3)	134 (#1) 148 (#2) 149 (3)	177010415 (#1) 177023015 (#2)	
Station Pays-Bas period	-	2019-01-16 to 2019-02-21	-	-
Station Laënnec period	2019-06-20 to 2019-07-12	2019-02-21 to 2019-06-28	2020-07-10 to 2020-12-01	2019-07-10 to 2019-07-16

Table 1 - Main information about the micro-sensors used in AQMO

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While it was originally planned to conduct experiences on both the Pays-Bas and Laënnec stations during extended period of time, difficulties has been encountered for the installation of the sensors, requiring several actors to be mobilized (technical services, Air Breizh, Rennes 1 University) – which has been cancelled and delayed during and because of the restrictions' measures taken for the Covid-19 pandemic. **We finally have focused on comparison using the Laënnec station that have more advantages than the Pays-Bas one**.

1.5 Data Analysis

1.5.1 Reference Methods

At station Laënnec, Air Breizh has deployed PM measurement equipment known as BAM-1020 and FIDAS 200. The first one gives the official reference measurement whereas the second is currently being validated.

On one hand, BAM-1020 automatically measures and records airborne particulate concentration using principle of beta ray attenuation. A filter tape is used to perform a beta ray count from a small carbon-14 source at the beginning of each sample hour, and then after 1 hour exposition of the filter tape to a measured and controlled amount of outside air. The difference between the two measures is converted to a PM mass concentration in outside air. **This equipment provides one data each hour**.

Figure 8 - BAM-1020 (source : Met One Instrument, Inc.)

On the other hand, FIDAS 200 (not to be confused with FIDAS FROG mentioned above) is an optical aerosol spectrometer which determines particle size by means of scattered light analysis according to Lorenz-Mie. This equipment is deployed at station Laënnec to determine the relevance to measure traffic air pollution in Rennes with such a sensor by comparison with ou reference equipment "BAM-1020". **This equipment provides 4 data each hour.**

These facilities are twice mentioned in the document "*Liste des appareils conformes pour la mesure réglementaire de la qualité de l'air*"[7] from the LCSQA national laboratory and used by Air Breizh to perform its reference measurement.

Air Breizh generally uses these reference measurements to compare data from other sensors (micro-sensors for example) to establish the quality of new data acquisition. This is the aim of the next chapters.

[7] List of instruments compliant for regulatory air quality measurement

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1.5.2 Micro-sensor Data Analysis

Different statistical criteria were employed to evaluate sensors against reference measurement:

- Determination of the coefficient R^2 : this coefficient is used to judge the quality of a linear regression. Near from 0, it means that there is no correlation between the two dataset whereas near from 1, it means that data from micro-sensors fit perfectly with regulatory data.
- Bias : this indicator describes the fidelity of the model i.e. whether our micro-sensor systematically overestimates or underestimates the regulatory values. The closer it is to 0 the better is the fidelity of the micro-sensor measurements compared with the regulatory measurements
- MFBE (Mean Fractionalized Bias Error) : Fractional bias is a normalisation of the value of the bias, thus allowing comparisons and making it easier to interpret bias. MFBE is between -2 and 2. 0 means that micro-sensors data and regulatory data have the same means. Positive MFBE implies that the micro-sensor underestimates the measurement compared to the regulatory measure whereas negative MFBE implies the opposite.

All these statistical criteria are calculated using Python software created by Air Breizh for its modelling tools and adapted to the needs of the AQMO project.

1.6 Results and Discussion

While we present in this report the exhaustive range of micro-sensors that were installed by AirBreizh, SDS011 and Atmotrack sensors installed in 2019 are not analyzed in this report, as those sensors will not be selected after the project. Therefore, only the OPC-N3 sensor selected and built for the AQMO project is studied.

1.6.1 Reference dataset to compare

The previous chapters have enabled us to come back to the reference measurement methods for fine particles used by Air Breizh. The AQMO project needed to be able to assess the quality of the micro-sensors in a global way. From this point of view, the methodology consists in positioning the micro-sensors in a reference measurement situation, in our case, at the Laënnec station in order to compare the measurements made by micro-sensors with those of the BAM-1020 (reference). As station Laënnec has a second device under ongoing validation – Fidas-200, based on the same measurement system (optical measurements) – it has enabled to rely on this second set of "pseudo-reference" data. Finally, a third device has been considered to qualify the measurement of micro-sensors (particularly in mobile environments) : the Fidas Frog.

1.6.2 What about Fidas Frog ?

Fidas Frog was positioned from the 10th to the 16th of July 2019 at the Laënnec station. The comparison shows an optimal operating rate but a fairly average correlation (R^2 of 0.49 in PM10 and 0.46 in PM2.5), in a summer period where the mass concentrations of PM are very low. This operational campaign did not allow Air Breizh to go further. However, the indoor air quality measure by Fidas Frog will be discussed in the 2020 study focus on the air quality in the landfill center of Saint-Brieuc Armor Agglomération.

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1.6.3 Time scope for the OPC-N3 analyses

From the 10th of July to the 27th of November 2020, 45% of hourly average has been lost due to a transmission problem and not to a measurement problem (2.4% / 1% data loss for BAM and Fidas). Nevertheless, since the 19th of November (after an upgrade of the LORA transmission module), this rate has increased up to 90% of acquired data successfully transmitted (data losses are still being observed).

Thus, we will focus on two specific periods on two seasons:

- First period in summer: from 10th of July to 05th of August 2020
- Second period in autumn: from 19th of November to the 1st of December 2020

During summer period (July and August), PM mass concentrations have been lower than during autumn (November) period. Indeed, 50% of the values in reference dataset (BAM-1020) are lower than 4 µg/m^3 whereas there are 50% less than 16 µg/m^3 in autumn. According to the low level of PM mass concentrations in summer, it is less relevant to compare the micro-sensors datasets to the reference dataset on this period.

With an average PM hourly mass concentrations in second period 4 times upper than in the summer period, we will focus on the autumn period.

1.6.4 First results from OPC-N3 sensors

Elements presented after are based on statistical results calculated: **(1)** over the total measurement period **(2)** over the summer period **(3)** over the autumn period. Main observations are:

- Firstly, **two OPC-N3 sensors are well correlated among each other** (R^2 close to 0.9 in PM2.5) but with a strong bias (with a MFBE close to 1). There is a systematic bias error: the OPC-N3 #1 signal underestimates compared to the OPC-N3 #2
- Secondly, **OPC-N3 sensors underestimates PM2.5 mass concentrations** compared to the BAM-1020 reference dataset. However, the OPC-N3 #2 signal is more accurate than the OPC-N3 #1 one.
- Finally, although the OPC-N3 sensor has an optical measurement system equivalent to the Fidas-200 one**, the two OPC-N3 do not reproduce the signal of the FIDAS-200** better than the BAM-1020 one. The results are slightly better but the gain is not significant (especially in autumn). At the same time, the two regulatory measures are highly correlated with low bias.

(1) Global period

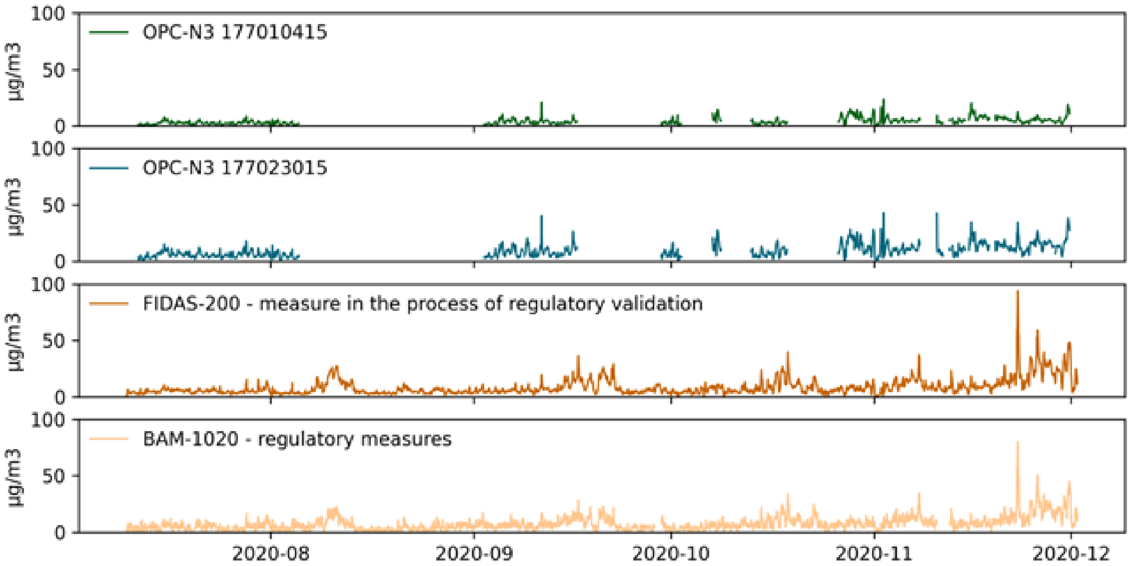

Figure 9 - General behaviour of OPC-N3 sensors along the whole test period

	OPC-N3(#1)	OPC-N3(#2)	FIDAS 200	BAM-1020
µg/m³				
Mean	2.6	5.8	4.7	4.5
Min	0.4	1.3	0.9	-2.8
Q1 (25 %)	1.6	3.8	3.3	2.5
Mediane (50 %)	2.3	5.3	4.4	4.3
Q3 (75 %)	3.2	7.3	5.7	6.2
Max	8.7	18.4	15.3	16.8

Table 2 - General description of hourly dataset during the first identified period

	OPC-N3(#1)	OPC-N3(#2)	FIDAS 200	BAM-1020
µg/m³				
Mean	5.4	14.5	21.7	18.0
Min	1.4	4.0	3.7	3.9
Q1 (25 %)	4.0	10.4	12.6	10.5
Mediane (50 %)	4.9	13.5	19.0	15.5
Q3 (75 %)	5.9	16.8	28.1	22.5
Max	19.2	38.3	93.8	80.0

Table 3 - General description of hourly dataset during the second identified period from 19th of November to 1st of December 2020

(2) First period: from 10th of July to 05th of August

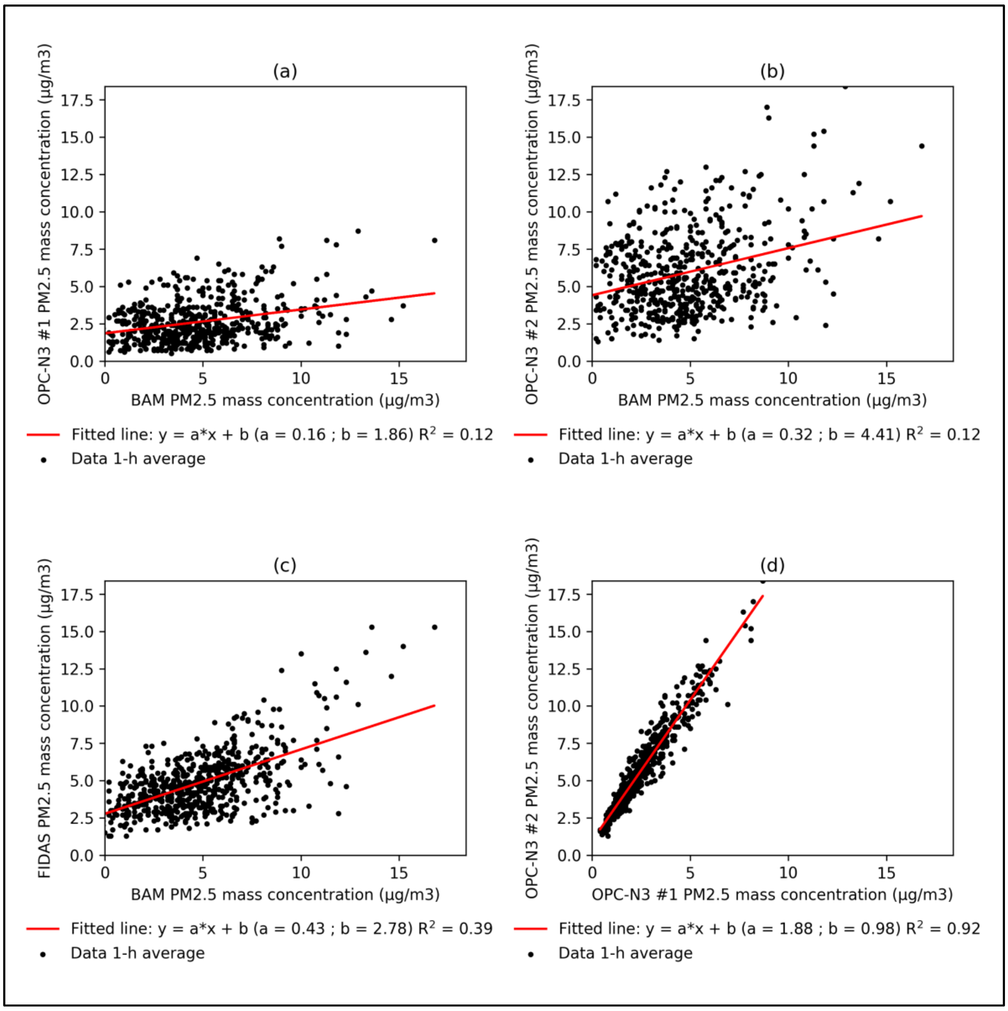

Figure 10 - Boxplots to evaluate correlation between the two OPC-N3 and BAM (a and b), then BAM and Fidas (c) and OPC-N3 (d) on the first focused period

	OPC-N3(#1)	OPC-N3(#2)	FIDAS 200	BAM-1020
	$0 < R^2 < 1$: optimal value = 1 -2 < MFBE < 2 : optimal value = 0			
OPC-N3(#1)				
OPC-N3(#2)	R^2: 0.92 MFBE : 0.78			
FIDAS 200	R^2: 0.38 MFBE: 0.64	R^2: 0.46 MFBE: -0.18		
BAM-1020	R^2: 0.12 MFBE: 0.54	R^2: 0.12 MFBE: -0.26	R^2: 0.39 MFBE : -0.05	

Table 4 - OPC-N3 1770110415 (#1) and 177023015 (#2) vs BAM and Fidas regulatory equipment from from 10th of July to 05th of August

(3) Second period: from 19th of November to 1st of December

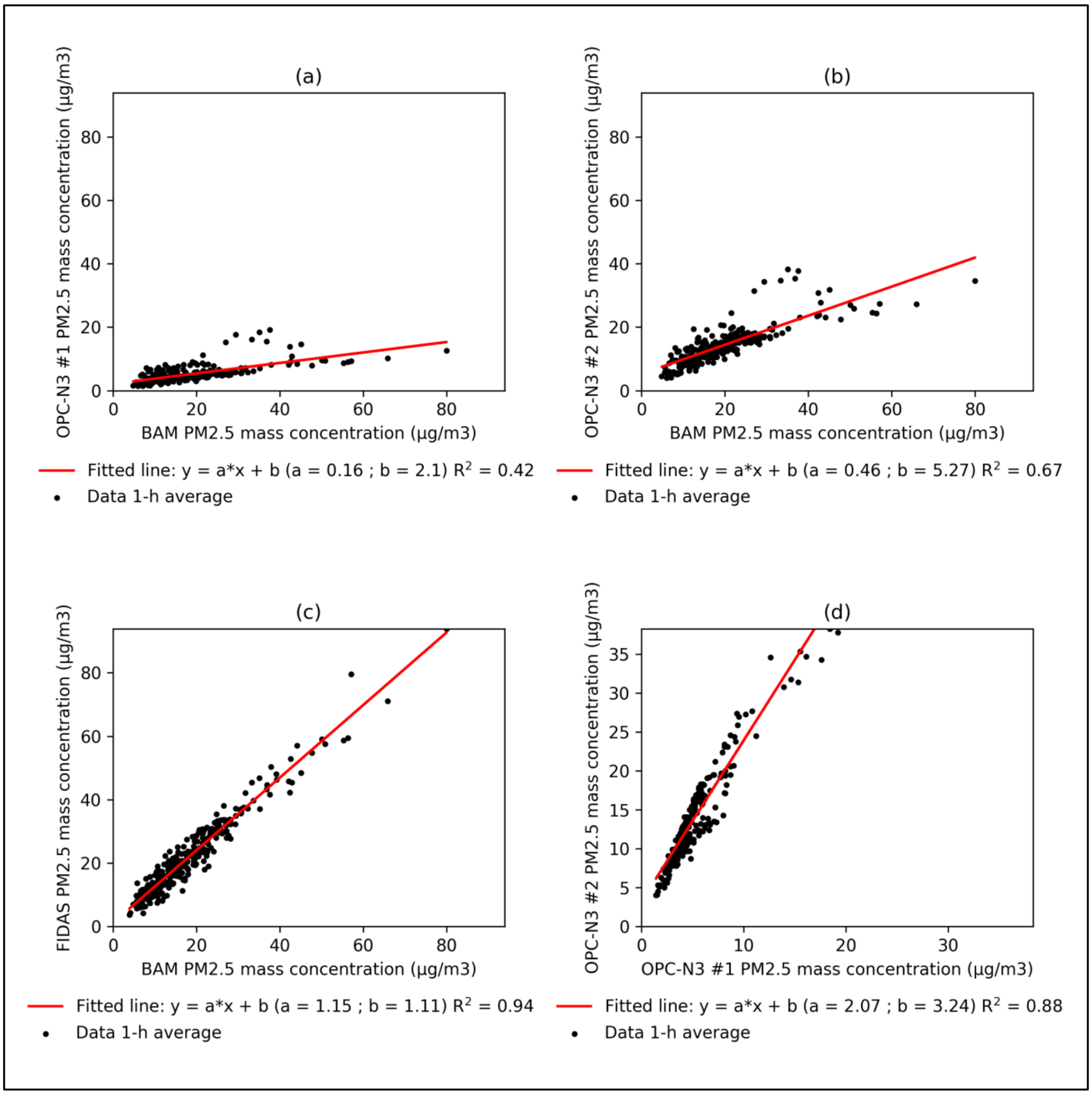

Figure 11 - Boxplots to evaluate correlation between the two OPC-N3 and BAM (a and b), then BAM and Fidas (c) and OPC-N3 (d) on the second focused period

	OPC-N3(#1)	OPC-N3(#2)	FIDAS 200	BAM-1020
	$0 < R^2 < 1$: optimal value = 1	-1 < MFBE < 1 : optimal value = 0		
OPC-N3(#1)				
OPC-N3(#2)	R^2: 0.88 MFBE : 0.91			
FIDAS 200	R^2: 0.43 MFBE: 1.27	R^2: 0.7 MFBE: 0.51		
BAM-1020	R^2: 0.42 MFBE: 1.15	R^2: 0.67 MFBE: 0.32	R^2: 0.94 MFBE : -0.19	

Table 5 - OPC-N3 1770110415 (#1) and 177023015 (#2) vs BAM and Fidas regulatory equipment from from 19th of November to 1st of December 2020

1.7 Conclusions on micro-sensors

Although data from SDS011 and Atmotrack were not analyzed for the purposes of this report, a quick analysis enabled us to establish first conclusions. Atmotrack could be a good alternative to equip a sensors' network but it is quite impossible to obtain information about the way that the raw data is retrieved and corrected. SDS011 is a good "teaching" sensor but not enough efficient for a measurement network.

Concerning the Fidas Frog, unfortunately no comparison has been already made between Fidas Frog and OPC-N3. The first comparison made between Fidas Frog and reference dataset did not provide enough details to draw firm conclusions. Results from operational campaign should give more information about the abilities of the Fidas Fog to be an alternative way to qualify micro-sensors used in mobility. Conducting more experimental tests with Fidas Frog equipment could be one of the next steps to confirm or not if it is a good way to qualify the OPC-N3 on the move.

This study, focused on the OPC-N3, has ensured that the micro-sensors have been confronted to the same conditions of pollutant concentrations as devices regulated by the LCSQA laboratory. It is essential to precise that we do not have a sufficient volume of continuous data to be able to perform a deeper analysis. The results could be associated to road traffic and meteorological parameters to go further. Moreover, it could be interesting to apply statistical methods such as the Interquartile Range rule [Moore et al., 2009].

It is important to note that the raw data of OPC-N3 has been directly used, unlike the Atmotrack one that is downloaded from a proprietary web portal. To use these OPC-N3 sensors, it would be interesting to further investigate the output data processing, in order to

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get a more accurate measurement (for example, with external parameters such as temperature and moisture).

Thanks to all the collaborations between the different actors of the project (mainly Rennes 1 University and its expertise in electronic and computer integration of micro-sensors, Air Breizh for the analysis of air quality data), it has been possible to show the level of performance of the OPC-N3 sensors and to show that the whole architecture deployed will allow, in the future, to integrate new measuring devices (such as the next-PM for example).

2 AQMO project integration best practices

This part summarizes the best-practices that have been identified while deploying the AQMO platform. This platform contains many heterogeneous hardware and software components. This characteristic makes the platform integration a particularly complex challenge. One of the major issue (contrary to software based only projects) that the project dealt with is that most of the testing process can only be performed in real operational conditions (See [4]).

It is important to note that the content of this part is complementary to usual software development best-practices such as continuous integration. The remainder of this part lists the main lessons learned during the implementation of AQMO.

2.1 Open-source and IP free release

Whenever possible the use of open-source software and not retaining IP has been privileged as a sustainability driver for the academic partners. Using open-source components provides the following benefits:

- It allows more flexible collaboration since it reassures the new partners that they won't be locked-in if they adopt the project's technology
- Open-source codes have better properties regarding sustainability and cyber-security (introspection is possible).
- It simplifies the re-uses by industrial partners of the developed technologies.
- It fosters serendipity

Not retaining IP for academic partners is also an approach that helps on improving the project efficiency and outcomes:

- Exploitation of results will be both faster and easier as negotiations over IP will be avoided, thus reducing time, effort and potential barriers to spread the project's outcomes
- IP free policy is often the best and most efficient way to display the results from the academic partners, in particular regarding the ratio between the income generated / resources allocated for IP management
- Projects such as AQMO are addressing societal issues. Regarding the contribution of the project it is in the general interest to allow seamless reuse of the results by the most efficient partners to bring the technology on the market (Companies can always add IP when going on the market)

It is important to note that the previous arguments mainly applies to projects such as AQMO which relies mostly on know-how and technology integration.

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2.2 Understanding infrastructure maintenance process

AQMO is an innovative project that uses operational infrastructures (e.g. bus network, LoRa network, air monitoring infrastructure) to deploy a proof of concept platform. Installing devices in this context happens generally during maintenance operations. Therefore the articulation of R&D activities and infrastructure operations can be complex and/or take a long time. There is a conflicting goal between R&D projects and maintenance operations. R&D projects are subject to many uncertainties (technical and temporal) while usually maintenance operations are scheduled on the basis of a strict and very constrained time frame. Furthermore regulations can be roadblocks.

Understanding the maintenance process and its timeframe is essential in order to plan the experimentations. It is also very important to create relationships between the maintenance crew and the R&D team. One step to achieve this is that it is essential to take the time to explain the project's objectives and technical specifications to the maintenance crew.

Last but not least, exchanges with the maintenance crew will help understand the potential for degradations (that may be important in a transportation network).

2.3 Long period device testing

Once installed the devices (e.g. central units and sensors in the bus) can be difficult to access physically. Therefore maintenance operations will not be frequent. As a consequence, device / software testing must be performed for a long period of time before being installed. Typically, in AQMO the embedded devices have been tested for months. Furthermore, testing must be done in conditions as close as possible as the operational ones.

One way to reduce the delays is to install parts as soon as they are ready rather than wait for the whole set of components to be ready. For instance, in AQMO, the installation of the central unit (i.e. the embedded computer) had started months before the first sensor installation.

During the long test phase, it is necessary to have real-time monitoring means. This may mean adding 4G connections etc. even if such a component will not be integrated in the final product. Every operation (e.g. software update) that can be performed remotely should be anticipated and implemented to be able to intervene smoothly on problems that can occur on a bus installation while the maintenance – and therefore a physical intervention – is scheduled months later.

2.4 Computer / IoT network integration

A common problem when dealing with an heterogeneous platform is to organize the communication between devices (themselves connected using different communication networks).

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Building as soon as possible a common Software Defined Network connecting all components (using VPNs) of the infrastructure simplifies and strengthens a lot the operations. Moreover, it allows to deploy workflows spreading all over the platform.

For example, integrating devices in a common SDN allows the use of protocols such as MQTT in a transversal manner. Many monitoring and data exchange operations are then made simpler, avoiding the need for proxies that would increase both the complexity of the platform and the maintenance.

Deploying SDN may prove to be more complex than anticipated even if powerful technologies are available (wireguard or zerotierone).

2.5 Early partial deployment

The AQMO platform is based on a large set of heterogeneous components (software and hardware). Any attempt to integrate all the components at once would have led to failure: integration must be incremental and performed on the pieces that are ready as soon as possible. One key to facilitate the integration is to ensure that well defined and documented APIs are implemented for all critical interfaces (e.g. HPC as a service).

2.6 Internal project communication at technical level

An important factor for a successful integration of the platform components is to facilitate the communication needed at a technical level. It is critical to ensure that people doing the development in different organisations communicate directly with each other rather than enforcing a hierarchical proxy between them. This reduces the number of meetings and allows for quicker and more efficient exchanges of technical information. For this to happen, trust is needed between the partners. Reaching a high level of trust must be part of the project strategy.

2.7 Early assessment of security issues

Security issues must be assessed from the start in order to avoid that security problems result in no-gos during the project's implementation. The use of highly secure protocols may not come from the start but their analysis and constraints have to be known very early before the beginning of the development. The security analysis will guide technical choices.

For instance, in AQMO we have chosen a TPM compatible embedded unit (i.e. Intel NUC). Even if the TPM is not installed from the start we have to ensure that in course of the project they can be added. Having done otherwise would have condemned the technical work to be redone as soon as industrial deployment would be envisioned. The cost of such re-development would then be a roadblock to achieve sustainability.

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2.8 Looking for technical vs administrative tradeoff

In AQMO we are dealing with multiple partners, each one answering to different regulations. It is important to find the best paths to the project goals to explore the tradeoffs between technical and administrative solutions in order to reduce the time to results.

For instance, ZRR regulation applies to IDRIS. This very constraining regulation limits the way IDRIS systems can be accessed. In AQMO to solve this problem a virtual machine has been added in order to fulfill the regulation and the technical issue.

Conclusion

This document proposes a method for exploring micro-sensors capabilities and a set of lessons learned during the integration the AQMO platform.

Micro-sensors are behaving very differently from air quality measurement scientific instruments. Nevertheless the use of micro-sensors has many benefits (e.g. sampling frequency, cost, size) under the condition that their functioning is understood and therefore that the data collected can be carefully interpreted / used.

Regarding the overall integration process, anticipation has been key and long testing periods, in operational conditions, have to be set. One of the most difficult organisation issues is to manage the R&D aspects of the project with the maintenance constraints of the operations (e.g. Air Breizh, Keolis).

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