A Q M O

Connecting Europe Facility 2014-2020

AQMO

Air Quality and MObility
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D0.1

Comparison of Air Quality Micro-sensors with Reference Stations operated by Air Breizh

Version: 0.1
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Date: 04 / September / 2019

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List of Acronyms and Abbreviations

AQMO	Air Quality and MObility
EC	European Commission
EU	European Union
HPC	High Performance Computing
INERIS	Institut National de l'Environnement industriel et des RISques
LCSQA	Laboratoire Central de Surveillance de la Qualité de l'Air
LNE	Laboratoire National de métrologie et d'essais
OPC	Optical Particle Counter
PM	Particulate Matter
SPMD	Service Public Métropolitain de la Donnée

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Executive Summary

This mid-term report documents the contribution of Air Breizh to the European AQMO project. The various tasks performed by the organization included:

- Conducting a micro-sensor inter-comparison exercise and comparing measurements with reference air quality stations;
- Developing Python code to collect measurement data from the micro-sensors;
- Providing partners with emission gridding and modelling output data;
- Designing an end-user interface to integrate data into the AQMO workflow.
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1 Introduction

The European Project Air Quality and MObility (AQMO) started in September 2018. Co-financed by the European Union through its Connecting Europe Facility (CEF) program, AQMO addresses the air quality challenge with the development of a smart city pilot project in the area of Rennes Métropole.

The Project is the collaboration between Air Breizh, AmpliSIM, CNRS/IDRIS, Genci, IRISA/University of Rennes 1, KEOLIS Rennes, NEOVIA Innovation, Rennes Métropole, Ryax Technologies, and Ucit. On 16 October 2018, the first official meeting with all the partners collaborating on the Project was organized in Rennes, France.

1.1 Presentation of Air Breizh

In France, ambient air quality is monitored at regional level by non-profit organizations accredited by the Ministry of the Environment (Ministerial Order of 19 April 2017 [1]). Regional organizations are grouped in a national federation called ATMO France. The four missions of all agencies are measuring air pollutant levels, forecasting pollution episodes, assessing the impact of mitigation measures, and informing authorities, media and public in case of episodes.

Air Breizh is the organization in charge of monitoring outdoor air quality in the French region of Brittany. The organization maintains a total of 18 stationary ambient air monitoring stations across the region (Figure 1).

Various instruments measure different air pollutants including nitrogen oxides (NO_x), ozone (O_3), fine particles (PM_{10}), very fine particles ($PM_{2.5}$), Polycyclic Aromatic Hydrocarbons (PAHs) and metals (i.e., Lead, Arsenic, Nickel, and Cadmium). A total of 7 sites are located in the urban area of Rennes.

A recent audit by the LCSQA (Central Laboratory of Air Quality Monitoring) approved the measurement methodology followed by Air Breizh. The LCSQA is composed of the INERIS (National Institute for Industrial Environment and Risk), LNE and IMT Lille Douai.

In accordance with European legislation, ambient concentrations collected by Air Breizh are part of the European Union's official air quality database, and as such, are reported on the European Environmental Agency's website.

In addition to monitoring operations, air quality assessment is also based on numerical models and pollutant emission inventories. Regional air quality agencies located in northwestern France, including Air Breizh, have combined their effort to operate a chemical transport model to forecast air quality across their combined regions. Concentrations of pollutants and resulting air quality index are provided on each agency’s website for the current and next day.

Modelling provides a cost-effective mean of estimating the current air quality situation and potential future changes, but these models require significant input data. Air

Breizh has then developed an extensive experience in the preparation of emission inventories for integration in air quality models. Moreover, models are calibrated with measurements performed at the monitoring stations to provide confidence in the simulation results.

Furthermore, Air Breizh conducts several campaign measurements every year in selected areas at the request of municipalities and health departments. Detailed reports are prepared by the agency's engineers and made available to the public on its website.

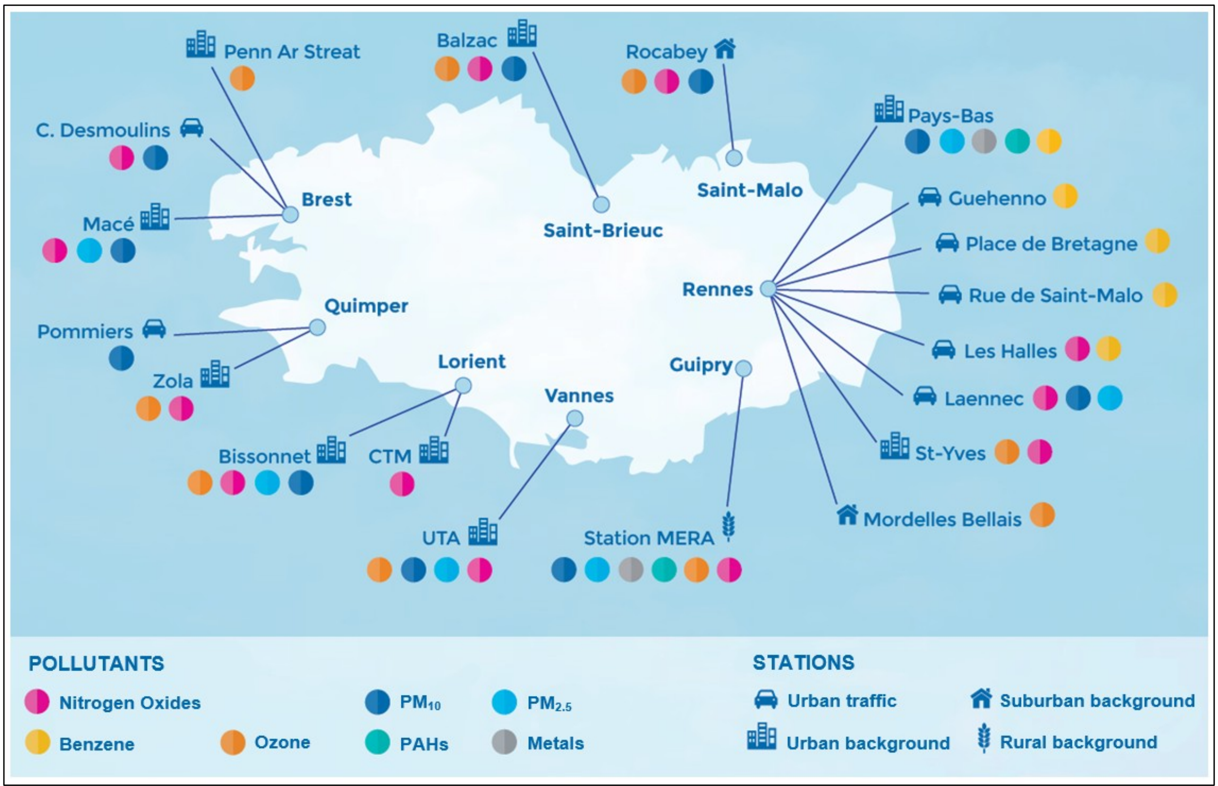

Figure 1: Air quality monitoring stations operated by Air Breizh in Brittany in 2019 (PM=Particulate Matter; PAHs=Polycyclic Aromatic Hydrocarbons; Metals=Lead, Arsenic, Nickel, and Cadmium).

1.2 Air Quality Monitoring

The air quality monitoring network is composed of fixed measurement sites which are used as reference stations to obtain a comprehensive picture of the air quality across the region. Sites are usually classified according to the type of environment where they are located and the contribution from pollution sources. The classification is as follows:

- **Urban sites** in continuously built-up urban area are representative of a few km^2;
- **Suburban sites** in largely built urban areas are representative of a few tens of km^2;
- **Traffic sites** are representative of air quality mostly impacted by emissions from nearby road traffic;
- **Rural sites** are located far away from agglomerations and at least a few km away from any built-up areas, industrial installations or major roads.

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In addition to the traditional fixed stations, mobile air monitoring units can be used to collect pollutant levels at “street level” in order to determine local exposures of individuals to specific pollutants [2]. This approach is generally taken on a case-by-case basis for specific studies, such as pollution hotspots. However, the associated cost can be high since moving vehicles are outfitted with standard real-time air analysers, GPS, data acquisition system and data storage system.

A cost-effective alternative is to replace expensive reference-grade instruments with low-cost micro-sensors in mobile units. For instance, sensors can be mounted on transit buses operated by public authorities, as proposed in the Project AQMO detailed in the following section.

1.3 The Project AQMO

AQMO will provide an end-to-end urban platform that extends current practices in air quality measurements. It will also provide citizens, local authorities, scientists and private companies with new air quality data derived from state-of-the-art numerical models. AQMO will ultimately lead to the improvement of air quality in the urban environment.

The project uses a transversal approach, spanning from micro-sensors to supercomputers, in order to deliver day-to-day data. AQMO intends to explore the use of High-Performance Computing (HPC) to create value for citizens and to back decision-making by public authorities. HPC capabilities are required to perform numerical simulations with fine-scale pollution dispersion models that would include sensors data-assimilation.

Thanks to the exploitation of the local transportation network (equipped with high quality mobile sensors), the project will be able to achieve rigorous air quality measurements in a wide area rather cost-effectively. This would then allow the extension of the geographical area covered and the use of more reliable and profitable sensors (e.g., drones for measurements in case of catastrophic events).

Through the use and implementation of HPC as a service and a support to decision-making, the results will grant better understanding of pollution propagation inside the Rennes area. Results will be made available to citizens via SPMD, an open data service managed by Rennes Métropole [3].

As illustrated in Figure 2, the AQMO project is addressing several technical challenges:

- Defining open-source APIs and data schemes taking advantage of the SPMD and existing European Data Portal;
- Implementing an efficient and cost-effective computing resource management;
- Validating and calibrating measurements with micro-sensors;
- Giving the public access to data for visualisation;
- Designing a reliable sensor platform installed on Rennes Metropole’s buses.

The AQMO project is the first European effort to provide such an end-to-end smart city platform using HPC for air quality monitoring purposes. The methodology and approach could be applied to other cities and organizations in the future. The project

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will take advantage of its partners' computer networks to spread its findings to scientific communities, decision makers and citizen.

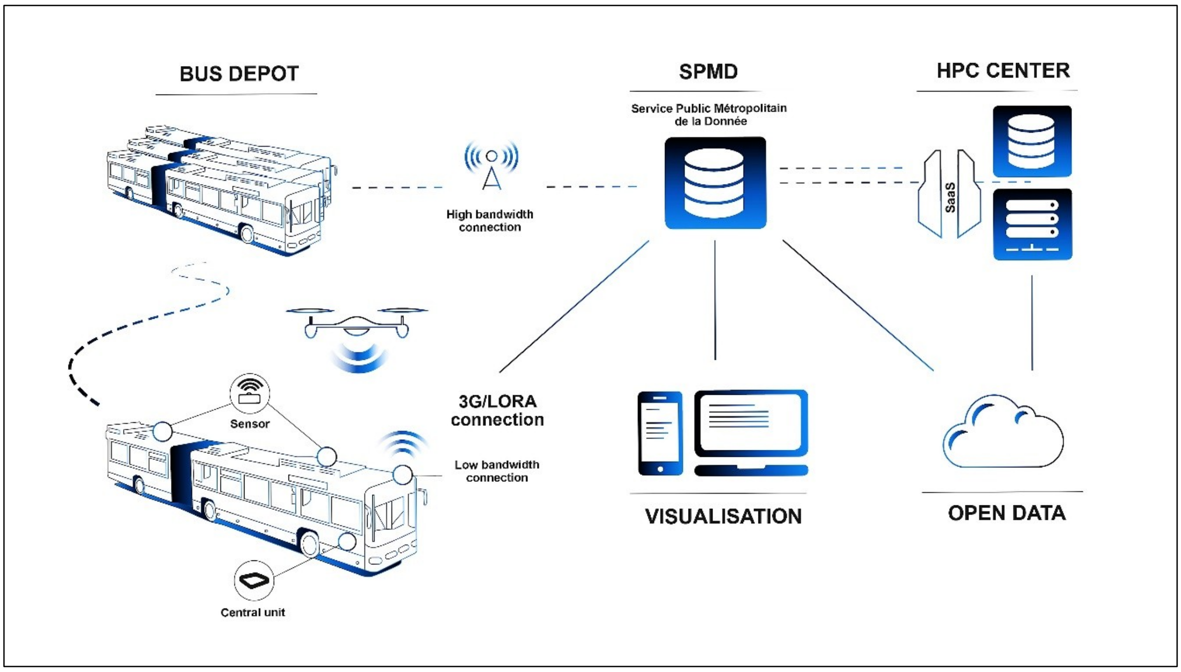

Figure 2: The various components of the Project AQMO.

Based on its 30-year expertise in air quality studies, Air Breizh was able to assist its various project partners in:

1. Identifying suitable micro-sensors to be mounted on buses;
2. Constructing a database of gridded atmospheric emission for the selected study area;
3. Testing the air quality model in several virtual machine configurations;
4. Developing Python scripts to be used on buses;
5. And informing the public and professionals regarding the AQMO project.

2 Assessment of micro-sensors

Low-cost micro-sensors make them suitable for deployment in large numbers to complement traditional monitoring instruments. However, the precision and accuracy of data produced may not be suitable for regulatory use. Over the past few years, many research groups have been involved in field studies to perform quality check of sensors' performance against conventional instruments [4][5].

2.1 Intercomparison Studies

In 2018, Airparif organized AIRLAB, an inter-comparison exercise of micro-sensors available on the market at that time [6]. The purpose of this study was to provide air quality agencies with an evaluation of micro-sensors based on several criteria, such as the cost, the portability, and the accuracy of the measurements. The few micro-sensors initially selected for AQMO were tested during AIRLAB.

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Similarly, the LCSQA conducted tests on micro-sensors from early January through mid-February 2018. The laboratory wrote a report detailing the methodology and the test outcomes for all selected sensors, while keeping them anonymous [7]. Results are presented with four qualitative criteria (i.e., energy, reliability, versatility and implementation), four quantitative (i.e., variability, mean absolute percentage error, coefficient of determination, slope of the regression line) and an Integrated Performance Index (IPI).

2.2 Sensor Deployment Strategy

To select suitable sensors for the Project, Air Breizh established a methodology detailed in the present section.

The first task is to test the selected micro-sensors in a controlled environment, i.e. Air Breizh's technical laboratory.

Sensors are then installed at outdoor air quality monitoring sites to compare their measurements to pollution levels provided by reference instruments. One urban background station and one traffic station were initially selected to assess the performance of sensors in two distinct environments (Figure 3).

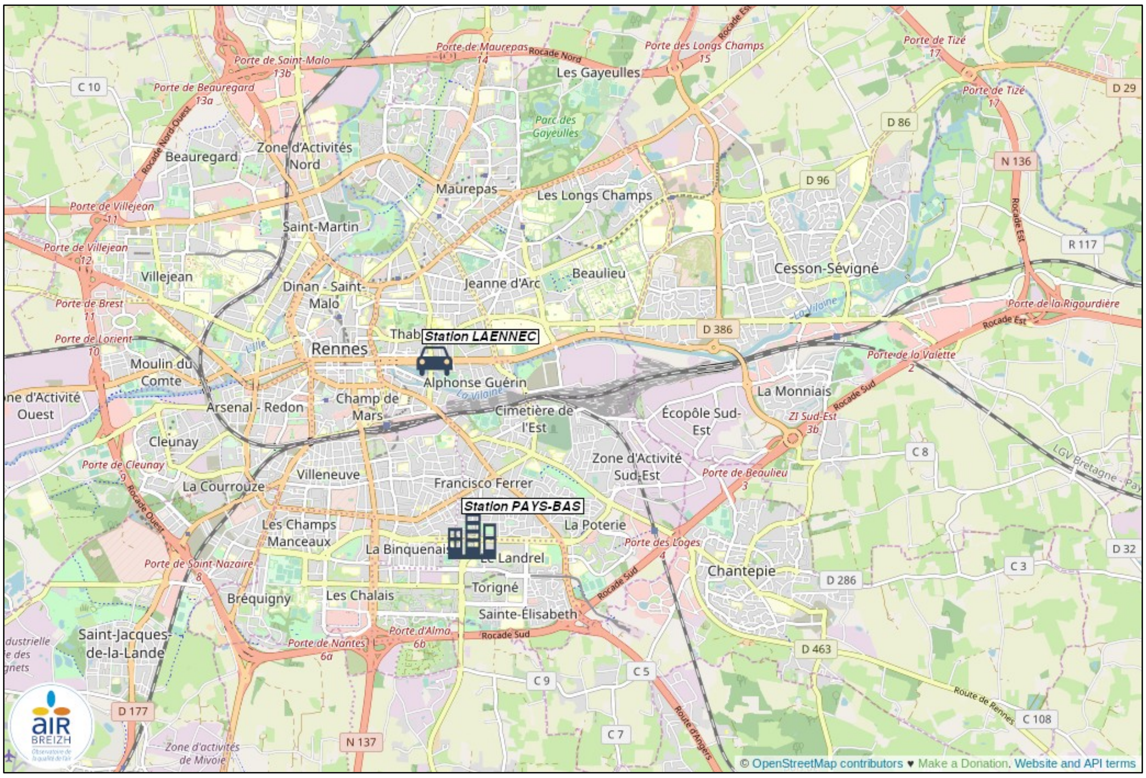

Figure 3: The two continuous air quality monitoring stations (Pays-Bas, Laënnec) operated by Air Breizh that were selected as reference sites in the AQMO study (Map data copyrighted OpenStreetMap contributors and available from https://www.openstreetmap.org).

Two of the same instruments can also be installed side-by-side at the same location for a few weeks to compare their measurement data.

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2.3 The Atmotrack Sensor

2.3.1 Experimental Setup

The IRISA initially selected the Atmotrack sensor to be installed on buses to feed pollution data to the AQMO workflow. Atmotrack sensors were designed by 42 Factory, a company located in Nantes, France. For simplification purposes, Atmotrack sensors will be referred to as “Atmotrack” or “Atmotracks” below.

With respect to AQMO, Air Breizh decided to use the version 1.0 of the sensor that measures PM_{10}, $PM_{2.5}$, ambient temperature, and relative humidity and provides geo-location in real-time. Two sensors were delivered to Air Breizh on January 4th, 2019. They were tested for few days in the office and were then deployed for several weeks at two air quality reference stations (Figure 4).

Figure 4: Two Atmotrack (white boxes on the right side of the picture) were set up at the station of Pays-Bas in Rennes.

42 Factory automatically uploads measurement data from the Atmotracks into their database. Users can then have access to the data collected by their sensors, only after registering to the web portal. Data can also be downloaded by using an API provided by ‘42 Factory’. For the AQMO project, Air Breizh downloaded PM levels through the web portal on a weekly basis (Figure 5).

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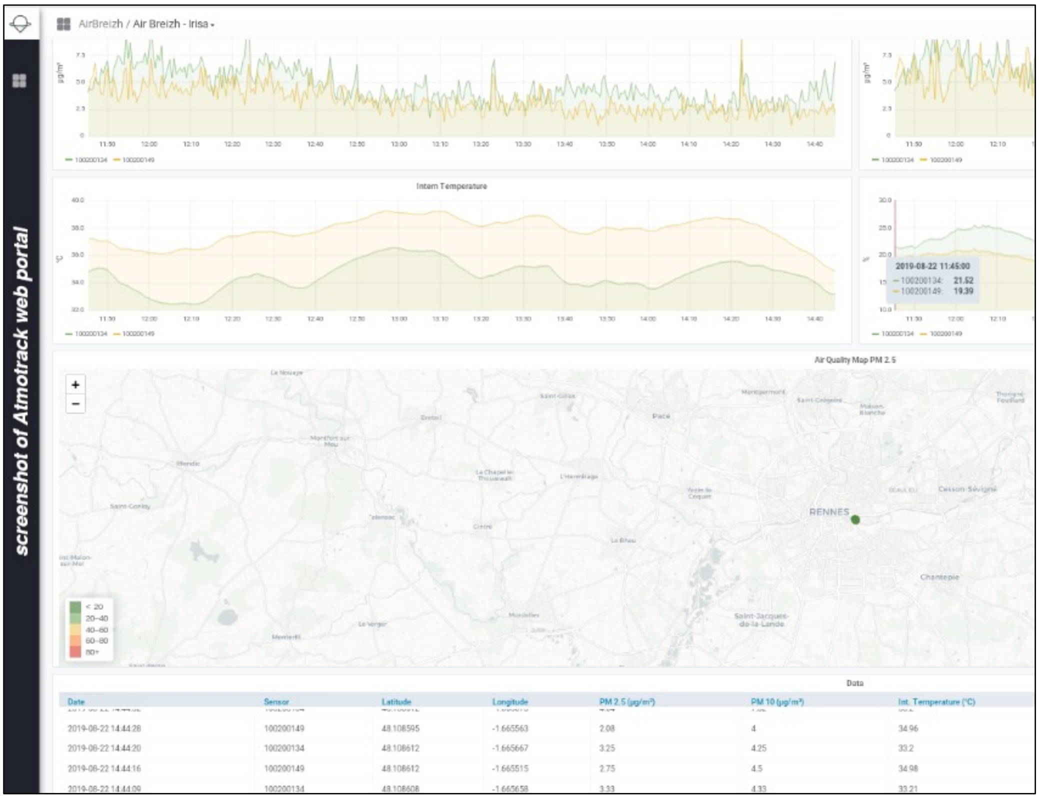

Figure 5: Screenshot of Atmotrack's web portal to access measurement data.

2.3.2 AIRLAB and LCSQA Tests

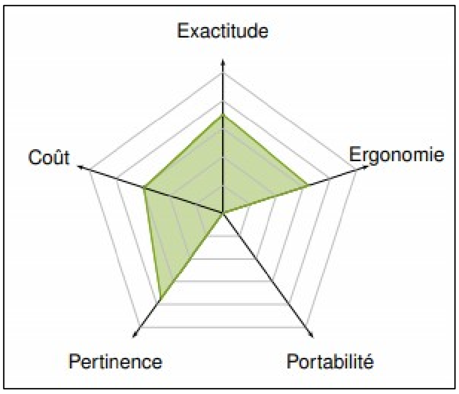

Figure 6: The five criteria (i.e., cost, accuracy, ergonomics, relevance, portability) employed to rate the Atmotrack in the AIRLAB inter-comparison study.

Based on the five criteria selected for the AIRLAB test, Airparif concluded that the Atmotrack was suitable to measure outdoor air quality from moving vehicles (Figure 6). Data quality was considered good for $PM_{2.5}$ and satisfactory for PM_{10}. Connection to the 3G network was of good quality and consistent. However, the sensor was not portable since it has to be connected to a permanent power supply.

The LCSQA also investigated the Atmotrack and gave it one of the best Integrated Performance Index for Particle Matter measurement, whereas several qualitative and quantitative criteria are low (<1.5/5).

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2.3.3 Preliminary Results

Beginning of January 2019, Air Breizh tested two Atmotracks on its premises. The purpose was to collect and examine raw data, i.e. PM concentrations, relative humidity and temperature, in a known environment.

After two weeks, both sensors were moved to the site of Pays-Bas in order to compare their PM levels to concentrations measured by the reference instrument. The inter-comparison exercise lasted six weeks until the end of February. This time period included a two-week long school break. Thereafter, they were moved to the site of Laennec where they are still located.

The site of Pays-Bas being an urban background station, concentrations are less subject to variations due to hourly activity in the city, whereas Laënnec is representative of emissions from road traffic and pollution level therefore shows more variability. Preliminary analysis of the raw data from the Atmotracks indicate that measurements from the sensor are less accurate in urban traffic conditions.

With respect to the Atmotrack fixed onto the bus, time series of raw PM data indicate that particulate levels were overall higher at street level than at Laënnec (Figure 8).

Figure 8: PM10 and PM2.5 concentration time-series (in µg/m3) on 8 April 2019 between 6:40 am and 9:50 am local time. The blue line indicates measurements on the moving bus. Yellow and green lines correspond to measurements at the fixed site of Laënnec.

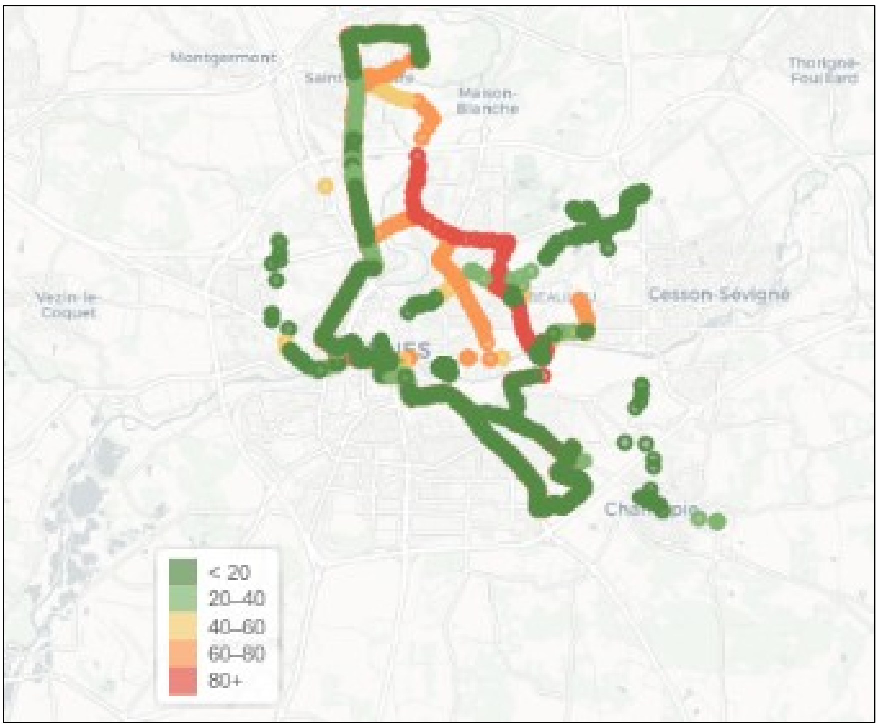

Figure 9: Spatial variability of the PM2.5 concentrations (in µg/m3) measured by the Atmotrack installed on the bus on 8 April 2019 from 6:40 am to 9:50 am local time.

Data from the sensors mounted on the bus will allow to study the spatial variability of concentrations at "street-level" across the urban area.

2.4 The Fidas Frog Sensor

End of May 2019, IRISA provided Air Breizh with a Fidas Frog portable sensor designed by Addair to monitor indoor particulate levels. The instrument was not part of the group of sensors selected for both AIRLAB and LCSQA inter-comparison exercises.

Monitoring air quality with the Fidas Frog is more straightforward than it is with the Atmotrack since the system integrates a battery, a screen to display PM levels in real-time, and a USB connection to download data.

The sensor was first tested on Air Breizh's premises for a few weeks. Next it was installed in a small weather shelter at the urban traffic site of Laënnec where it still is (Figure 10). Since the sampling line is relatively short, the instrument collects air inside the shelter. We've decided not to extend the line to collect air outside the shelter since the length of the line may influence the air flow going into the sensor. At this moment, data from the sensor have not been downloaded yet.

Finally, there are currently discussions to install a Fidas Frog inside a bus.

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Figure 10: (a) The Fidas frog was installed in a weather shelter at Laënnec to measure particulate levels; (b) concentrations are provided by size bins (PM1, PM2.5, PM4 and PM10); outputs also include temperature and relative humidity.

2.5 The Alphasense OPC-N3 Sensor

The Alphasense OPC-N3 was identified as a suitable sensor for AQMO only recently. Air Breizh ordered two of them in the summer of 2019 and they were delivered end of August (Figure 11). They were not part of the LCSQA inter-comparison exercise.

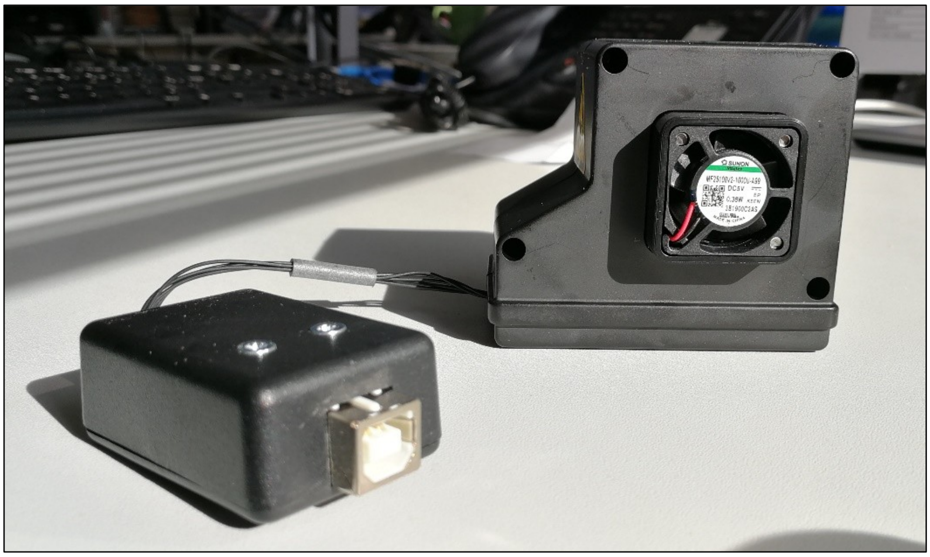

Figure 11: First encounter with the Alphasense OPC-N3 in Air Breizh's office.

In September 2019, one OPC-N3 will be fixed onto a bus and the other will be installed at the site of Laënnec.

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2.6 Accessing data

With respect to the sensors installed at the fixed monitoring sites, Air Breizh developed Python scripts to: (1) collect measurements from the different types of sensors, (2) apply data reduction techniques over specific time periods (e.g., 15 minute-period is the standard for air quality monitoring), (3) plot data and do statistics. The different tasks are:

1. Download Atmotracks' raw data with the initial time step as CSV files from the web portal or by using an API;
2. Reduce data from the initial time step to 15-min period and convert local time to GMT time;
3. Download 15-minute measurement data from reference instruments;
4. Combine both datasets into a table including as many columns as there are variables for all the sensors and save the table to a CSV file;
5. Plot time-series to examine data variability;
6. Calculate statistics and plot boxplots to compare datasets.

Since sensors generate lots of data that may not be useful right away, Air Breizh had also to develop an in-house data framework to store all measurements.

Regarding the sensors fixed onto buses, the problematic is different. Those sensors will be directly connected to a book-size bare-bone computer such as the Intel NUC to run scripts to collect raw data, identify inconsistency in the datasets, associate air quality events to video recording, etc…

For this purpose, Air Breizh started to develop a data architecture and a process chain to implement into the bare-bone computer (Figure 12).

The architecture is based on https://grafana.kabano.net, which is a currently active web portal presenting air quality measurements from Air Breizh's operational surveillance network and the Luftdaten micro-sensors' network in Rennes. The architecture is based on the time-series database InfluxDB and the web dashboard tool Grafana, which are fully compatible with Python.

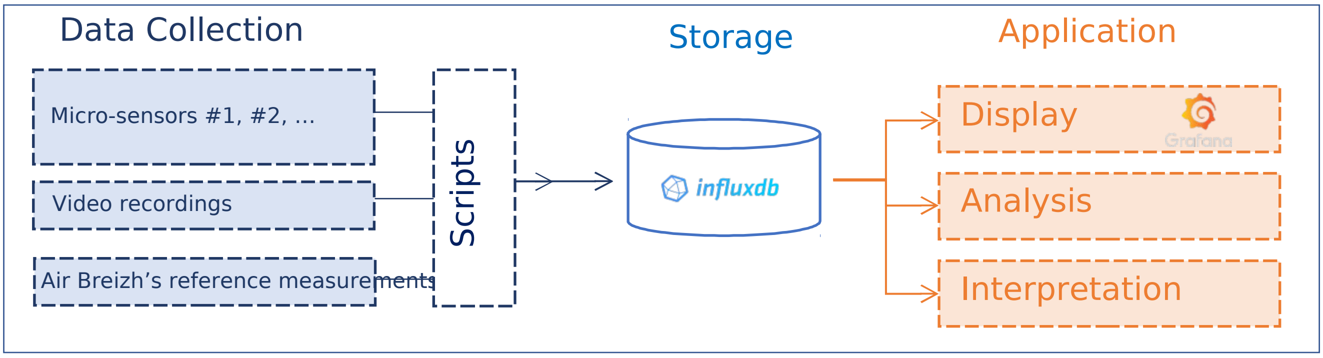

Figure 12: Architecture collection/storage/application.to implement into a bare-bone system.

3 Ancillary Activities

3.1 Gridded Emission Inventories

Building gridded emission inventories is part of the key tasks conducted by Air Breizh on a daily basis. It routinely collaborates with other air quality agencies in north-western France, in particular “Air pays de la Loire” and “Lig’air”, in order to define a common methodology and to apply the most accurate and reliable input data.

At the beginning of the project, Air Breizh, Amplisim and other partners collaborated on defining a study domain (Figure 13) in Rennes, where gridded emission inventories were available. Two versions of inventories were delivered to Amplisim in February and May 2019, respectively. The former includes emission sources for the year 2016 (Table 1).

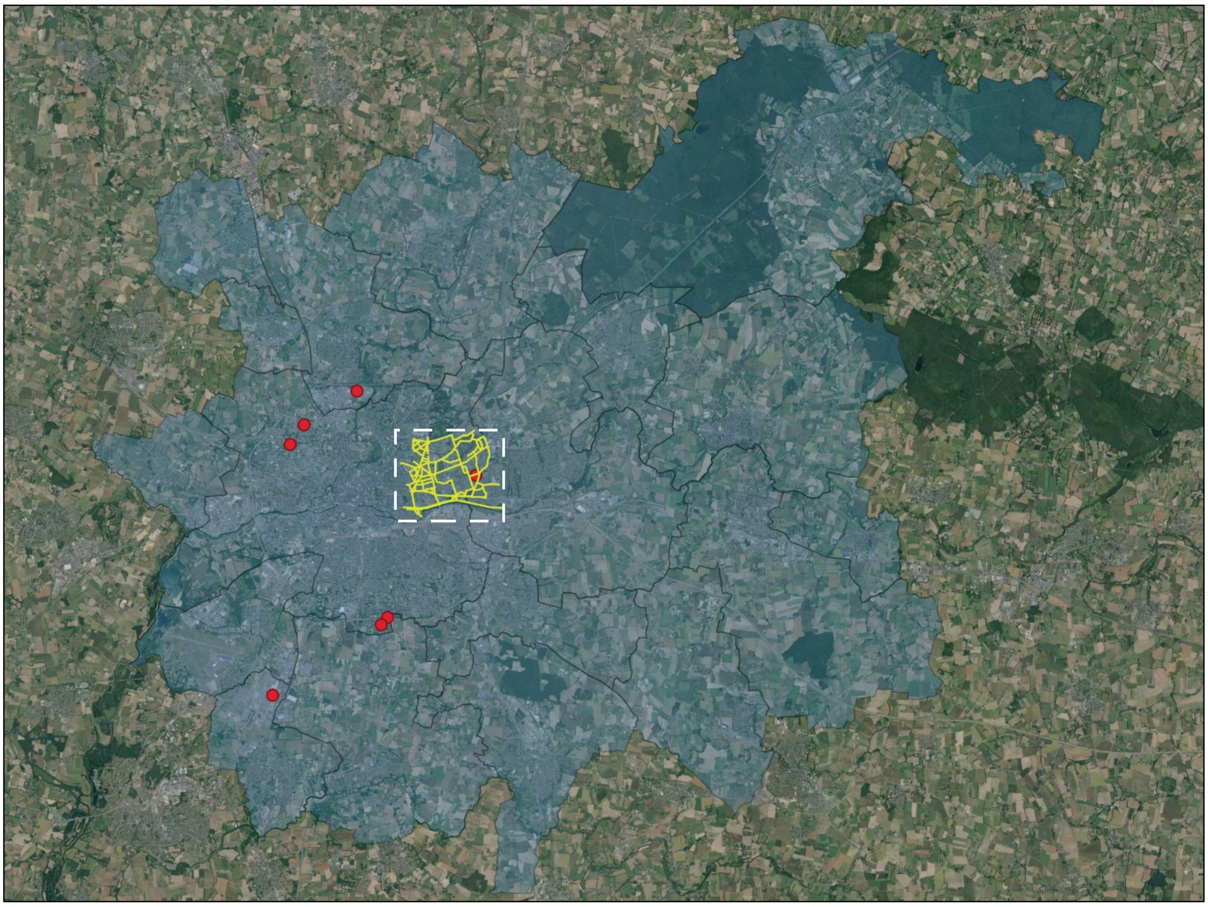

Figure 13: The AQMO study domain (white dashed rectangle) is centered on 18 (in blue) of the 43 municipalities constituting Rennes Métropole. The domain includes the campus of University of Rennes I. Major roads are indicated in yellow.

Table 1: Annual emissions (in tonnes/year) by sectors and pollutants in 18 municipalities of Rennes Métropole and in the study domain.

		Species		
Area	**Sector**	**NO_x**	**PM_{10}**	**$PM_{2.5}$**
18 Municipalities	Agricultural	109	55	16
	Waste	62	1	1
	Road Traffic	2076	230	151
	Other Transportation	60	15	7
	Commercial	165	4	4
	Residential	236	128	123
	Industrial	428	201	117
Study domain	Road Traffic	38	5	3
	Industrial	236	2	1

Geo-referenced emissions by source types and pollutants (i.e., NO_x, PM_{10}, and $PM_{2.5}$) were used by Amplisim as input data to model air quality at street level with the model SIRANE [8]. This exercise was conducted in collaboration with the model developers from the LMFA ("Laboratoire de Mécanique des Fluides et d'Acoustique" or Fluid Mechanics and Acoustics Laboratory), part of French engineering school "Ecole Centrale de Lyon".

3.2 Installing SIRANE on Virtual Servers

Another key mission of Air Breizh is to build an operational methodology for modelling air quality at urban scale. For this purpose, the agency has developed an expertise in applying SIRANE to cities' airsheds in Brittany.

Air Breizh is helping Ucit deploy the high-resolution air quality model on different types of virtual servers. For instance, the agency sent Ucit an exhaustive set of input data to model pollutant dispersion for the city of Brest. A version of the model tailored to their needs was also provided by the LMFA.

Running SIRANE on various servers allows to collect benchmarks for different operating systems and hardware configurations. Simulation exercises permit debugging the code, which will in turn improve model performance.

3.3 Development of Python scripts

In addition to the programs written to deal with InfluxDB and Grafana, detailed in a previous section, Air Breizh and Ryax Technologies started to collaborate on the development of Python scripts to collect raw data from sensors mounted on buses and to compare those data to Air Breizh's reference measurements.

Final versions of those scripts will eventually be deployed on computers installed on buses to process real-time measurements. Building a database of pollutant levels will help select the most suitable micro-sensor to put on buses.

3.4 The 2019 In & Out Conference

End of March 2019, the annual "In & Out" event took place in Rennes. On March 28-29, 1500 professionals attended the [In]door conference to discuss latest technology

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regarding mobility. On March 30-31, the general public was invited to meet the professionals.

In particular, engineers from Air Breizh and IRISA met visitors in an electric bus located at the Keolis' information booth (Figure 14). It gave both agencies the opportunity to inform the public about the AQMO project and to describe how Air Breizh, the University of Rennes and other partners were conducting innovative experiments regarding the measurement of air quality with mobile platforms.

Air Breizh posted messages on its Twitter account to promote the In & Out event.

Figure 14: Air Breizh meets the public during the 2019 In & Out event (source: Air Breizh).

4 Conclusion

As part of the Project AQMO, Air Breizh installed different PM micro-sensors at two operational monitoring sites to conduct an inter-comparison study with reference instruments. Preliminary versions of scripts were developed to download data and to start to build a database in order to interpret PM levels provided by the low-cost sensors.

In addition, Air Breizh is actively collaborating with its partners on the implementation of code to collect data from sensors fixed onto buses and on the simulation of air quality in the city of Rennes with the model SIRANE.

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