Final Report

Clarity and Atmo Normandie Co-location Testing Project in Rouen, France

Clarity Movement Co.
November 8, 2018

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EXECUTIVE SUMMARY

Objective

Clarity Movement Co. (Clarity) and Atmo Normandie of France piloted a co-location project testing Clarity's Air Monitoring Solution at two air monitoring sites in Rouen, France.

Approach

The study ran from February 5, 2018 to March 21, 2018. Two Clarity Node-S devices (solar powered) were installed at each site for a total of four nodes. The sites chosen were Quai de Paris (QDP), a near roadway site, and Palais de Justice (JUS), an urban background site, which have pre-existing government reference monitors recording data.

Results

The Clarity devices, after correction with Clarity's Smart Calibration, were relatively accurate and precise:

- The mean absolute error (MAE) as compared to the government stations was very low across all Clarity devices (24h: 2.09 µg/m^3; SD: 1.74 µg/m^3; 1h: 3.10 µg/m^3; SD: 2.83 µg/m^3).
- All Clarity devices were very accurate compared to the government reference monitors (Daily Pearson R^2: 0.89 – 0.93, Hourly R^2: 0.75 – 0.88) and had high precision with each other (Daily R^2: 0.988-0.997, Hourly R^2: 0.977-0.979).
- All Clarity devices met the performance metrics set forth in the Product Specifications sheet (error within 10 µg/m^3 for readings below 100 µg/m^3, and within 10% for readings above 100 µg/m^3).
- All Clarity devices were able to categorize air quality into the appropriate air quality index buckets (EU Common Air Quality Index and WHO PM2.5 Standard) that matched the reference monitors approximately 86% and 95%, respectively.
- Errors between Clarity devices and reference monitors were not dependent on temperature and relative humidity.
- Most Clarity devices had very high data retrieval rates (96-97%) except for one (86%). Internal analysis into why this node was unable to report some data is ongoing. This often has to do with cellular connectivity issues, but further review is needed.

Insights for a Future Deployment

The ability of Clarity Nodes to provide accurate PM2.5 data provides valuable insights for future applications of a larger air monitoring network to supplement the existing one. In addition to good data quality, the project demonstrated the following:

- The Clarity Node-S (solar) works exceptionally well in Rouen with sufficient solar irradiation. The sampling frequency can be increased to one reading every ~8min without reduction in operations, which will also improve PM2.5 accuracy and ability to capture transient pollution events.

- The Use of Clarity Node-S allows for additional measurement points in areas that do not have access to power.

- These positive results from this co-location testing needs to be confirmed under longer testing timeframe and under different types of site and environmental conditions.

01 INTRODUCTION

Clarity Movement Co. (Clarity) provides cities with highly accurate, real-time air quality monitoring data at an unparalleled resolution. Clarity's Solution expands existing air quality monitoring networks from tens to hundreds of measurement points at a minimal cost, providing actionable air quality data that is not otherwise economically obtainable with traditional monitoring technologies or approaches.

Atmo Normandie is a governmental agency charged with monitoring air quality in the Normandie region. Atmo Normandie raised interest in assessing the accuracy of emerging technologies for air quality monitoring, and in particular, low-cost microsensors; and evaluating algorithms that enhance the readings of low-cost air quality sensors with the goal of enhancing their accuracy.

Clarity, in partnership with Atmo Normandie, conducted a demonstration of a distributed air quality monitoring network in Rouen. The goal of this demonstration is to validate the accuracy of Clarity's Solution by co-locating Clarity's Nodes with two (2) of the government stations over a period of one and a half (1.5) months.

The outcomes of this demonstration will be used to support discussions of a city-wide dense air quality monitoring network that supplements the existing network to provide highly localized and real-time air quality information.

02 GOALS

The specific goals of this demonstration are the following:

1. Demonstrate the ability of Clarity devices and subsequent data correction and analysis using Clarity's Smart Calibration algorithm to provide value by supplementing the existing air monitoring network in Rouen, France:
    - A. Assess the accuracy and precision of Clarity devices
    - B. Verify that Smart Calibration algorithm is able to enhance the accuracy of the Clarity devices
    - C. Assess the ability of the Clarity Nodes to provide correct categorization using European Air Quality Index (EU CAQI) and violations of WHO standards
    - D. Provide additional air quality insights

2. Determine specifications of a hypothetical future deployment of Clarity devices
    - A. Determine if solar power is sufficient in Rouen for use of solar powered nodes
    - B. Assess the temperature and relative humidity dependencies, if any, of the devices

03 PROJECT DETAILS

SITE SELECTION

To validate the accuracy of the Clarity Solution, Clarity Nodes were co-located at two (2) of the existing government monitoring sites that operate in Rouen.

Table 1. Co-location Site Locations

Site Name	Type of Site	Node ID
Quai de Paris (QDP)	Near Roadway	A88W6WY9 A96PNDQP
Palais de Justice (JUS)	Urban Background	ASBMY5MM A3TCQJGS

Figure 1. Co-location sites in Rouen, France

DEPLOYMENT

The Nodes were installed at the two sites from February 5, 2018. The co-location ended on March 21, 2018.

At each of the two sites, Atmo Normandie installed two Clarity Node-S (solar powered). This allowed for testing of the solar irradiance availability in Rouen.

Nodes were installed at the reference stations as near as possible to the reference equipment air inlets.

Figure 2. Clarity Node-S deployed at Quai de Paris and Palais de Justice in Rouen, France

04 RESULTS AND DISCUSSION

DATA CAPTURE AND PROCESSING

The Clarity data were averaged to the hour to allow for comparisons to the reference data to determine accuracy and precision. Daily (24-hour) averaged data were also analyzed to determine the general data trends at these two time-resolutions.

During the project period, the Clarity Nodes were deployed for a total of 1,057 hours (44 days), during which the nodes has various amounts of data capture (**Table 2**). While A3TCQJGS had the lowest data capture (86%), we are still assessing the reason for the missing data.

Table 2. Hourly data capture by site and node ID

Site Name	Node ID	Type	# Hourly readings*	% Capture
QDP	A96PNDQP	Node-S	1022	96.7
	A88W6WY9	Node-S	1024	96.9
JUS	ASBMY5MM	Node-S	1014	95.9
	A3TCQJGS	Node-S	909	86.0

*Test Duration: 1057 hours

Data from government reference monitors was used to train the Smart Calibration algorithm. Smart Calibration was activated one month into the project once enough training data was acquired, and retroactively applied to all the period under analysis.

SMART CALIBRATION OVERVIEW: DATA CORRECTION

Overview

The purpose of Smart Calibration is to correct the relative PM2.5 readings from the optical sensor contained in the Clarity Node to an absolute measurement comparable to the gravimetric one taken by the reference instrument. Low-cost optical sensors are unable to detect particulate matter composition, so these sensors assume a certain composition and apply a constant factor set during factory calibration to transform optical readings to gravimetric readings. This results in a concentration estimate that is correlated with that of the reference monitor but off by a factor which depends on actual aerosol composition. This factor may change spatially and temporally.

Smart Calibration works with sensor data and reference data to dynamically determine the correction factor and apply it to the network. This ensures that the estimation error remains constant over time. To correct sensors that are not co-located with reference monitors, an analysis of spatial auto-correlation is performed to select the appropriate correction factors for each site. Additionally, temperature and humidity corrections are applied. The results are expected to improve with the deployment of a denser network and the deployment of additional co-located devices. This improves the accuracy of the spatial auto-correlation analysis. The algorithms used are linear regressions and physics-based.

Example

Low-cost sensors are factory calibrated and hard-coded with assumed pollutant composition. Field calibration accounts for actual pollutant composition for enhancing accuracy in applications where a low mean absolute error is required.

Traditional calibration:

- Deploy all sensor nodes next to reference monitor for some time
- Calculate bias and offset correction factors comparing output of nodes with output of monitor
- Once calibration is done, deploy sensor nodes at desired sites for the duration of the project
- At the end of data collection, correct data with correction factors obtained before

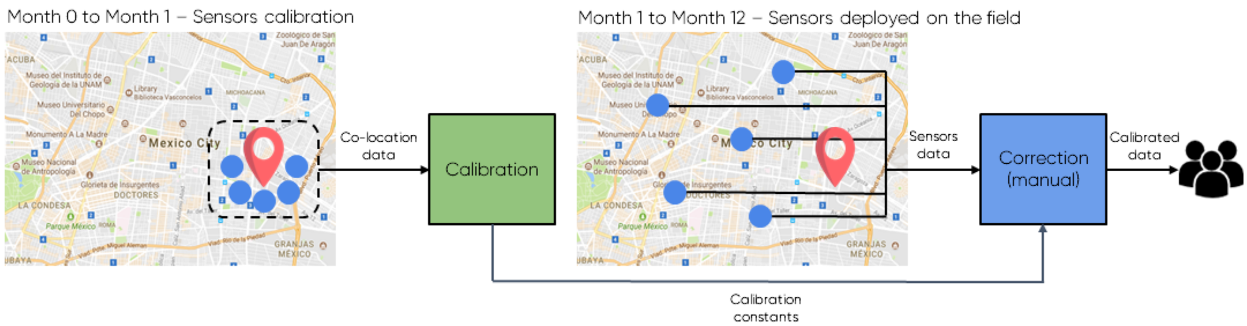


Figure 3. Traditional sensor calibration procedure

Smart calibration:

- Ensure sensor-to-sensor consistency (precision) at the factory
- Deploy one sensor node next to reference monitor, and all other sensor nodes at desired sites since the beginning
- Use data from co-located node and monitor to calculate bias and offset correction factors periodically
- Apply up-to-date correction factors to the output of the sensor nodes in real-time

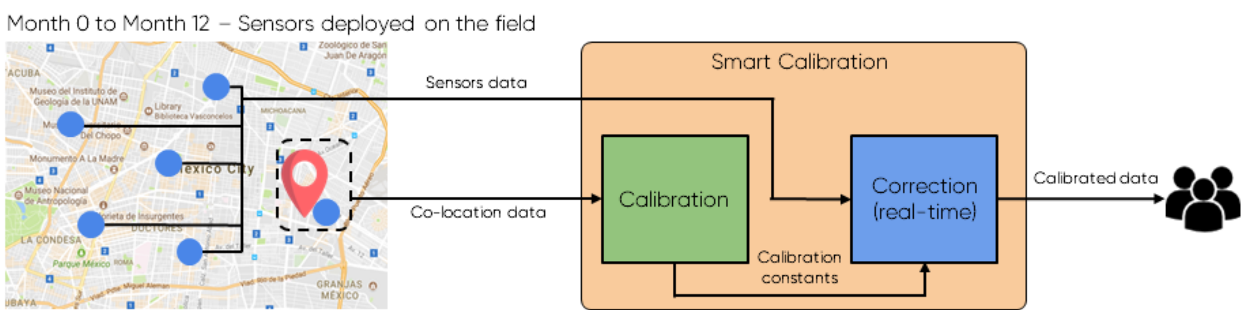


Figure 4. Smart calibration procedure

ACCURACY AND PRECISION RESULTS

The accuracy and precision of the Clarity Nodes, enhanced by Smart Calibration algorithm, were determined using three metrics for both hourly and 24-hour averaged PM2.5 data.

- **The Pearson correlation coefficients (R^2)** between the Clarity Nodes and the government stations.
  - For both 24 hour and hourly data, the Clarity Nodes correlated very well with the government references (Daily Pearson R^2: 0.89–0.93, Hourly R^2: 0.75–0.88). The Clarity Nodes were also highly precise (Daily R^2: 0.988-0.997, Hourly R^2: 0.977-0.979).
  - **Note:** while R^2 is a common accuracy metric, it should not be used in isolation. It is highly sensitive to outliers, and even high R^2 values may hide systematic biases and errors. We look at other metrics and do additional outlier analysis (in "Detailed Error Analysis") to assure that the Nodes are accurate.

- **Mean absolute error (MAE)** was also calculated to determine whether the differences in PM2.5 mass concentrations between the Clarity Nodes and the reference stations were significant.
  - For 24-hour data, the MAE for both nodes was low (mean: 2.09 µg/m³; SD: 1.74 µg/m³).
  - The hourly data had similarly low MAE (3.10 µg/m³; SD: 2.83 µg/m³).
  - These promising results demonstrate that the average difference between Clarity Nodes and the government stations are very small under the experimental conditions of the co-location period.

- Finally, the results were compared against the **Clarity performance metric** as set forth in the Product Specifications sheet.[1]
  - For 24-hour averaged data, the error between Clarity Nodes readings and reference readings was within acceptable boundaries for 100% of all readings.
  - For hourly averaged data, the error between Clarity Nodes readings and reference readings was within acceptable boundaries for ~95% of all readings.
  - The time series of errors can be seen in the **Appendices** on the time-series plots.

The R^2 was also used to calculate precision between two Clarity Nodes. Summary statistics regarding accuracy and precision are in **Table 3**. Detailed time series comparing Clarity Nodes readings and reference readings are in the **Appendices.** As mentioned above, the impact of outliers on the R^2 are further explored in the following section.

[1] Clarity Nodes measure PM2.5 within 10 µg/m³ (<100 µg/m³) and within 10% (≥100 µg/m³).

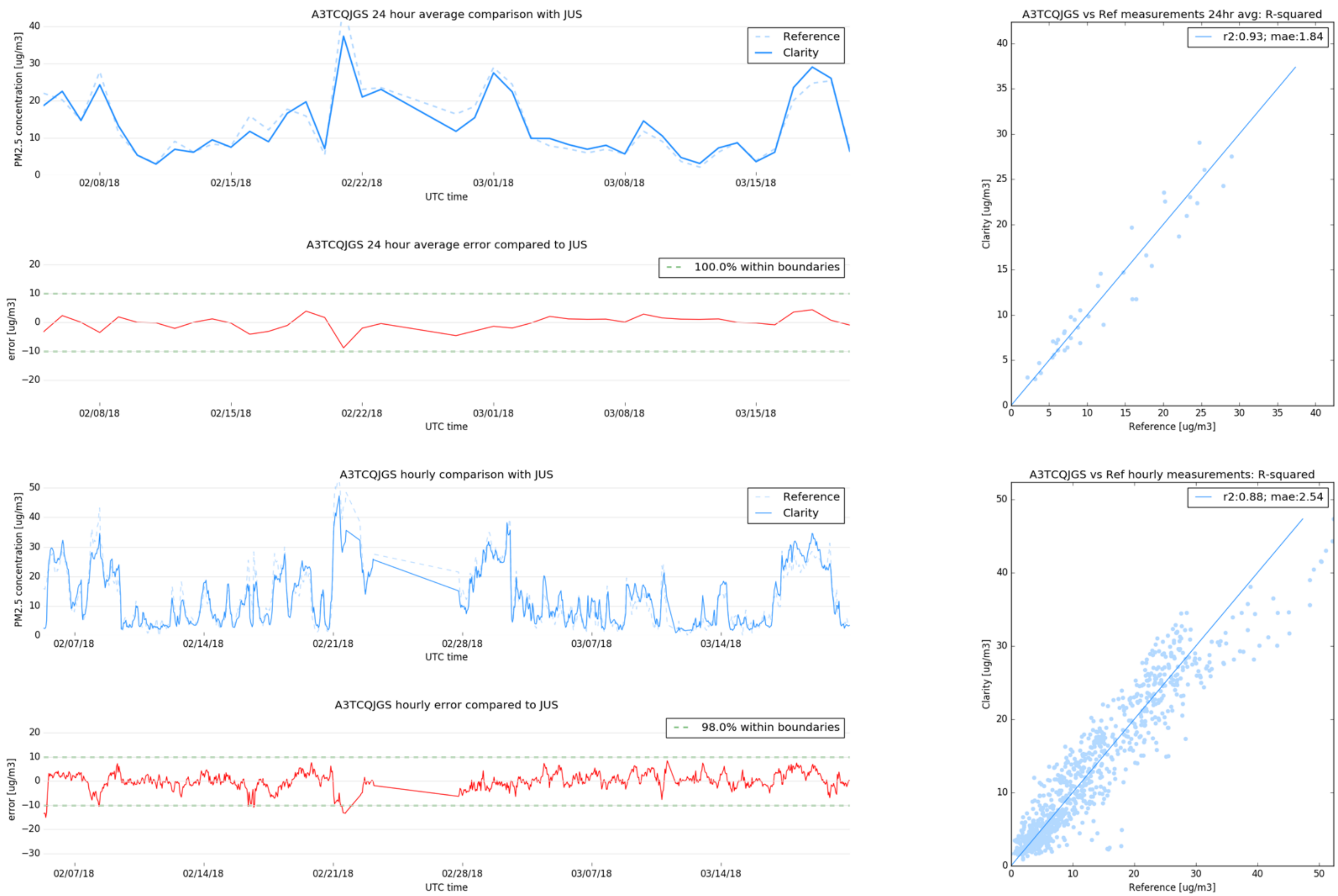


Figure 5. Comparison of (*top*) 24-hour and (*bottom*) hourly averaged Clarity PM2.5 (µg/m^3) time-series, error, and correlations against government station at Palais de Justice (JUS) site

Table 3. Accuracy and precision of Clarity Nodes, enhanced by Smart Calibration algorithm, for hourly and 24-hour averaged PM2.5 mass concentration data

		Daily (24h) Average				Hourly Average			
Site Name	Node ID	% within error boundaries	MAE (µg/m³)	R^2 (accuracy)	R^2 (precision)	% within error boundaries	MAE (µg/m³)	R^2 (accuracy)	R^2 (precision)
QDP	A96PNDQP	100%	2.33	0.89	0.997	96%	3.60	0.75	0.977
	A88W6WY9	100%	2.30	0.89		96%	3.59	0.75	
JUS	ASBMY5MM	100%	1.88	0.92	0.988	99%	2.59	0.87	0.979
	A3TCQJGS	100%	1.84	0.93		88%	2.54	0.88	

Note: Accuracy is comparing the Clarity Node against the government reference monitor. Precision is comparing two Clarity Nodes at the same site.

Smart Calibration Enhancement

In this section we verify the ability of smart Calibration algorithm to enhance the accuracy of the Clarity devices by comparing uncalibrated to calibrated data. Figure 6 shows calibrated versus uncalibrated PM2.5 concentration data from the Clarity Nodes compared to the data from the reference monitor. The plots on the left (time-series plots) show how the uncalibrated readings overestimate in all cases the pollutant concentration, while the calibrated measurements overlap well with the measurements from the reference monitor.

In the middle plots it can be observed that, even though both calibrated and uncalibrated readings have a visible correlation with the reference measurements, only the calibrated readings overlap with the 1:1 red line, while the uncalibrated readings are mostly above the 1:1 line.

The error plots on the right show that the difference between uncalibrated readings and reference measurements is mostly out-of-spec and probably too high for correctly categorizing different CAQI PM2.5 sub-indices, while the error for the calibrated readings is within specs and acceptable. Table 4 quantitatively reports the improvements as a result of Smart Calibration. As expected the MAE is higher for uncalibrated data, while the R^2 is similar (Table 5).

Please note that to fully evaluate the Smart Calibration algorithm, a blind cross reference study design should be used. In this study, the co-located Clarity devices are separated into two groups: a calibration set and a test set. Clarity will have access to data from Clarity devices and the reference monitor in the calibration set. In the test set, Clarity will only have access to data from the Clarity devices, but these devices will also be co-located. These test devices are "blind" to the reference data.

Clarity will develop the calibration algorithm based on data (Clarity data and reference data) from the calibration set. The calibration model will then be applied to the test dataset to determine performance of the algorithm on "blind" locations.
This approach can also be applied in time to see how an initial calibration based on one month of data holds over time.

Uncalibrated vs Calibrated data

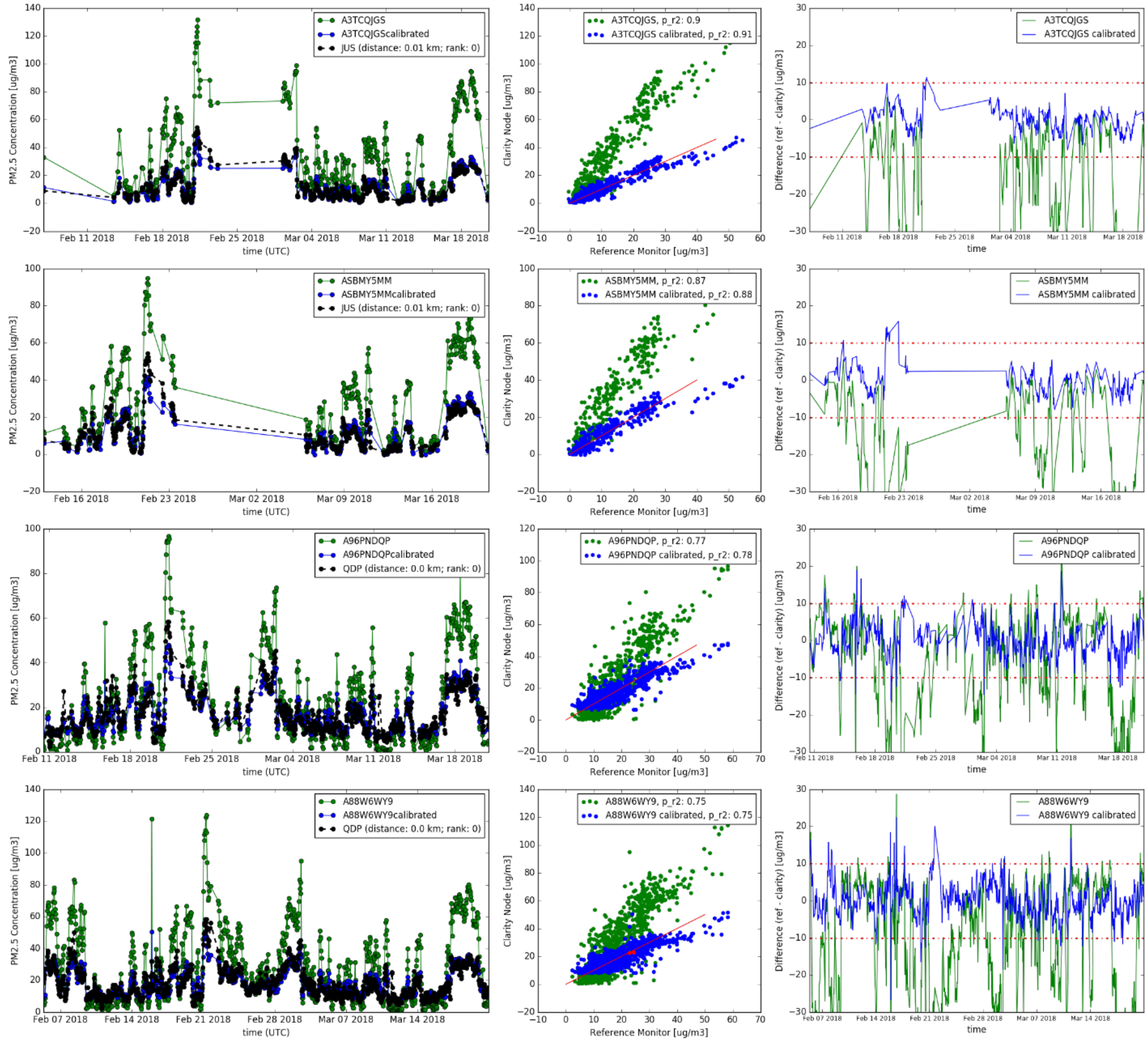


Figure 6. Comparison of uncalibrated versus uncalibrated PM2.5 concentrations from the four Clarity devices in (left) time series, (middle) correlation and (right) error as compared to the government reference monitor

Table 4. Average error and mean absolute error (MAE) of the Clarity Nodes for 24-hour and hourly averaged uncalibrated PM2.5 data

	Daily (24h) average					Hourly Average				
	Average Error (μg/m³)		Mean Absolute Error (MAE) (μg/m³)		% Within Error Boundaries	Average Error (μg/m³)		Mean Absolute Error (MAE) (μg/m³)		% Within Error Boundaries
Node ID	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
A3TCQJGS	20.64	15.21	20.64	15.21	29.27	20.10	18.05	20.34	17.78	42.13
A88W6WY9	10.87	12.56	11.76	11.71	59.09	10.46	15.70	14.09	12.55	52.05
A96PNDQP	5.51	9.75	7.79	8.00	70.45	5.19	12.48	10.25	8.82	62.82
ASBMY5MM	13.18	9.48	13.18	9.48	56.82	13.00	11.54	13.22	11.30	50.79
Overall	12.41	12.98	13.21	12.16	54.33	11.96	15.50	14.31	13.36	52.23

Table 5. Pearson coefficient (R^2) for 24-hour and hourly averaged PM2.5 concentrations for uncalibrated and calibrated data

	Uncalibrated PM2.5 Data		Calibrated PM2.5 Data	
Node ID	Daily (24h) Average, R^2	Hourly Average, R^2	Daily (24h) Average, R^2	Hourly Average, R^2
A3TCQJGS	0.93	0.88	0.89	0.75
A88W6WY9	0.89	0.75	0.89	0.75
A96PNDQP	0.89	0.75	0.92	0.87
ASBMY5MM	0.90	0.86	0.93	0.88

DETAILED ACCURACY ANALYSIS

To better understand the accuracy results, the error metrics were examined further in the following analyses:

1. The impact of extreme outliers on R^2 values was analyzed since the Pearson R^2 is known to be overly sensitive to outliers.
2. The bias was also calculated to see if Clarity Nodes consistently under or overestimated the PM2.5 values.
3. The correlation of error with external factors such as temperature and relative humidity was also examined.

Extreme Outliers Had Minimal Impact on Pearson R^2

While the Pearson R^2 values from the Nodes are high, Pearson R^2 values could be reduced by a few extreme outliers in the error. As the Clarity devices were sampling intermittently while the government stations were sampling continuously, the Clarity devices may have missed short-term spikes in air pollution. To avoid penalizing the accuracy score of the Clarity devices due to the presence of isolated outliers, we ran a second accuracy analysis in which the top 0.5% of errors were removed from the analysis and the R^2 values were re-calculated. The results can be seen in **Table 6** below.

According to this analysis, removing the few extreme outliers from the daily (24h) data didn't not drastically change the Pearson R^2. The hourly data had a slightly increased Pearson R^2 as there were more outliers.

Limited Systematic Bias

Next, we tested for systematic overestimation and underestimation. While the MAE revealed that the magnitude of error was typically small, direction of the error was determined from the average error.

Average error and standard deviation were low for both daily (mean=-0.20 μg/m^3, SD=2.72 μg/m^3) and hourly (mean=-0.07 μg/m^3, SD=4.20 μg/m^3) data **(Table 7).** This showed that the Clarity devices were not significantly biased, and on average captured the PM2.5 levels fairly well.

Limited Correlation with External Factors

Finally, limited correlation was found between error and external factors like humidity (R^2= 0.20), temperature (R^2= 0.01), and concentration (R^2= 0.16) (Appendix: **Figure 17**). This indicates that the Clarity device accuracy was not significantly affected by external conditions. Additional field testing can be done throughout the year to verify these results.

Table 6. Impact of removing the highest 0.5% of errors on Pearson coefficient (R^2) for 24-hour and hourly averaged calibrated PM2.5 data

		Daily (24h) average			Hourly Average		
Site	Node ID	R^2 (before)	R^2 (after)	# outliers removed	R^2 (before)	R^2 (after)	# outliers removed
QDP	A96PNDQP	0.89	0.89	0	0.75	0.78	8
	A88W6WY9	0.89	0.89	0	0.75	0.77	9
JUS	ASBMY5MM	0.92	0.92	1	0.87	0.88	3
	A3TCQJGS	0.93	0.93	0	0.88	0.88	0

Table 7. Average error and mean absolute error (MAE) of the Clarity Nodes for 24-hour and hourly averaged calibrated PM2.5 data

	Daily (24h) average					Hourly Average				
	Average Error (µg/m³)		Mean Absolute Error (MAE) (µg/m³)		% Within Error Boundaries	Average Error (µg/m³)		Mean Absolute Error (MAE) (µg/m³)		% Within Error Boundaries
Node ID	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
A3TCQJGS	-0.28	2.53	1.84	1.75	100	-0.07	3.43	2.54	2.31	98.35
A88W6WY9	-0.17	2.89	2.30	1.73	100	-0.06	4.79	3.59	3.16	95.80
A96PNDQP	-0.14	2.89	2.33	1.68	100	-0.05	4.75	3.60	3.09	95.99
ASBMY5MM	-0.23	2.61	1.88	1.80	100	-0.09	3.54	2.59	2.41	98.62
Overall	-0.20	2.72	2.09	1.74	100	-0.07	4.20	3.10	2.83	97.15

CLASSIFICATION ACCURACY

To test the accuracy of Clarity Nodes on a real-world application, we evaluated the ability of Clarity devices to provide air quality data that would be categorized similarly as a government station according to the following:

- Hourly EU Common Air Quality Index (CAQI) sub-indice for PM2.5[2],
- World Health Organization (WHO) PM2.5 standard[3]

Clarity and government station data were categorized according to these two standards and the results show that Clarity devices can achieve very high accuracy in classification compared to the government stations. Overall, Clarity devices were able to accurately categorize the hourly PM2.5 mass concentrations according to the EU CAQI sub-indice categories for PM2.5 approximately 86% of the time and WHO-level exceedances approximately 95% of the time.

As the categorizations drive actions taken by Atmo Normandie, these results demonstrate the potential use cases Clarity devices, enhanced by Smart Calibration, offer if they are used to supplement the existing network in areas where monitoring is currently difficult or cost-prohibitive. The Clarity device can provide insights that were previously difficult to obtain.

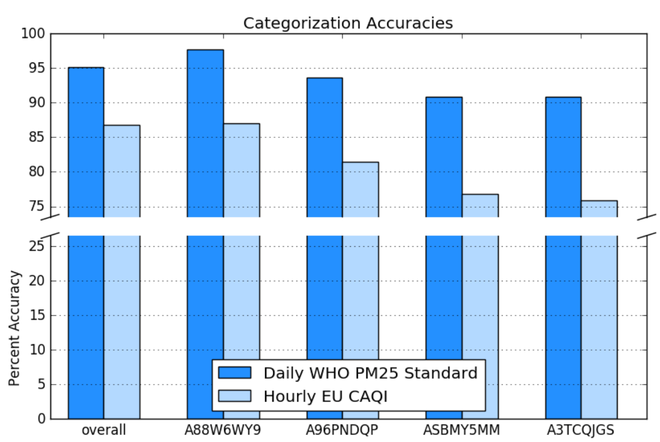


Figure 7. Categorization accuracy for WHO and EU PM2.5 air quality indices compared to the government station

[2] European Regional Development Fund Regional Initiative Project (2012). "CITEAIR: CAQI Air quality index Comparing Urban Air Quality across Borders – 2012"
[3] Source: "WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide Global update 2005 Summary of risk assessment"

The CAQI PM2.5 sub-indice band only accounts for PM2.5 concentrations and are calculated as follows:

Index class	Grid	Traffic						City Background							
		core pollutants			pollutants			core pollutants				pollutants			
		NO2	PM10		PM2.5		CO	NO2	PM10		O3	PM2.5		CO	SO_2
			1-h.	24-h.	1-h.	24-h.			1-h.	24-h.		1-h.	24-h.		
Very low	0	0	0	0	*0*	*0*	0	0	0	0	0	*0*	*0*	0	0
	25	50	25	*15*	*15*	*10*	5000	50	25	*15*	60	*15*	*10*	5000	50
Low	25	50	25	*15*	*15*	*10*	5000	50	26	*15*	60	*15*	*10*	5000	50
	50	100	50	*30*	*30*	*20*	7500	100	50	*30*	120	*30*	*20*	7500	100
Medium	50	100	50	*30*	*30*	*20*	7500	100	50	*30*	120	*30*	*20*	7500	100
	75	200	90	50	*55*	*30*	10000	200	90	50	180	*55*	*30*	10000	*350*
High	75	200	90	50	*55*	*30*	10000	200	90	50	180	*55*	*30*	10000	*350*
	100	400	180	100	*110*	*60*	20000	400	180	100	240	*110*	*60*	20000	500
Very High*	> 100	> 400	>180	>100	> *110*	>*60*	>20000	> 400	>180	>100	>240	> *110*	>*60*	>20000	>500

NO_2, O_3, SO_2: hourly value / maximum hourly value in µg/m^3
CO 8 hours moving average / maximum 8 hours moving average in µg/m^3
PM_{10} hourly value / daily value in µg/m^3

* An index value above 100 is not calculated but reported as " > 100"

Figure 8. CAQI PM2.5 sub-indice calculation figure

The CAQI PM2.5 sub-indice bands only account for PM2.5 concentrations and are calculated using the cut-points highlighted in **Figure 8**.

The categorization accuracy is defined as the number of hours in which both reference monitor and Clarity Node (enhanced by Smart Calibration) both output a PM2.5 sub-indice which falls in the same class, divided by the total number of test hours, multiplied by 100. The classes are "Very low, Low, Medium, High, Very High", as indicated above.

APPLICATIONS AND INSIGHTS

The broader goal of testing the Clarity devices is to demonstrate value that such a technology can provide to Atmo Normandie, other agencies, and the public by supplementing the existing network in Rouen. Here we overview a few applications and supplemental insights from the Clarity devices.

Air quality classification

First, the very high accuracy in translating PM2.5 mass concentration data from Clarity devices to qualitative categories (See Section "Classification Accuracy") demonstrate that there is inherent value in locating Clarity devices in currently unmonitored areas to rapidly and cost-effectively provide air quality information previously unattainable. For a full evaluation of Clarity's devices and Smart Calibration, Clarity devices should be deployed in a dense network as part of longitudinal studies in real-world conditions with both co-located and standalone devices. This longer duration and denser deployment in areas where people reside and work can help provide qualitative indications of air quality that were previously cost-prohibitive or technologically infeasible. These data can improve health risk communication to the public, inform epidemiological studies, or identify areas where agencies can invest more resources to address environmental concerns.

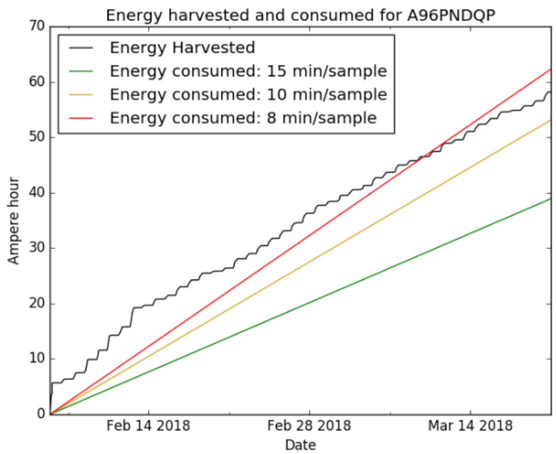
Energy consumption and usage

Analysis of the energy consumption of the Clarity Node-S (solar) demonstrates that the solar version performs exceptionally well in Rouen given the high solar radiance under the conditions of the co-location period. We find that the sampling frequency of the Node-S can be dynamically changed for higher accuracy, higher resolution data, and longer operational life as needed.

The solar energy harvested at every hour of the study can be accurately reconstructed from the node's reported solar current measurements. Furthermore, the energy consumed per hour for a given sampling frequency (sleep time) can be calculated and compared to energy harvested.

Figure 9 shows the total solar energy harvested in black. The colored lines represent total energy consumed for different sampling frequencies. The current sampling frequency of 15 minutes per sample consumes much less energy than what is available. The sampling frequency can be increased up to about 8 minutes/sample while remaining operational. Therefore, it is possible to increase our sampling frequency (and thus our accuracy, as shown in earlier sections) without reducing battery life in the field.

Moreover, these energy calculations can be done in real time, meaning we can modify the sampling frequency intelligently. If there is a period of poor solar radiance, or there is an abnormal event requiring higher resolution monitoring, the sampling frequency can be remotely and intelligently changed to stay operational while still sampling as frequently as possible.



Not being reliant on external power also greatly expands the locations where Clarity devices can be deployed to provide Atmo Normandie with additional measurement points when needed.

Figure 9. Comparison of energy consumed to energy harvested in Clarity Node-S

Temporal Trends

Another potential use case is to look at temporal pollution trends with respect to hour of the day and day of the week.

Figure 10 shows the measured concentrations for the two Clarity Nodes and government monitors at Quai de Paris. The measurements are grouped and averaged by day and hour of the week to identify temporal trends and observe whether the Clarity devices captured similar patterns compared to the government station.

A diurnal cycle is observed which is consistent and matches with the reference data as well as reported hourly data from haze.gov. The standard deviation of these averages (denoted by the light blue and light red areas) is also fairly consistent, indicating that there is some natural variation around this trend but usually only by 10µg/m^3 or less.

Figures for all sites can be found in the **Appendices**.

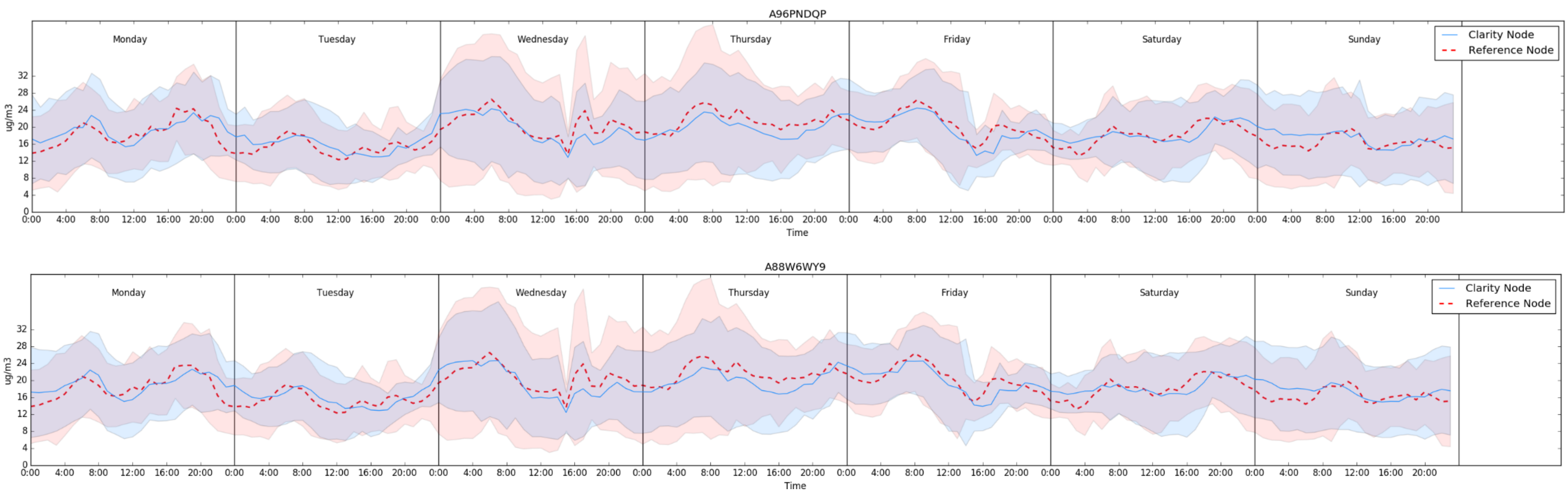


Figure 10. PM2.5 temporal trends of Clarity Node as compared to the government station throughout hours of days of the week at Quai De Paris

ACCURACY: ADDITIONAL SITES

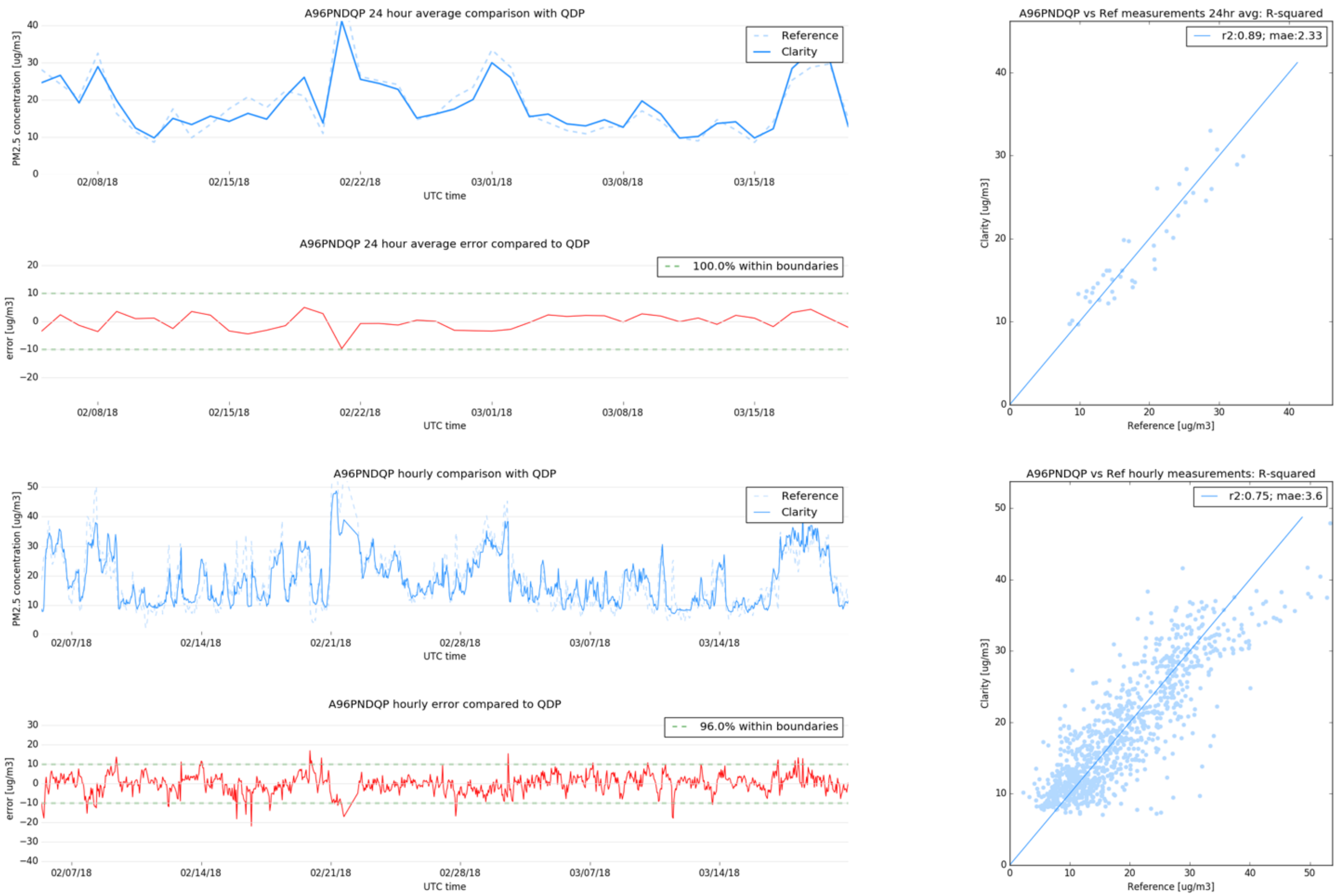


Figure 11. Comparison of (*top*) 24-hour and (*bottom*) hourly averaged Clarity PM2.5 (μg/m^3) time-series, error, and correlations against government station at Quai de Paris for Node ID: A96PNDQP

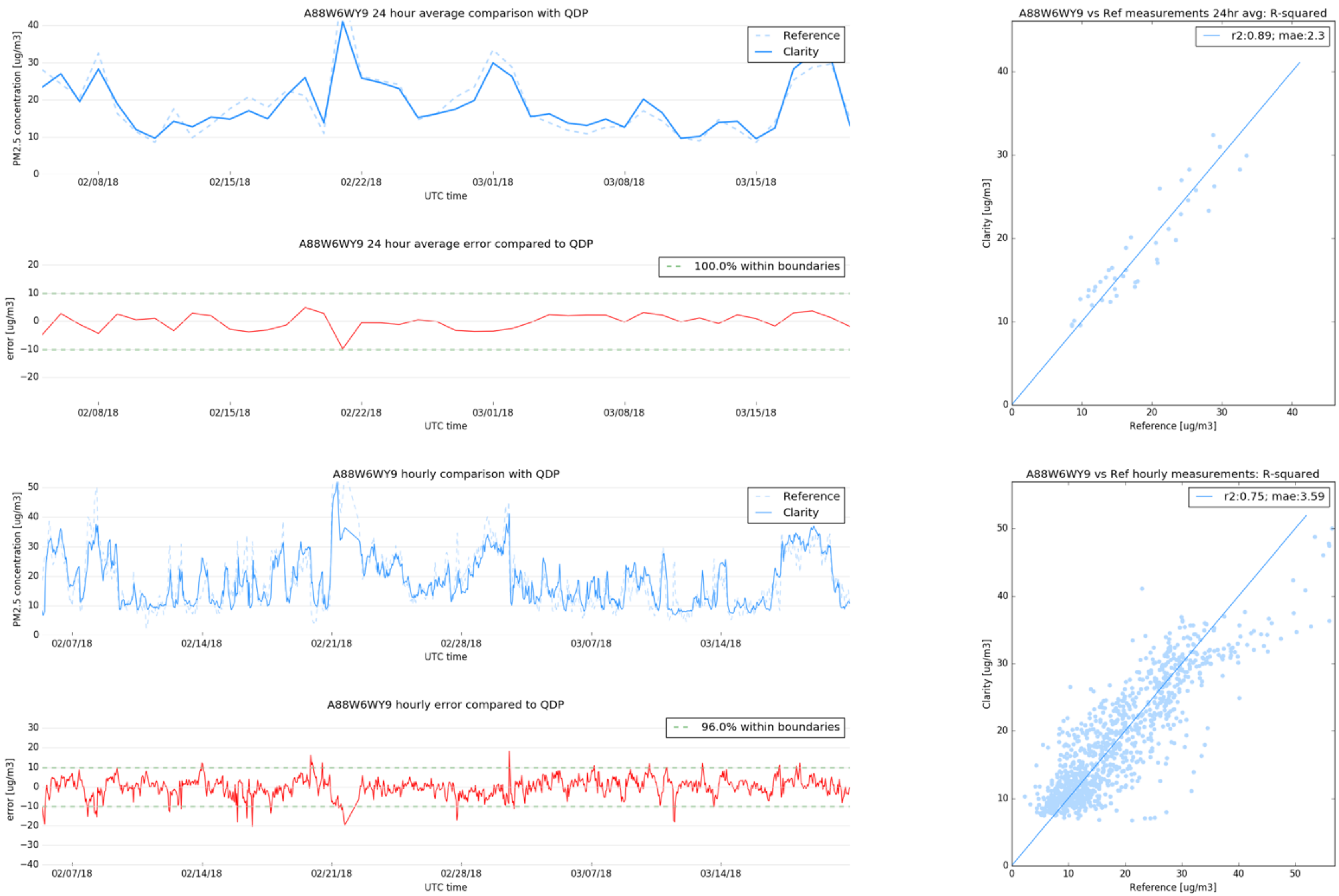


Figure 12. Comparison of (*top*) 24-hour and (*bottom*) hourly averaged Clarity PM2.5 (µg/m^3) time-series, error, and correlations against government station at Quai de Paris for Node ID: A88W6WY9

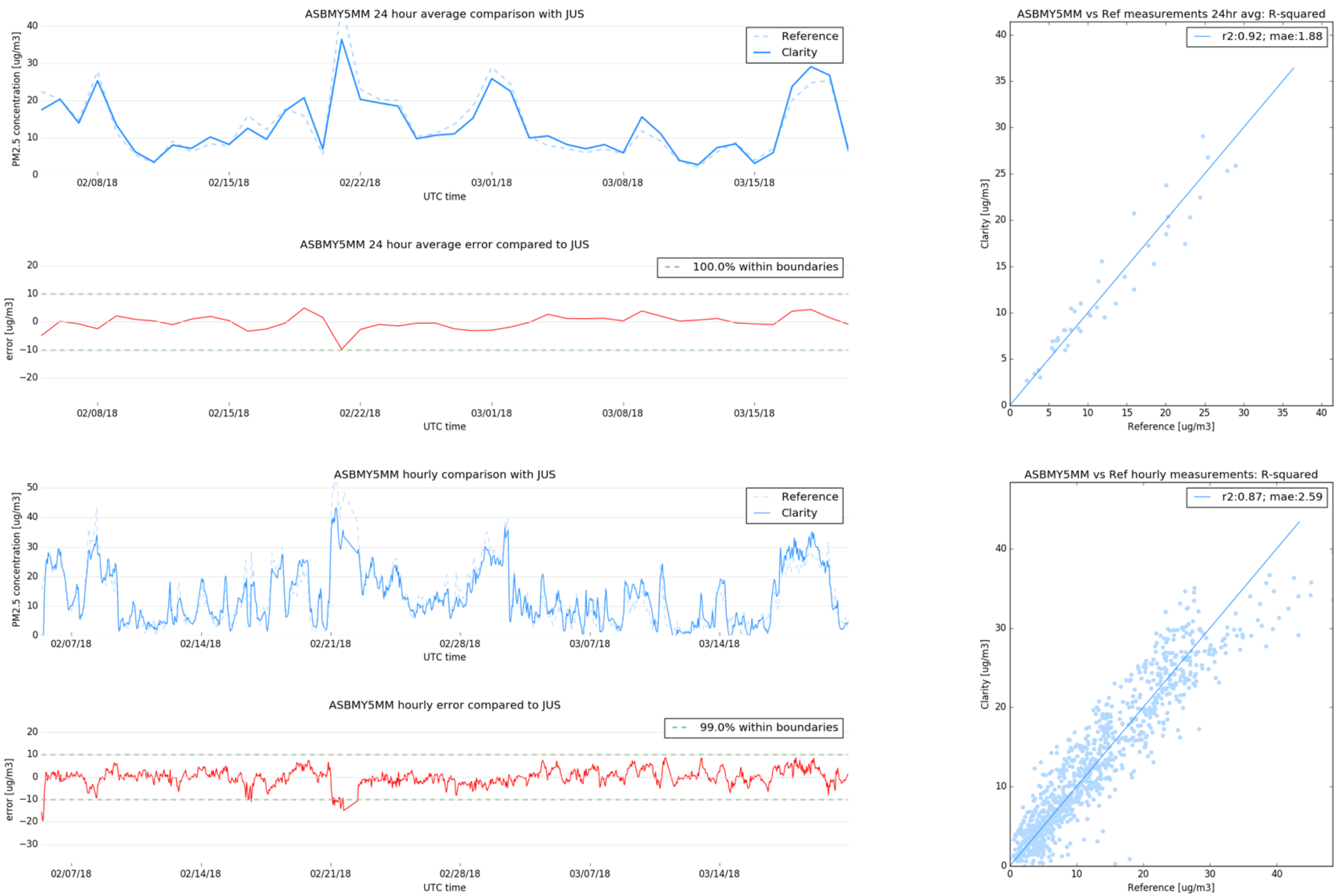


Figure 13. Comparison of (*top*) 24-hour and (*bottom*) hourly averaged Clarity PM2.5 ($\mu g/m^3$) time-series, error, and correlations against government station at Palais de Justice for Node ID: ASBMY5MM

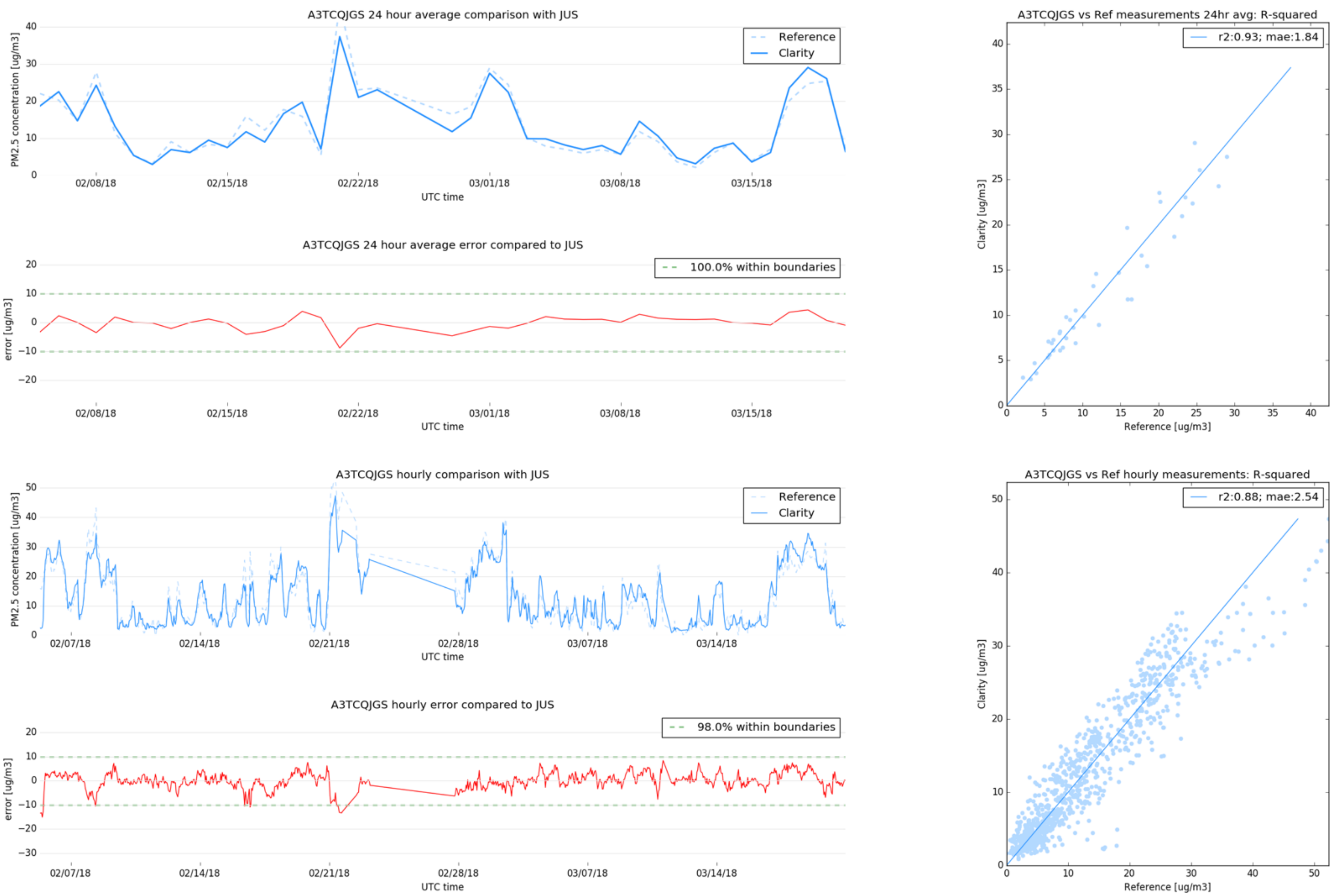


Figure 14. Comparison of (*top*) 24-hour and (*bottom*) hourly averaged Clarity PM2.5 (μg/m^3) time-series, error, and correlations against government station at Palais de Justice for Node ID: A3TCQJGS

Quai de Paris (QDP) Site

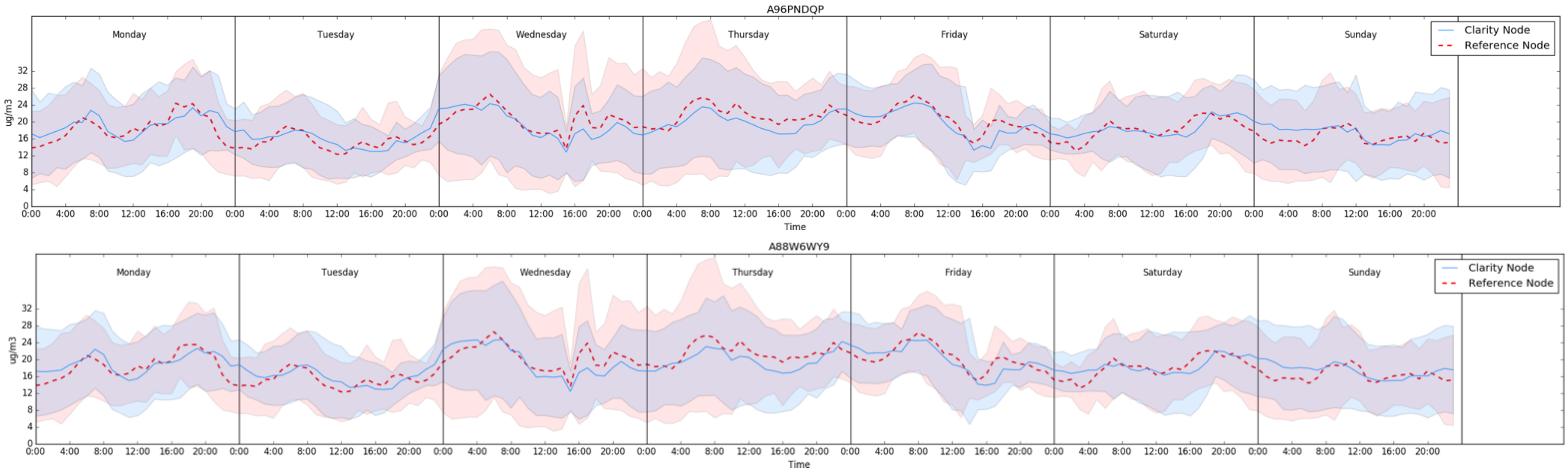


Figure 15. Temporal trends for Clarity Nodes (blue) and government station (red) at QDP, averaging by hour of day and day of week. Standard deviation of this trend highlighted in light blue/red.

Palais de Justice (JUS) Site

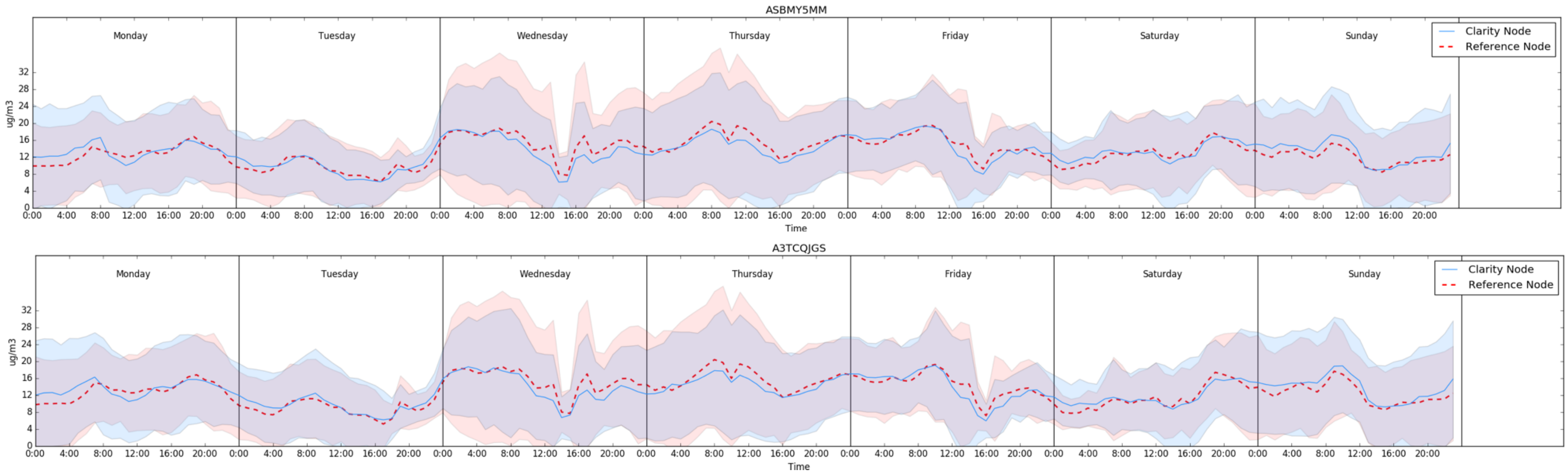


Figure 16. Temporal trends for Clarity Nodes (blue) and government station (red) at JUS, averaging by hour of day and day of week. Standard deviation of this trend highlighted in light blue/red.

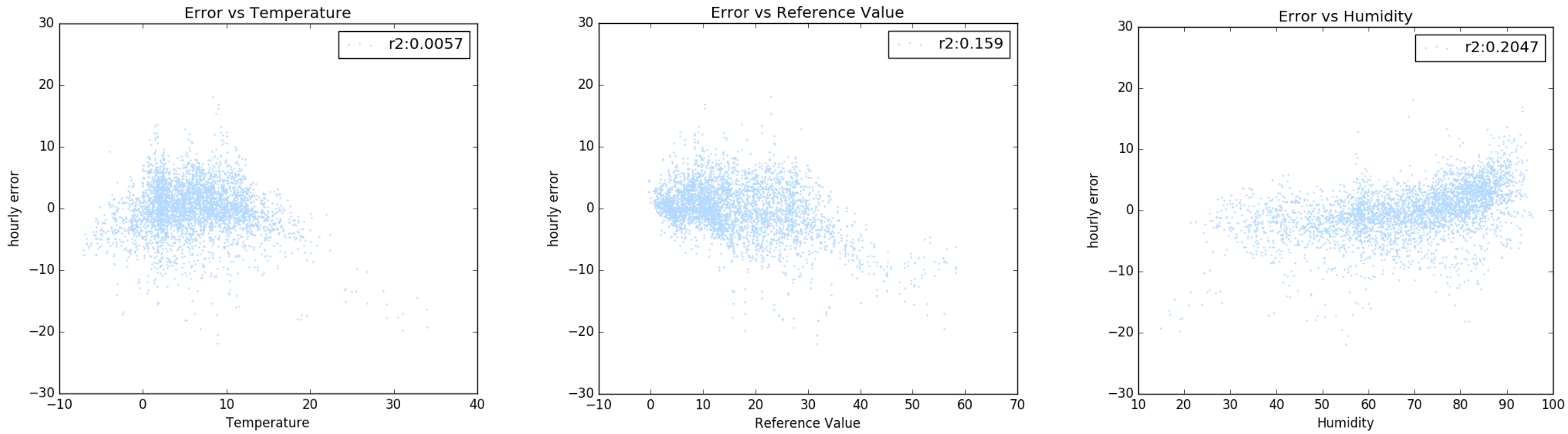


Figure 17. PM2.5 error across the range of (*left*) temperature, (*middle*) reference PM2.5 concentration values, and (*right*) relative humidity