

## Analysis of 20-year air quality trends and relationship with emission data: The case of Florence (Italy)



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### ABSTRACT

In EU, a significant percentage of urban population is exposed to pollutant concentrations above limit/target values stated by air quality legislation. In Italy, this percentage is even higher: 71% for PM<sub>10</sub> (daily limit value), 58% for O<sub>3</sub> (target value), and 45% for NO<sub>2</sub> (annual limit value).

In this paper a 20-year (1993–2012) air quality analysis in the city of Florence (Italy) is reported based on observations from all stations of urban air quality monitoring network. Main atmospheric pollutants have been examined: SO<sub>2</sub>, CO, NO, NO<sub>2</sub>, PM<sub>10</sub>, and O<sub>3</sub>. Actually, Florence is affected by serious air quality problems, with NO<sub>2</sub>, O<sub>3</sub> and PM<sub>10</sub> limit values regularly exceeded in recent years. Trends of annual pollutant concentrations have been analysed to assess the significance of their long-term pattern. Trends of inventory emission data have been related to concentrations through a linear regressive framework to assess the capability of each emission category to control annual concentration trends.

As a result, primary pollutants exhibited a significant decrease, while this was poorly significant for secondary species despite remarkable reduction in their precursors emissions. A major role is played by meteorological conditions strongly unfavourable to pollutant dispersion, along with vehicle fleet increase and variation over the years.

# The SensorWebBike for air quality monitoring in a smart city

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**Keywords:** Arduino, Urban GeoDatabase, WebApp, air quality, mobile platform.

## Abstract

Air quality is a crucial issue for urban environment, urging national and local administrators to implement new approaches and strategies that ensure better environmental governance and public accountability for health.

The SensorWebBike is a web-based information service framework designed to support the participative sensing approach [1] for urban environmental monitoring, composed of 3 main components: 1) Arduino-based mobile platforms, installed on bikes, to monitor urban air quality and weather parameters; 2) an Urban GeoDatabase; 3) Web Application, that enables users to view and analyse the data of volunteered geographic information gathered by bikers. The system integrates the analytic and the synthetic method and respects the Open Data approach and the geospatial standards throughout the entire process workflow.

Bikers become voluntary “citizens-sensors” [2], and their active involvement could increase the awareness on air quality issues: using their bikes, they populate Urban GeoDatabase with georeferred data of pollutants ( $\text{CO}_2$ ,  $\text{CO}$ ,  $\text{NO}_2$ ,  $\text{CH}_4$ ,  $\text{O}_3$ ) concentration, temperature, relative humidity and solar radiation, and contribute to build a comprehensive and constantly updated spatial representation of air quality pattern of the urban area.

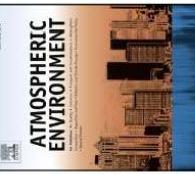
The SensorWebBike framework is on test in Siracusa (Italy), in a Living Lab operating into a futuristic smart city.



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## Atmospheric Environment

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# Improving high resolution emission inventories with local proxies and urban eddy covariance flux measurements

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## HIGHLIGHTS

- Official emission inventories lack validations against observations.
- Eddy covariance is used to assess emission inventories at yearly to hourly scales.
- Local data of road traffic and gas consumption are used to develop temporal proxies.
- Inventories based on local data are improved by 47% monthly, 26% weekly, 32% hourly.

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## ABSTRACT

Emission inventories are the fundamental official data on atmospheric emissions of pollutants and greenhouse gases at a variety of spatial and temporal scales worldwide. This study makes use of direct CO<sub>2</sub> emission measurements made with the eddy covariance technique over a completely urbanized area, with no confounding effect of vegetation, where emissions are mostly controlled by natural gas combustion processes and road traffic. Objectives are: i) to validate top-down spatially and temporally disaggregated emission inventories at yearly, monthly, weekly and hourly time scales; ii) to quantify the improvement achieved in official inventories when replacing built-in temporal disaggregation proxies with customized proxies based on local data of road traffic and natural gas consumption. We demonstrate that the overall performance of official inventory at yearly scale is rather good with an emission of 3.08 g CO<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup> against a measured emission of  $3.21 \pm 0.12$  g CO<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup> RMSE). When temporally disaggregating annual emissions, the agreement between inventory and observations always significantly improves when using local proxies, by 47% (from 0.70 to 0.37 g CO<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup> RMSE) at monthly scale, by 26% (from 0.58 to 0.43 g CO<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup> RMSE) at weekly scale, and by 32% (from 1.26 to 0.85 g CO<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup> RMSE), at hourly scale. The validity of this analysis goes beyond CO<sub>2</sub> since the temporal proxies used by the inventories mimic the intensity of specific emission processes, therefore species emitted in the same processes as CO<sub>2</sub>, would benefit from the improved parameterization of temporal proxies shown here. These results indicate that effort should be put into developing improved temporal proxies based on local rather than national scale data, that can better mimic site dependent behaviors.

**Keywords:**  
Emission inventory validation  
Emission measurements  
Eddy covariance  
Spatial disaggregation  
Temporal disaggregation

# Influence of road traffic, residential heating and meteorological conditions on PM<sub>10</sub> concentrations during air pollution critical episodes

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**Abstract** The importance of road traffic, residential heating and meteorological conditions as major drivers of urban PM<sub>10</sub> concentrations during air pollution critical episodes has been assessed in the city of Florence (Italy) during the winter season. The most significant meteorological variables (wind speed and atmospheric stability) explained 80.5–85.5 % of PM<sub>10</sub> concentrations variance, while a marginal role was played by major emission sources such as residential heating (12.1 %) and road traffic (5.7 %). The persistence of low wind speeds and unstable atmospheric conditions was the leading factor controlling PM<sub>10</sub> during critical episodes. A specific PM<sub>10</sub> critical episode was analysed, following a snowstorm that caused a “natural” scenario of 2-day dramatic road traffic abatement (−43 %), and a massive (up to +48 %) and persistent (8 consecutive days) increase in residential heating use. Even with such a strong variability in local PM<sub>10</sub> emissions,

the role of meteorological conditions was prominent, revealing that short-term traffic restrictions are insufficient counter-measures to reduce the health impacts and risks of PM<sub>10</sub> critical episodes, while efforts should be made to anticipate those measures by linking them with air quality and weather forecasts.

**Keywords** Particulate matter · Critical episodes · Restriction policy · Anthropogenic sources · Weather conditions

# A Statistical Model to Assess Air Quality Levels at Urban Sites

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**Abstract** A multivariate analysis was performed in the city of Florence (Italy) to investigate the influence of road traffic and meteorology on air pollution levels at urban traffic stations. Focussing on main traffic-related pollutants (CO, NO, NO<sub>2</sub>, NO<sub>x</sub> and PM<sub>10</sub>), two typical urban road configurations were analysed: a street canyon and an open road. In addition to traffic flows, basic meteorological parameters were considered: wind speed, air temperature and relative humidity. The influence of all drivers by period of the year and day of the week was analysed with correlation analysis, while a statistical model was developed to predict concentrations at traffic stations by using predictors as urban background concentrations, traffic flows and a site-specific constant. Trained on a 1-year period (2008), the model was validated over an independent 1-year period (2007). The highest correlation of urban traffic concentrations was found vs. background concentrations, markedly for PM<sub>10</sub> ( $r=0.85\text{--}0.87$ ). The influence of road traffic was the highest for NO<sub>2</sub> ( $r=0.51\text{--}0.58$ ) and the lowest for PM<sub>10</sub> ( $r=0.36\text{--}0.40$ ). Urban-scale poor advection conditions proved to affect PM<sub>10</sub> peak levels more significantly than local traffic increase. For

all pollutants, good forecasting capability was achieved by the developed statistical model, generally performing better at the street canyon ( $r=0.79\text{--}0.86$ ) than at the open road ( $r=0.72\text{--}0.82$ ).

**Keywords** Urban air pollution · Multivariate analysis · Road traffic · Meteorological data · Statistical models



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**An integrated low-cost road traffic and air pollution monitoring platform for next citizen observatories**

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### Abstract

An integrated monitoring platform was developed for real-time monitoring of air pollution and traffic flows in urban areas. The air quality monitoring unit, integrating the “Arduino” open-source technology with low-cost and high-resolution sensors, collects concentrations of CO, NO<sub>2</sub> and CO<sub>2</sub>. The traffic monitoring device, equipped with a camera sensor and a video analysis software, collects vehicles’ counts, speed and size. Air pollution and traffic readings are archived on a spatial data infrastructure composed of a central GeoDatabase, a GIS engine, and a web interface. A platform’s description and the results of its installation in Florence (Italy) are presented.

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## An integrated low-cost road traffic and air pollution monitoring platform to assess vehicles' air quality impact in urban areas

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### Abstract

An integrated monitoring platform (IMP) was developed for real-time monitoring of traffic flows and related air pollution in urban areas. The IMP includes: (i) an air quality monitoring unit, integrating the “Arduino” open-source technology with low-cost and high-resolution sensors, to measure air pollutant concentrations; (ii) a traffic monitoring device, equipped with a camera sensor and a video analysis software, to detect vehicles’ counts, speed and category; (iii) a spatial data infrastructure, composed of a central GeoDatabase, a GIS engine, and a web interface, for data storage and management. The IMP was tested in Florence (Italy) by installing sensor devices at a road site where a 1-year measuring campaign was carried out. A reference meteorological station in the city centre was used to provide observations of wind speed and direction, air temperature, and relative humidity.

In this work, a statistical analysis was performed to investigate the influence of local road traffic and meteorological conditions on CO, NO<sub>2</sub> and CO<sub>2</sub> concentrations. Two different methods were applied: a linear regression model and an artificial neural network. To investigate the role played by emissions from road traffic, the influence of all drivers by period of the year (cold vs. warm months) and day of the week (weekdays vs. weekends) was analysed. As a result, the contribution of local road traffic on pollutant concentrations proved to be lower than meteorological parameters.

Article

# Development of Low-Cost Air Quality Stations for Next Generation Monitoring Networks: Calibration and Validation of PM<sub>2.5</sub> and PM<sub>10</sub> Sensors

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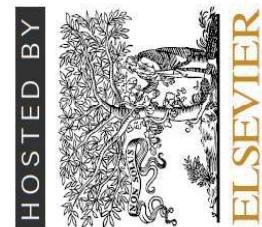
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**Abstract:** A low-cost air quality station has been developed for real-time monitoring of main atmospheric pollutants. Sensors for CO, CO<sub>2</sub>, NO<sub>2</sub>, O<sub>3</sub>, VOC, PM<sub>2.5</sub> and PM<sub>10</sub> were integrated on an Arduino Shield compatible board. As concerns PM<sub>2.5</sub> and PM<sub>10</sub> sensors, the station underwent a laboratory calibration and later a field validation. Laboratory calibration has been carried out at the headquarters of CNR-IBIMET in Florence (Italy) against a TSI DustTrak reference instrument. A MATLAB procedure, implementing advanced mathematical techniques to detect possible complex non-linear relationships between sensor signals and reference data, has been developed and implemented to accomplish the laboratory calibration. Field validation has been performed across a full “heating season” (1 November 2016 to 15 April 2017) by co-locating the station at a road site in Florence where an official fixed air quality station was in operation. Both calibration and validation processes returned fine scores, in most cases better than those achieved for similar systems in the literature. During field validation, in particular, for PM<sub>2.5</sub> and PM<sub>10</sub> mean biases of 0.036 and 0.598 µg/m<sup>3</sup>, RMSE of 4.056 and 6.084 µg/m<sup>3</sup>, and R<sup>2</sup> of 0.909 and 0.957 were achieved, respectively. Robustness of the developed station, seamless deployed through a five and a half month outdoor campaign without registering sensor failures or drifts, is a further key point.

**Keywords:** air quality monitoring; low-cost sensors; next generation networks; laboratory calibration; field validation; PM<sub>2.5</sub>; PM<sub>10</sub>



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# Atmospheric Pollution Research

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## Forecasting PM<sub>10</sub> hourly concentrations in northern Italy: Insights on models performance and PM<sub>10</sub> drivers through self-organizing maps

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### ARTICLE INFO

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Self-organizing maps (SOMs)

### ABSTRACT

A linear and an artificial neural network (ANN) statistical model have been developed and validated for short-term forecasting of PM<sub>10</sub> hourly concentrations in the city of Brescia (Italy). PM<sub>10</sub> observed concentrations were biased by less than 1% by each model, though the ANN outperformed the linear model, as exhibiting NRMSE of 0.48 vs. 0.53, and  $r^2$  of 0.57 vs. 0.48. The self-organizing maps (SOMs) showed that both models predictions exhibit the same clustering as the observations, with the ANN at worst capable of under-estimating clustered PM<sub>10</sub> peak concentrations by 5.8  $\mu\text{g}/\text{m}^3$ .

In Brescia, PM<sub>10</sub> most critical conditions were detected in wintertime in the early morning or late afternoon under unfavourable meteorological conditions, i.e. reduced advection enhancing PM<sub>10</sub> stagnation, and lack of precipitations capable of reducing PM<sub>10</sub> resuspension. Under these conditions, PM<sub>10</sub> accumulation is driven by local anthropogenic emissions ascribing to two main sources: heating plants, responsible of emissions of primary PM<sub>10</sub> (mostly PM<sub>2.5</sub>, likely resulting from wood and biomass burning); and road traffic (basically diesel vehicles), mainly responsible of emissions of secondary PM<sub>10</sub> precursors (mostly NO<sub>x</sub>), and secondly of primary PM<sub>10</sub> emissions.

The SOM analysis clearly indicated that PM<sub>10</sub> most critical conditions are driven by the secondary rather primary PM<sub>10</sub> component.





Article

# Long-Term Performance Assessment of Low-Cost Atmospheric Sensors in the Arctic Environment

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**Abstract:** The Arctic is an important natural laboratory that is extremely sensitive to climatic changes and its monitoring is, therefore, of great importance. Due to the environmental extremes it is often hard to deploy sensors and observations are limited to a few sparse observation points limiting the spatial and temporal coverage of the Arctic measurement. Given these constraints the possibility of deploying a rugged network of low-cost sensors remains an interesting and convenient option. The present work validates for the first time a low-cost sensor array (AIRQino) for monitoring basic meteorological parameters and atmospheric composition in the Arctic (air temperature, relative humidity, particulate matter, and CO<sub>2</sub>). AIRQino was deployed for one year in the Svalbard archipelago and its outputs compared with reference sensors. Results show good agreement with the reference meteorological parameters (air temperature (T) and relative humidity (RH)) with correlation coefficients above 0.8 and small absolute errors ( $\approx 1$  °C for temperature and  $\approx 6\%$  for RH). Particulate matter (PM) low-cost sensors show a good linearity ( $r^2 \approx 0.8$ ) and small absolute errors for both PM<sub>2.5</sub> and PM<sub>10</sub> ( $\approx 1 \mu\text{g m}^{-3}$  for PM<sub>2.5</sub> and  $\approx 3 \mu\text{g m}^{-3}$  for PM<sub>10</sub>), while overall accuracy is impacted both by the unknown composition of the local aerosol, and by high humidity conditions likely generating hygroscopic effects. CO<sub>2</sub> exhibits a satisfying agreement with  $r^2$  around 0.70 and an absolute error of  $\approx 23 \text{ mg m}^{-3}$ . Overall these results, coupled with an excellent data coverage and scarce need of maintenance make the AIRQino or similar devices integrations an interesting tool for future extended sensor networks also in the Arctic environment.

**Keywords:** low-cost sensors; Arctic environment; atmospheric composition

# Innovative low-cost air quality stations as a supporting means for road traffic regulations in urban areas

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**Abstract.** Air pollution is currently one of main issues affecting urbanized areas worldwide. Industrial activities, road traffic and heating systems are main emission sources significantly increasing the levels of atmospheric pollutants as particulate matter, ozone, and nitrogen oxides. Local administrations monitor these harmful gases by means of reference monitoring stations provided by regional/national environmental protection agencies. These stations, however, have limitations due to the little presence over the whole municipality, low time-frequency, and high costs. In this framework, CNR-IBE, University of Florence – Department of Agriculture, food, environment, and forestry (DAGRI), Tuscany Region Environmental Protection Agency (ARPAT) and epidemiologists of the Pisa University agreed an initiative to create an environmental “living lab” aimed at assessing the impacts due to anthropogenic activities on air quality and thus on population exposure. Two study areas located in the Tuscany region (Italy) were chosen: the rural town of Capannori, and the city of Florence. The town of Capannori was selected since it lies within a critical area both affected by a variety of emission sources and winter weather conditions unfavourable to pollutant dispersion. The city of Florence was chosen for assessing air quality in urban areas following a possible traffic reduction due to creation of new urban tramway lines. The air quality analysis was carried out by means of a monitoring network comprising innovative low-cost stations (named AIRQino). PM concentrations were mainly considered for providing indicative air quality measurements. The preliminary results indicated that: i) low-cost stations, after calibration and validation against more than one-year observations from a reference air quality station, confirmed their reliability in measuring air quality data; ii) AIRQino data can supplement air quality information from reference stations and may be used to help traffic regulation actions at urban scale.

**Keyword:** Air quality; Urban area; Low-cost stations; PM concentrations; Road traffic.

# Design and performance of a low-cost atmospheric composition monitor for deployment in extreme environments

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**Abstract.** The Arctic is one critical environment for monitoring climate change as well as variations in background concentrations of atmospheric components. The associated logistic difficulties, though, make hard to deploy an extensive monitoring network of sensors, limiting long time-series to only sparse and costly point observations. Low-cost sensors are experiencing a widespread employment in research and monitoring applications and could be an interesting tool to deploy spatialized monitoring networks even in extreme environments. In this context, two CNR Labs (IBE and ISAC) made a long-term deployment of a prototypal low-cost sensor for atmospheric composition monitoring in the polar research village of Ny-Ålesund (Svalbard, Norway). In about one year of measurements the low-cost sensor showed: i) a good consistency in the data series with minimal data loss, ii) no significant requirements for maintenance and iii) the capability of capturing the main atmospheric trends of the Arctic lower troposphere.

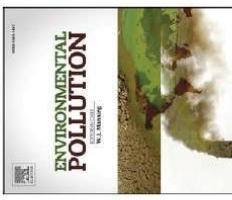
**Keyword:** Atmospheric composition; Extreme environment; Low-cost stations.



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## Quantifying road traffic impact on air quality in urban areas: A Covid19-induced lockdown analysis in Italy<sup>☆</sup>

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### A B S T R A C T

Covid19-induced lockdown measures caused modifications in atmospheric pollutant and greenhouse gas emissions. Urban road traffic was the most impacted, with 48–60% average reduction in Italy. This offered an unprecedented opportunity to assess how a prolonged (~2 months) and remarkable abatement of traffic emissions impacted on urban air quality. Six out of the eight most populated cities in Italy with different climatic conditions were analysed: Milan, Bologna, Florence, Rome, Naples, and Palermo. The selected scenario (24/02/2020–30/04/2020) was compared to a meteorologically comparable scenario in 2019 (25/02/2019–02/05/2019). NO<sub>2</sub>, O<sub>3</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> observations from 58 air quality and meteorological stations were used, while traffic mobility was derived from municipality-scale big data. NO<sub>2</sub> levels remarkably dropped over all urban areas (from –24.9% in Milan to –59.1% in Naples), to an extent roughly proportional but lower than traffic reduction. Conversely, O<sub>3</sub> concentrations remained unchanged or even increased (up to 13.7% in Palermo and 14.7% in Rome), likely because of the reduced O<sub>3</sub> titration triggered by lower NO emissions from vehicles, and lower NO<sub>x</sub> emissions over typical VOC-limited environments such as urban areas, not compensated by comparable VOCs emissions reductions. PM<sub>10</sub> exhibited reductions up to 31.5% (Palermo) and increases up to 7.3% (Naples), while PM<sub>2.5</sub> showed reductions of ~13–17% counterbalanced by increases up to ~9%. Higher household heating usage (+16–19% in March), also driven by colder weather conditions than 2019 (–0.2 to –0.8 °C) may partly explain primary PM emissions increase, while an increase in agriculture activities may account for the NH<sub>3</sub> emissions increase leading to secondary aerosol formation. This study confirmed the complex nature of atmospheric pollution even when a major emission source is clearly isolated and controlled, and the need for consistent decarbonisation efforts across all emission sectors to really improve air quality and public health.

#### Keywords:

Covid-19  
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