Characterization of $PM_{2.5}$ episodes linked to residential wood burning, using a dense low-cost sensor network

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Introduction, Study Areas and Methods

Epidemiological studies have established an association of mortality and cardiovascular disease with **short-term exposure to ambient fine particles**.

There are conditions where local sources can induce such strong diel variability that **peak concentrations exceed multi-fold the 24-h guidelines (e.g. EPA, WHO)**.

Wintertime residential wood burning (RWB) in cities is such an example, where intense emissions combined with low boundary layer during the **night** and low winds lead to **extreme $PM_{2.5}$ events** lasting for many hours.

Greek cities and especially the **greater area of Athens (GAA)** are severely affected by this phenomenon especially during the years after the Greek economic recession (*Tsiodra et al., 2021*).

Trying to improve the spatial characterization of the **RWB impact on air quality (AQ) and population exposure** to fine particulate matter, the PANhellenic infrastructure for Atmospheric Composition and climatE change (PANACEA) has recently developed a **low-cost monitoring network (>100 sites)** throughout the country (**Fig. 1**), complementing the existing regulatory AQ monitoring network.

To visualize and present the monitoring data in **near real time, an IoT web platform** (**https://air-quality.gr/**) has been developed, aiming to inform online the public and the local stake holders (regional authorities, municipalities etc).

Spatial monitoring of $PM_{2.5}$ concentrations in the GAA benefits from the PANACEA low-cost network, **operating since 2019 and currently consisting of 28 measuring** sites, mostly at urban/suburban background locations over the Athens basin (**Fig. 2**).

The network is based on **PurpleAir PA-II monitors** (**Fig. 3a**), that use the Plantower PMS5003 low cost OPC (**Fig 3bc**).

Data provided by the PA-II are processed by applying **calibration** equations, calculated through linear regression after **collocation** of the low cost devices with **reference monitors** at the NOA Thissio supersite (**Fig. 4**; *Stavroulas et al., 2020*).

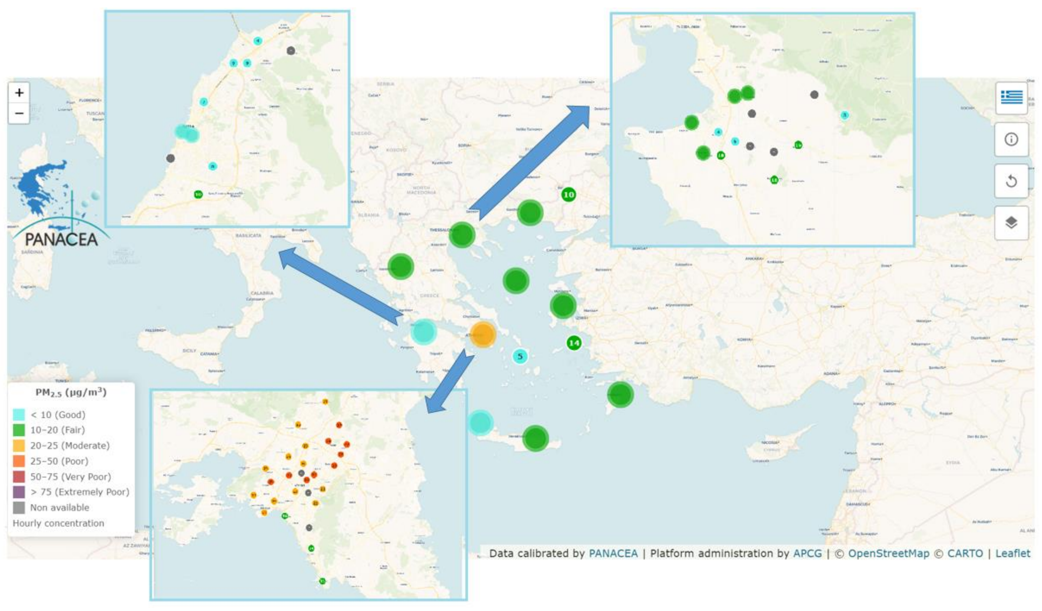

Figure 1: The $PM_{2.5}$ low-cost monitoring network developed throughout Greece in the framework of the PANACEA project

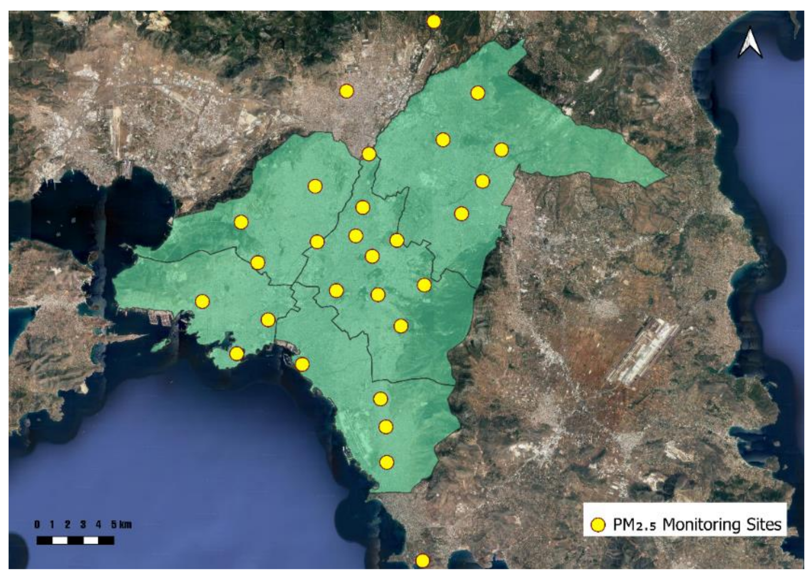

Figure 2: The current state of the PANACEA low-cost $PM_{2.5}$ monitoring network in the Athens basin, consisting of 28 monitoring locations

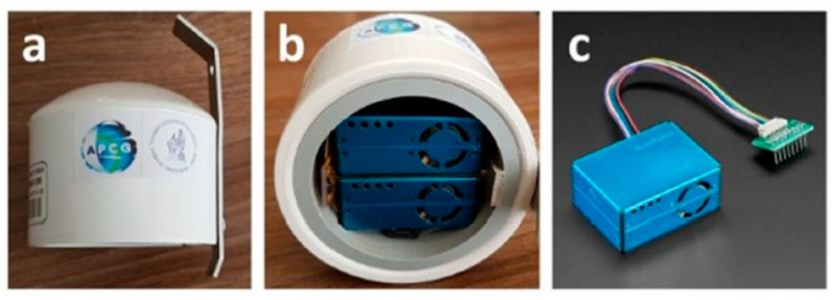

Figure 3: The PurpleAir PA-II low cost PM monitor side (a) and bottom (b) views based on two Plantower PMS5003 (c) optical particle counters.

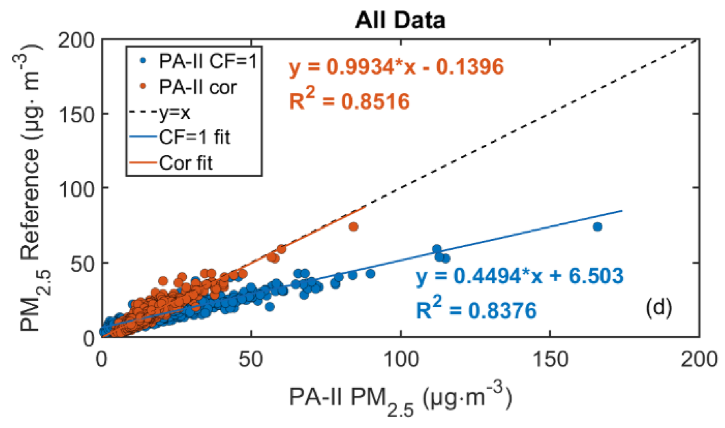

Figure 4: Scatter plots and linear regression of reference over low-cost $PM_{2.5}$ data during co-location at the Thissio Station in Athens.

Since the focus here was on **RWB episodes**, data from **three consecutive cold periods** (15 Nov – 15 Mar) for the years 2019, 2020 and 2021 were analyzed.

A RWB episode was defined for the purposes of this study as an event when $PM_{2.5}$ concentrations at a given site were **above 50 μg m^{-3} for at least 3 consecutive hours**.

The 50 μg m^{-3} threshold was selected since it is used **to indicate "very poor" air quality** in the relevant air quality index of the European Environment Agency. The analysis is performed in a regional unit level as detailed below (5 regional units in the central basin of the GAA).

Results

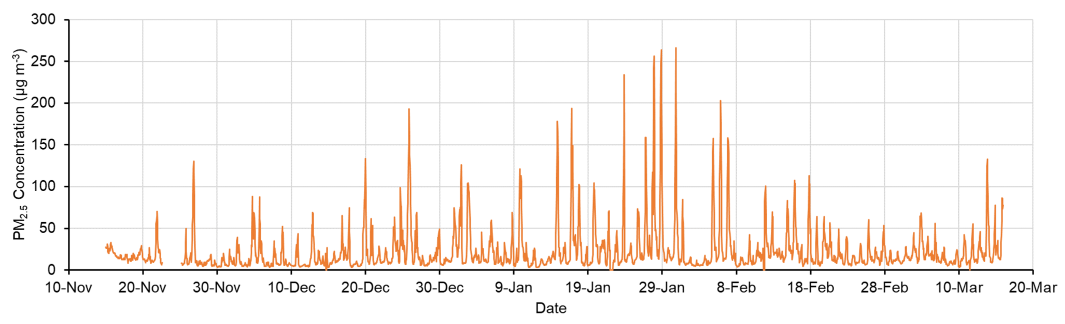

Figure 5, Top left panel: $PM_{2.5}$ **hourly time-series** in the **winter** of 2021-22 at a suburban background site (Chalandri). Displaying **extreme short-term peaks,** as high as 250 μg m^{-3}.

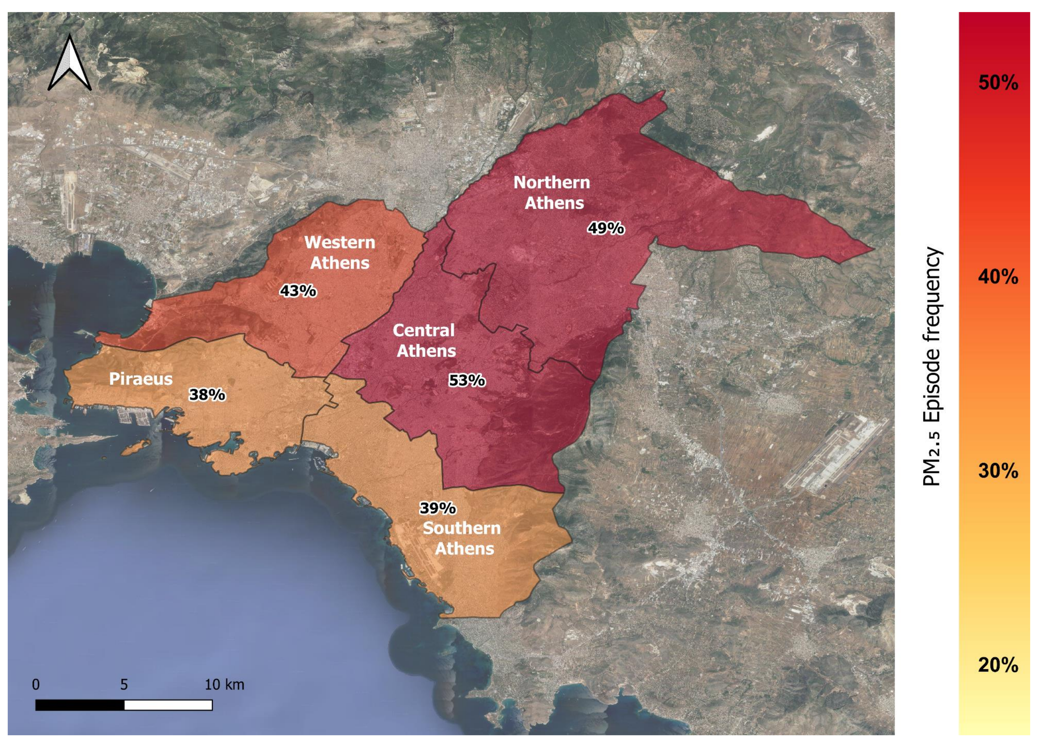

Figure 5, Middle left panel: **RWB episode frequency** in the different parts of the Athens basin in the winter of 2021-2022 (an episode corresponds to a day where at least one episode occurred at a site within a regional unit). **High frequencies (38% or higher) were recorded in all zones.**

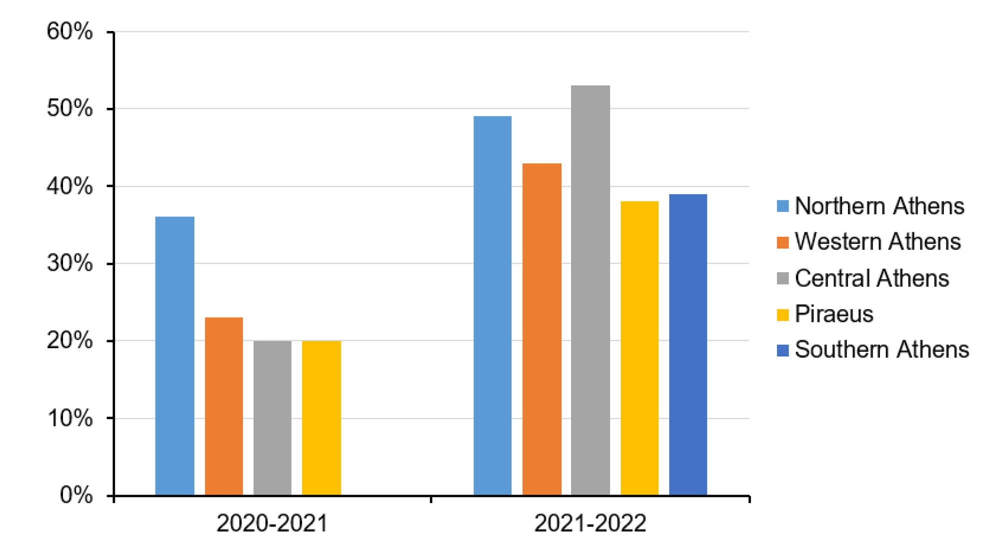

Figure 5, Bottom left panel: Distribution of episode frequency per regional unit for **2020-21 & 2021-22** is displayed. A significant rise in episode frequency was recorded in the 2[nd] winter, due to a milder 2020-21 winter and the onset of the energy sector crisis during the 2021-22 cold period.

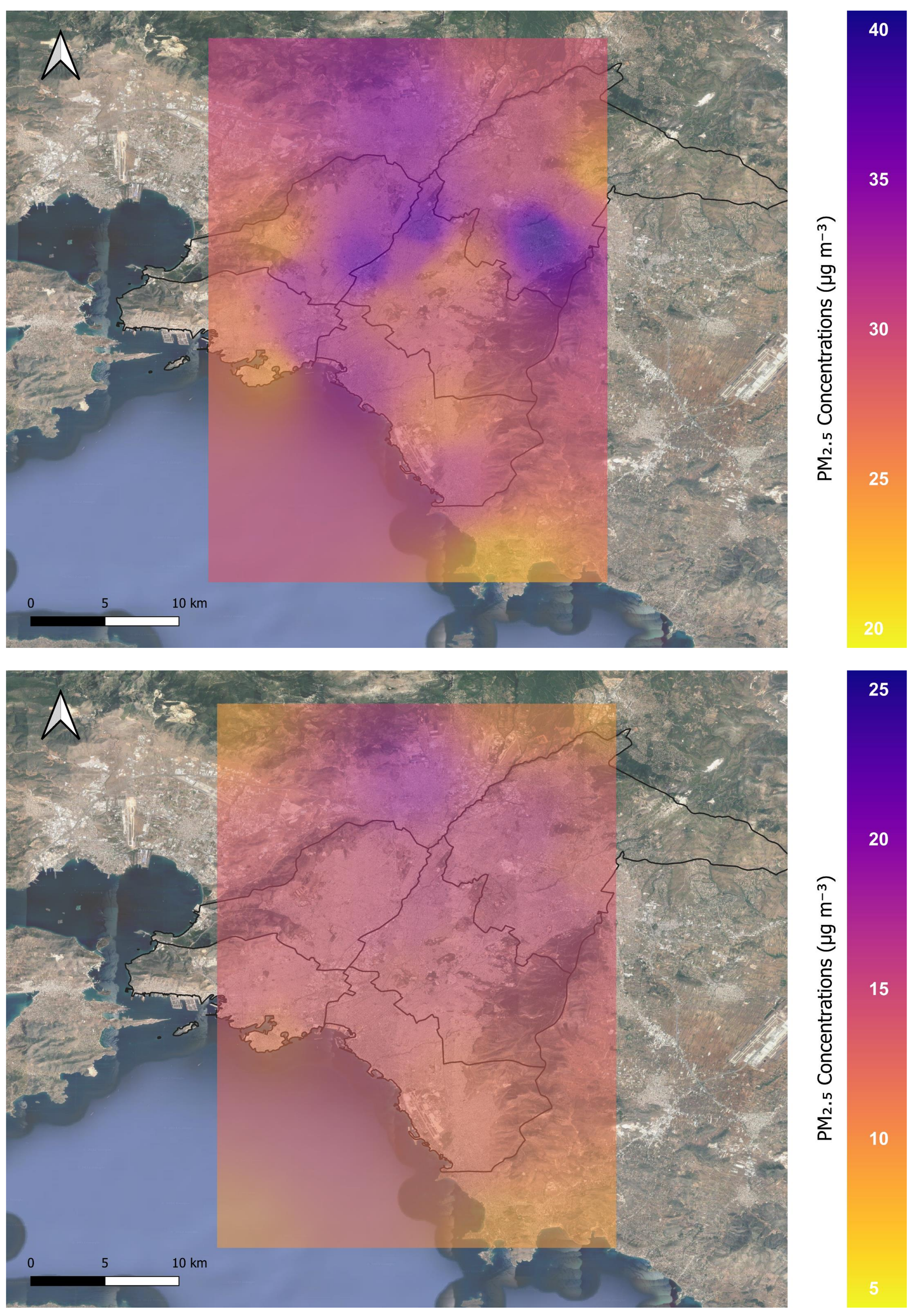

Figure 6: Spatial interpolation using the Inverse Distance Weighting (IDW) method. Data from 21 urban and suburban sites (representative of ambient exposure at residential areas) were used in the geostatistical model.

An optimal *p*-exponent was selected after repeated trials and LOOCV- leave one out cross validation (LOOCV R=0.59-0.66, for *p*=5).

Top and bottom panels show the estimated daily $PM_{2.5}$ concentrations (μg m^{-3}) over the GAA when **RWB episodes** were recorded, **and on "no-episode" days, respectively.**

Levels in the absence of RWB episodes were substantially lower. Moreover, they were uniformly distributed in the basin.

During **episode days**, certain parts, mostly to the north, **northwest and center** of the basin are more affected with over 2-fold higher estimated daily concentrations.

Outcomes

- Openly available real-time information on ambient $PM_{2.5}$ concentrations, using sensor and IoT technologies, is a powerful tool for informed citizens that can adjust their activities to avoid excessive exposure during air pollution episodes.
- Significant number of $PM_{2.5}$ episodes has been recorded during past winters in all regional units of Attica.
- Northern and Central areas of Athens have registered the highest number of episodes over time.
- Ambient exposure to $PM_{2.5}$ appears to be unevenly distributed on episode days. Certain areas in Athens (North, West) are more burdened.

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References

1. Tsiodra et al., 2021, Atmos. Chem. Phys., 21, 17865–17883, https://doi.org/10.5194/acp-21-17865-2021
2. Stavroulas et al., 2020, Atmosphere, 11(9), 926, https://doi.org/10.3390/atmos11090926