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ASSESSING THE AIR QUALITY IMPACT OF SMART TRAFFIC CONTROL IN THESSALONIKI

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Abstract: A combined measurement and modelling campaign was performed during a 20-month period over an extended area of the center of Thessaloniki, Greece, aiming to assess the effect of smart traffic management on street-scale air quality, taking advantage of a newly developed measurement and data management platform. In the frame of the MobiSpaces project, eight multi-pollutant sensor boxes were installed near major intersections in a highly congested part of the city, providing continuous air quality measurements while traffic load and speed measurements were used to calculate hourly traffic emissions. In the first part of the work presented here, the Operational Street Pollution Model was applied on the basis of hourly calculated emissions in order to obtain hourly concentration levels for every road link. Compared to sensor measurements, model results exhibit good correlation but with a consistent negative bias, pointing to the need for application of distance-dependent dilution factors as a means to account for dispersion further away from the kerbside. Utilizing operational data from the traffic light management system, periods of significant intervention near the traffic intersections are being identified and the corresponding impact on hourly concentrations over the whole study area will be quantified.

Key words: street-scale modelling, traffic emissions, roadside measurements, data management platform

INTRODUCTION

Traffic management systems have been applied for several years as a means to reduce traffic congestion and improve flows, particularly near busy intersections. However, their effect on traffic emissions and traffic-affected air quality has not been adequately studied over extended urban areas which encompass different road types and traffic patterns. Air quality measurements are typically performed in a limited number of managed links capturing only the localized effect of any intervention. It is evident that a modelling strategy based on consistent traffic and emission information over wider areas can effectively generalize locally observed trends towards a holistic assessment of the air quality impacts of traffic management. In the frame of the MobiSpaces project (URL1), a combined measurement and modelling campaign was performed during a 20-month period over an extended area of the center of Thessaloniki, Greece, aiming to assess the effect of smart traffic management on street-scale air quality, taking advantage of a newly developed measurement and data management platform. Eight multi-pollutant sensor boxes were installed near major intersections in a highly congested part of the city, providing continuous air quality measurements at 5-minute intervals. Contemporaneous traffic load and speed information from 181 locations across the local road network were used to calculate traffic emissions using the COPERT model. The process was optimised through MobiSpaces' resource allocator and data management algorithms, enhancing the efficiency of the preprocessing and model assessment. The Operational Street Pollution Model was then applied, taking into account the urban background concentrations as well as the effect of local meteorological fields and photochemistry. In the first part of the study presented here, the aim was to assess and validate the modelling tools against the available set of roadside measurements for a wide variety of meteorological and traffic conditions as well as in the different street environments represented by the eight roadside measuring locations.

As one of the selected case study areas for the deployment of the MobiSpaces platform, Thessaloniki provides an excellent testbed for combining information from traffic measurements, background monitoring stations and roadside air quality sensors enabled by an advanced data management platform.

METHODOLOGY

The first part of the study focused on assessing, both through roadside measurements and dispersion modelling, the effect of traffic patterns over an extended area of the Thessaloniki city center by estimating hourly emissions and street-scale concentrations for a period of approximately six calendar months. During this period, observational data sets of traffic loads, urban background concentrations, and roadside measurements of eight multi-pollutant measuring devices, deployed and operated by Bosch, were collected and aggregated through the MOBISPACES platform. All eight measuring stations were located near intersections where traffic is managed through smart traffic lights which intervene using prolonged green light periods depending on local traffic load and speed.

For the modelling application, the road network contained in the area of application shown in Figure 1 was selected. In total, 822 individual road segments were included, counting each road direction of two-way streets as a separate traffic link. Estimation of hourly traffic emissions was performed using the COPERT 5 model (Ntziachristos et al., 2009) on the basis of traffic load and speed measurement data, which were obtained through the Regional Administration of Central Macedonia. The Operational Street Pollution Model (OSPM; Hertel et al. 1991) was then applied to obtain street-level concentrations for each of the road segments in the study region.

Traffic link geometry was set-up based on the OSM 'roads' layer, incorporating roads designated as major/motorway, secondary and tertiary, where a separate line source was considered for each traffic direction and road link. Detailed street geometry characteristics were derived after processing building census data provided by the Hellenic Statistical Authority (URL2). In particular, wall-to-wall widths of street canyons, heights of adjacent building as well as the geometry of openings near road intersections were estimated based on an extruded "2.5-dimensional" dataset after correcting obvious inconsistencies like zero-height building or missing building blocks. Automated geospatial tools were then used in a geographical information platform (QGIS; reference) to assign street geometry and adjacent building heights to each of the road sections under study. An obvious limitation of this approach is that street width is approximated exclusively based on ground plan outlines ignoring actual building geometry. Additionally, the set of roads studied encompasses a wide range of aspect rations (H/W, where H is the adjacent building height and W the street width), which in the case of Thessaloniki can include street canyons with ratios exceeding 2.5, but also includes application cases like open intersections and obstacles on the one side of the road only. It was assumed that OSPM could provide reliable estimates also in these extreme cases, although in this cases the relative wind direction can strongly affect the accuracy of calculated street increments.

In order to obtain modelled concentrations directly comparable to field observations, background concentration data of all simulated pollutants (O3, NO, NO_2, PM_{10}, $PM_{2.5}$) were provided as input to the OSPM model. The related observation data were obtained from an urban background monitoring station operated by the Municipality of Thessaloniki (Figure 1). Finally, hourly meteorological data (wind speed and direction, temperature and solar radiation) were obtained from a measurement station located near the city center, about 1 km to the north of the study area (Figure1).

In the first part of the study a period encompassing almost the entire calendar year of 2023 (January 15th to December 31st) was simulated and the performance of the modelling approach for real emissions assessed through comparison with measurements at the eight multi-pollutant sensor locations. For each of the pollutants, the bias, root mean square error (RMSE), Pearson correlation coefficient (cc) and index of agreement (IoA; Willmott 1981) were calculated. In subsequent parts of the study, the validated model will be used to quantify the effect of smart traffic control near the intersections and assess any potential gains in air quality by generalizing smart traffic control in additional intersections throughout the study area. Nine emission scenarios have been created based on policy measures currently under implementation at the local or national level. The effect of these scenarios on street-level concentrations in the study area is currently

being assessed, also with the aim to evaluate the sensitivity of the modelling approach, based on real world applications of the MobiSpaces platform.

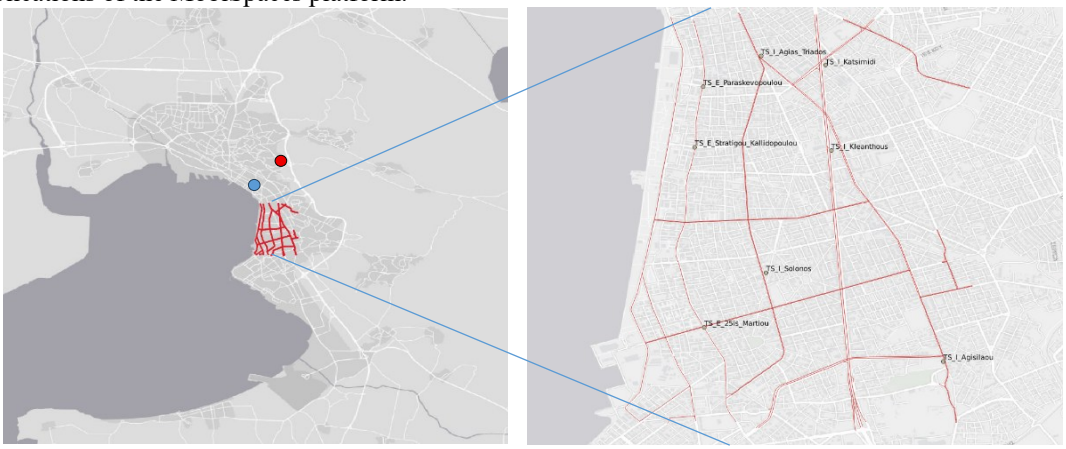

Figure 1. Study area and modelled road segments near the center of Thessaloniki. Blue and Red pins (left) indicate the locations of the meteorological station and background AQ station, respectively. Gray pins and labels (right) indicate the locations of the eight roadside sensor boxes.

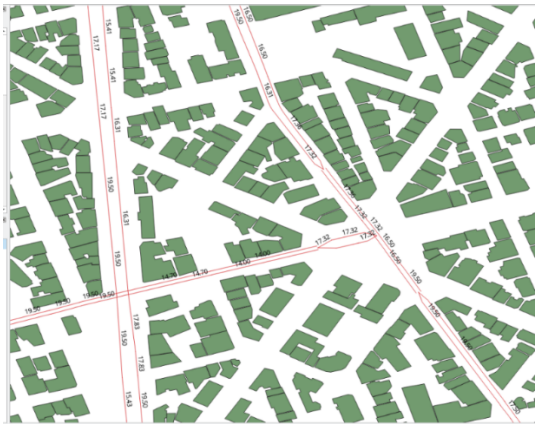

Figure 2. Example of automatic assignment of road segment width and adjacent building height for each road segment.

RESULTS

A comparison of average calculated and observed concentrations was performed for the main pollutants calculated by OSPM which were also available from the roadside measurements, namely NO_2, PM_{10} and $PM_{2.5}$. A consistent overestimation of the order of 50-60% is observed for all pollutants and locations, which can be attributed to dilution as pollutants are dispersed from the kerbside further away to the location and height of the sensor (Ioannidis et al., 2024). In line with the CFD study of Ioannidis et al. performed in a similar city centre environment, an appropriate dilution factor of 0.4 was applied on OSPM results in all measurement sites and for all pollutants. An overview of calculated concentrations for the first semester of 2023 is shown in Figure 3 for the heavily congested Kleanthous street, illustrated here without dilution correction applied. It is evident that most pollutants are strongly correlated to traffic patterns, with hourly values of kerbside NO_2 reaching 1500 μg/m^3. Based on known traffic conditions at this site, hourly peaks can be correlated with heavy congestion combined with traffic light starts at a steep incline (>10%). Seasonal patterns indicate higher values during the winter and early-spring months, while a peak period during late April is correlated with documented unfavorable meteorological conditions during this period.

In Figures 4 and 5, three-week timeseries for November 2023 are shown for calculated concentrations of NO_2 and $PM_{2.5}$, respectively, while Figure 6 shows the corresponding correlation plots for NO_2, PM_{10} and $PM_{2.5}$. A good correlation can be observed for small to medium concentrations, but with a considerable population of outlier hourly values that deviate from the 1:1 line. A slight underestimation can be observed

for NO_2, suggesting that a more conservative dilution factor could be used. Looking at the performance metrics in Table 1, calculated for the same site, a moderate negative bias is evident for NO_2 and PM_{10}, despite the fact that the model can overpredict isolated congestion peaks, while $PM_{2.5}$ exhibits a much smaller positive bias. Correlation values are very near the quality limit of 0.5 and obviously depend on the quality of the meteorological input provided to the model, which currently comes from measurements at a single location. Gridded meteorology provided by an operational model is currently under consideration for use as input in the next round of calculations, aiming to improve the representation of local wind effects.

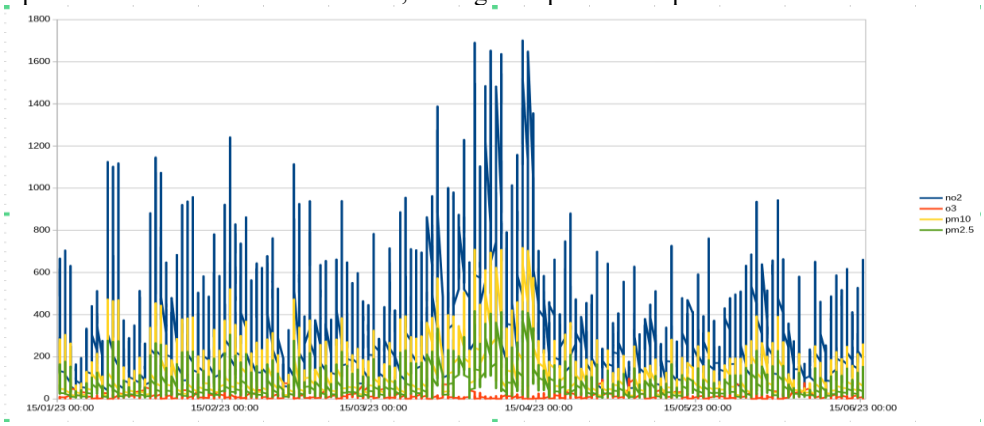

Figure 3. Simulated time series of pollutant concentrations for the Kleanthous measurement site for a 6-month period (uncorrected for dilution).

Values of IoA indicate a very good overall agreement, however one should keep in mind that part of the overall correlation can be attributed to the non-street component, namely the urban background measurements that are fed as inputs to the model.

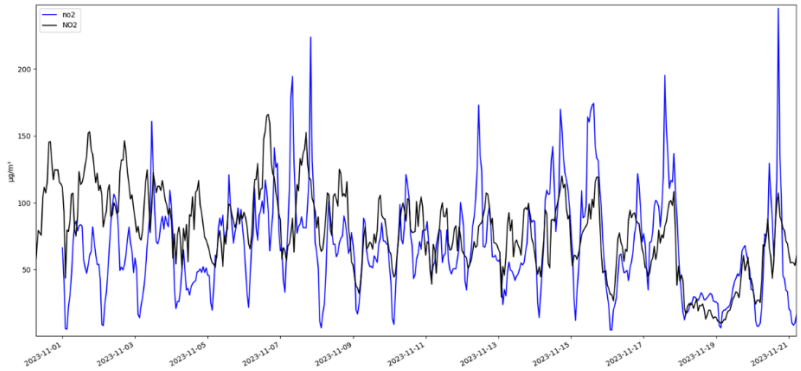

Figure 4. Comparison of calculated $PM_{2.5}$ concentrations (blue) compared to roadside measurements (black) at the 25is Martiou intersection over a three-week period. A dilution correction factor of 0.4 has been applied.

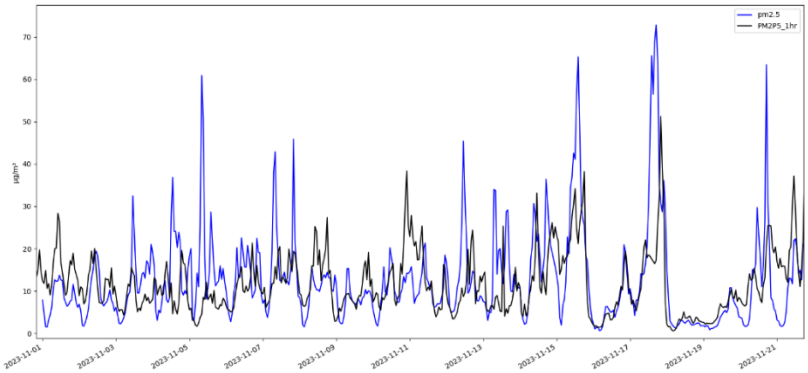

Figure 5. Comparison of calculated $PM_{2.5}$ concentrations (blue) compared to roadside measurements (black) at the 25is Martiou intersection over a three-week period. A dilution correction factor of 0.4 has been applied.

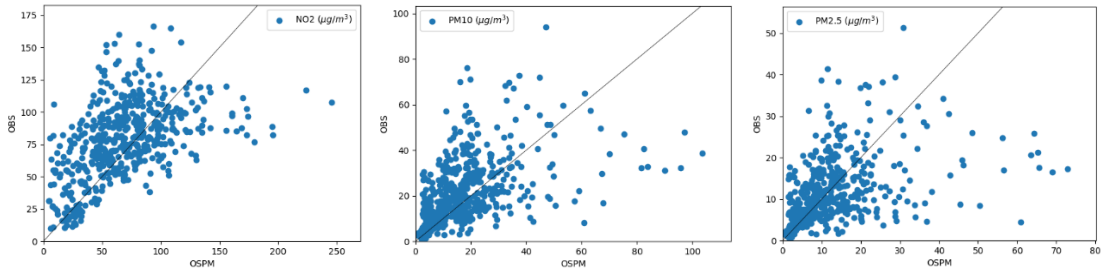

Figure 6. Scatter plots of NO_2 (left), PM_{10} (middle), and $PM_{2.5}$ (right) hourly concentrations compared to roadside measurements at the 25is Martiou intersection over a three-week period. A dilution correction factor of 0.4 has been applied.

Table 1. Performance metrics based on calculated hourly NO_2, PM_{10} and $PM_{2.5}$ street-scale concentrations at the 25is Martiou intersection

	NO_2	**PM_{10}**	**$PM_{2.5}$**
Bias (μg/m³)	-10.78	-4.22	0.80
RMSE (μg/m³)	35.23	16.00	10.65
CC	0.50	0.46	0.41
IoA	0.78	0.75	0.77

CONCLUSIONS

The first part of a street-scale modelling case study over a heavily congested area of Thessaloniki indicated that OSPM combined with high-quality input datasets, managed through the Mobispaces platform, can provide a consistent and reliable way to predict traffic-induced concentrations of the main pollutants. Detailed information on the operation of smart traffic control in eight intersections is being used to assess the effects of traffic optimization on street-scale air quality, while the assessment of a series of emission reduction scenarios will further highlight the potential of city-wide measures to mitigate traffic induced pollution. The results of our ongoing campaign provide valuable insights into the merits of using realistic emissions, street-level measurements and dispersion modelling both for operational and scenario-oriented air quality assessment.

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