Air4EU

Air Quality Assessment for Europe: from local to continental scale

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Individual case study report 11: Assessment of PM levels and contributions in the Athens region

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1. Executive Summary

Efficient Air Quality Management is based on a detailed and accurate air quality assessment where the relative source contribution is identified and, if possible, quantified. In addition, effective formulation of control strategies for the ambient levels of various air pollutants requires knowledge of the sensitivity of the calculated concentrations of those pollutants not only to the primary and precursor emissions, but to every input data to the model, including initial and boundary conditions. Therefore, in this case study, a combination of monitoring and modelling methods was employed, in order to derive information on current and future Athens air quality respectively. The study focused mainly on PM_{10} because of their recognised health impacts and the increased scientific interest they recently have received.

The current air quality in Athens was analysed using measurements, by collecting and comparing urban and suburban PM_{10} data for the years 2001-2003. In this way, the prevailing trends during this short time period have been revealed and they were then connected through the modelling studies with the main contributing sources, thus indicating the appropriate emission reduction strategy. The data demonstrated an increase of PM_{10} annual values, mainly in the urban but also in the suburban stations, between 2001 and 2002, while a decrease was observed between the years 2002 and 2003. However, the number of PM_{10} exceedances relative to the 2005 EU limit was significantly reduced between 2001 and 2002, as well as in some cases between 2002 and 2003. The emissions indicated that road transport was the main source contributing to NOx and CO concentrations, whereas the industry sector was mainly responsible for PM and SO_2 emissions. Although the PM industry emissions were high, they affected a smaller population size than traffic-induced PM_{10} emissions in the street canyons.

In this case study, the OFIS urban scale dispersion model was used for the spatial assessment of PM levels in the study area and for the development of maps allowing the identification of heavily polluted areas within the study domain. Further research efforts for source contribution involved sensitivity simulations on PM background concentrations and natural emissions, which were performed for several future emission scenarios for the years 2005, 2008 and 2010, in order to examine future compliance with standards, and suggest where more stringent mitigation measures should be applied. Also, OFIS simulations were performed to investigate the sensitivity of the predictions to the initial and boundary conditions and to meteorological input data. The OSMP street scale model was applied indicatively for one station, and the USEPA – AP42 resuspension module was also incorporated for the estimation of non-exhaust emissions. The results confirmed the importance of resuspension as an urban PM_{10} source. A sensitivity study to BC revealed the necessity of including natural emissions for a realistic estimation of urban PM_{10} concentrations. Also, the findings of the case study suggest the need to use a local scale model in order to assess the impact of local scale emissions, such as in a street canyon or potential emissions from new developments. This would enhance the development of an efficient emission reduction strategy, in which local scale measures will also be included, thus confronting increased concentrations in “hot-spot” areas.

2. Case study description

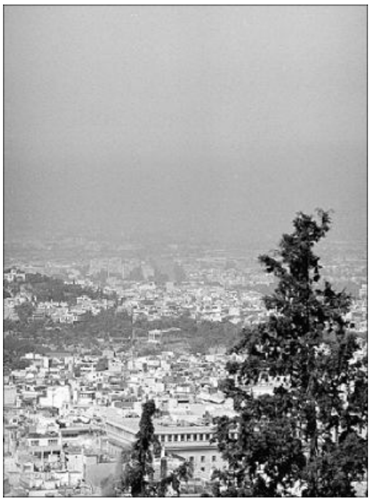
2.1 Background

The city of Athens is located in a basin of approximately 450 km^2 (Figure 1). This basin is surrounded at three sides by fairly high mountains (Mt. Parnis, Mt. Pendeli, Mt. Hymettus and Mt. Aegaleon), while to the SW it is open to the sea. Industrial activities take place both in the Athens basin and in the neighbouring Thriasion plain (cf. solid areas in Figure 1). The Athens basin is characterised by a high concentration of population (about 40% of the Greek population), accumulation of industry (about 50% of the Greek industrial activities) and high motorisation (about 50% of the registered Greek cars).

Anthropogenic emissions in conjunction with unfavourable topographical and meteorological conditions are responsible for the high air pollution levels in the area. The visual results of atmospheric pollution “nephos”, a brown cloud over the city, made their appearance in the 70’s. Alarmingly elevated pollutant concentrations already threaten public health and at the same time cause irreparable damage to invaluable ancient monuments.

Visibility impairment during pollution episodes is due to high burdens of aerosol particles in the atmosphere while the yellowish-brown colour of the cloud is due to high nitrogen dioxide concentrations. In Athens, as in most densely populated urban areas, non-black particles are formed in the lowest part of the atmosphere as secondary aerosols (ammonium sulphates and nitrates).These particles have gained recently a high-priority in environmental reporting following wide spread concern about their health effects, which is mainly due to their small size that makes them respirable.

The main characteristics of the air pollution in Athens for 2003 can be summarised as follows:



Examination of the temporal variation of the measured air pollutant concentrations in the greater Athens area, since 1984, shows a general decline of the concentrations of certain air pollutants. This decrease is mainly observed in the concentrations of the primary air pollutants, such as carbon monoxide, sulphur dioxide and black smoke. Such a decline is noteworthy, given the increase in population and economic activity that have occurred in the area during the considered time period.

The main air pollution problem in Athens is tropospheric ozone, a product of the combination of intense sunshine with considerable emissions of ozone precursors.

Particulate Matter with aerodynamic diameter less than 10 µm (PM_{10}), which is the main focus of this study, also shows high concentrations.

Higher concentration values of SO_2, NO_2, CO and Black Smoke are measured at the downtown monitoring sites, while for ozone, higher values are typically observed at the suburban sites. Topography combined with low speed (< 5m/s) southwestern winds (sea breeze) often result in ozone accumulation in the northern and north-eastern suburbs, especially during the summertime afternoon hours or when a temperature inversion occurs.

For NO_2, exceedances of the indicative “new” hourly limit value (270 µg/m^3) were observed at two sites (1 hour in Peristeri station and 5 hours in Patision station), while exceedances of the indicative yearly limit value, were observed at 3 out of 17 stations. Maximum NO_2 values are typically measured between 10:00 and 12:00.

SO_2, CO and black smoke concentrations during the winter period are greater that those during summer period. Maximum CO values are typically measured between 8:00 and 10:00 and between 21:00 and 23:00.

During the weekends, all measured air pollutant concentrations except ozone, show a decline. Brief air quality results for 2003 are presented in the following table:

Table 1: Athens Air Quality values for the year 2003

Compound	Comments	Problem
SO_2	Daily Exceedances recorded at no stations	No
	Hourly Exceedances recorded at 2 stations (max 3 hours)	No
PM_{10}	Daily Exceedances recorded at 2 stations (max 113 days)	Yes
	Annual exceedance recorded at 3 stations	Yes

NO_2	Hourly Exceedances recorded at no stations Annual exceedance recorded at 3 stations	No No
Lead	Annual exceedance recorded at no stations	No
CO	Daily Exceedances recorded at no stations	No
Benzene	Annual exceedance recorded at 1 station	Yes
Ozone	Daily Exceedances* recorded at 13 stations (max 40 days)	Yes

* Hourly alarm limit value of 180 μg/m^3

The existing network in Athens comprises today of seventeen (17) fully automated monitoring stations. The monitoring network is operated, managed and maintained exclusively by the Directorate of Atmospheric Pollution and Noise Control (Department of Atmospheric Quality, Greek Ministry for the Environment). The existing stations of the monitoring network and the pollutants monitored are listed in the following table:

Table 2: The stations of the Athens monitoring network and the pollutants measured

Station					**Pollutants measured**								**Meteo**
Location				**Station type**									
Name	**Longitute**	**Latitute**	**Altitute (m -asl)**		**SO_2**	**NOx**	**CO**	**O_3**	**PM_{10}**	**TSP**	**BTX**	**BS**	
Athinas – ΑΘΗ	23° 43΄ 30΄΄	37° 58΄ 42΄΄	100	Urban-Traffic	v	v	v	v				v	
Aristotelous – ΑΡΙ	23° 43΄ 39΄΄	37° 59΄ 16΄΄	95	Urban - Traffic	v	v			v			v	
Geoponiki – ΓΕΩ	23° 42΄ 25΄΄	37° 59΄ 01΄΄	50	Suburban-Industrial	v	v	v	v					v
Liosia – ΛΙΟ	23° 41΄ 52΄΄	38° 04΄ 36΄΄	165	Suburban -Background	v	v		v					v
Lykovrisi – ΛΥΚ	23° 46΄ 35΄΄	38° 04΄ 11΄΄	210	Suburban		v	v	v	v	v			v
Marousi – ΜΑΡ	23° 47΄ 14΄΄	38° 01΄ 51΄΄	145	Urban - Traffic	v	v	v	v	v				v
Nea Smyrni – Ν.ΣΜΥ	23° 42΄ 54΄΄	37° 55΄ 58΄΄	50	Urban - Background	v	v	v	v					
Patision – ΠΑΤ	23° 43΄ 59΄΄	37° 59΄ 57΄΄	105	Urban - Traffic	v	v	v	v			v	v	v
Piraeus 1 – ΠΕΙ-1	23° 38΄ 51΄΄	37° 56΄ 36΄΄	20	Urban - Traffic	v	v	v	v	v	v			
Peristeri – ΠΕΡ	23° 41΄ 46΄΄	38° 00΄ 55΄΄	80	Urban - Background	v	v	v	v					
Ag. Paraskevi – ΑΓ.ΠΑΡ	23° 49΄ 10΄΄	37° 59΄ 42΄΄	290	Suburban - Background	v	v		v	v	v			v
Galatsi – ΓΑΛ	23° 44΄ 53΄΄	38° 01΄ 13΄΄	145	Urban - Background	v	v		v					v
Goudi – ΓΟΥ	23° 46΄ 04΄΄	37° 59΄ 04΄΄	155	Urban - Traffic		v			v				
Elefsina – ΕΛΕ	23° 32΄ 18΄΄	38° 03΄ 05΄΄	20	Suburban - Industrial	v	v		v					v
Zografou – ΖΩΓ	23° 47΄ 13΄΄	37° 58΄ 11΄΄	245	Suburban - Background	v	v		v	v	v			
Thrakomakedones – ΘΡΑ	23° 45΄ 29΄΄	38° 08΄ 37΄΄	550	Suburban - Background		v		v	v				v
Piraeus 2 – ΠΕΙ-2	23° 39΄ 10΄΄	37° 56΄ 32΄΄	25	Urban - Background	v	v		v					

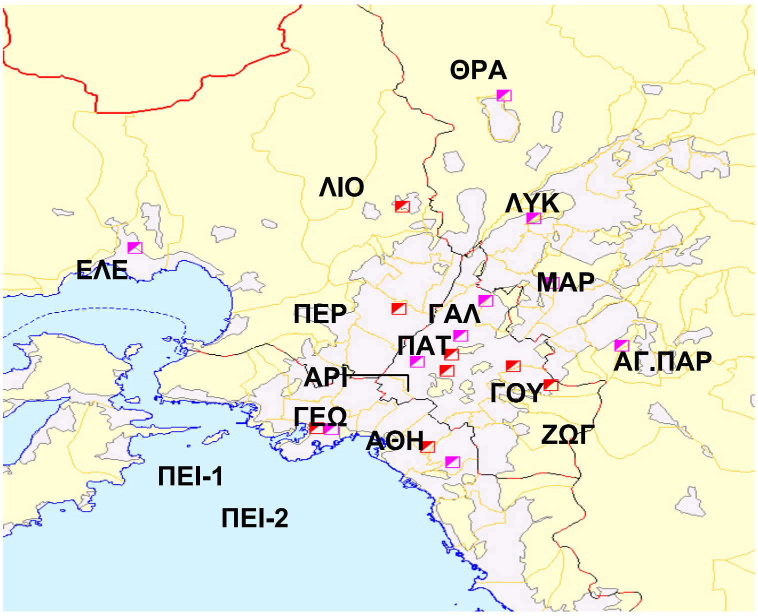
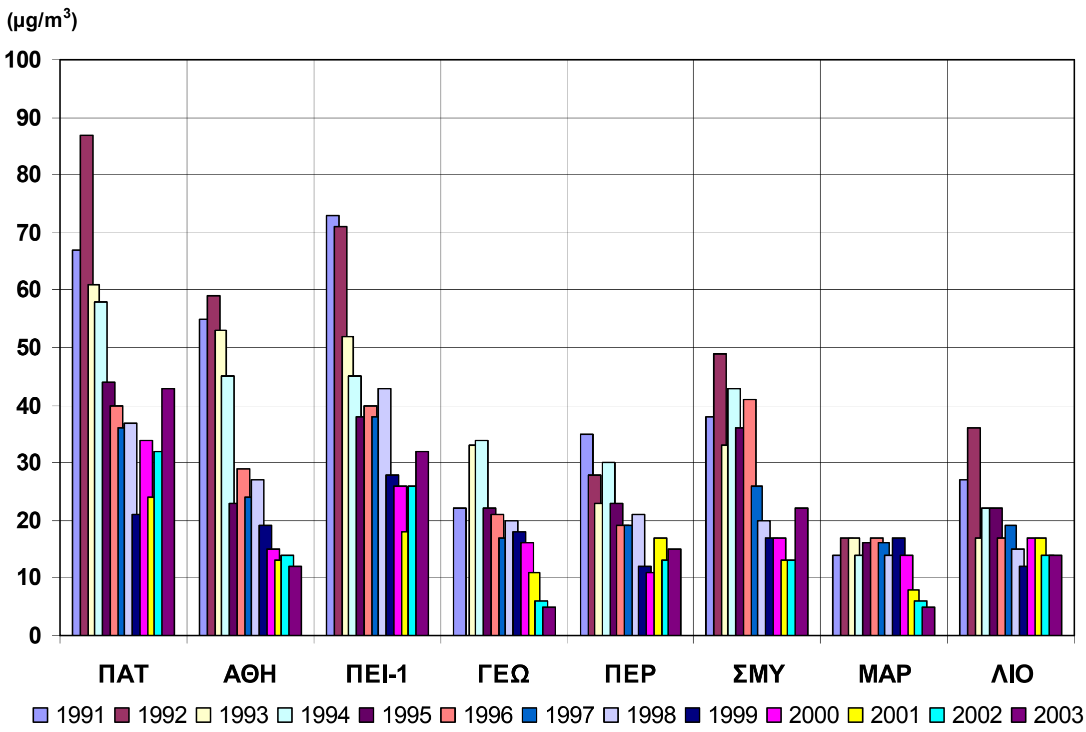


Figure 1: Stations location of the monitoring network in Athens.



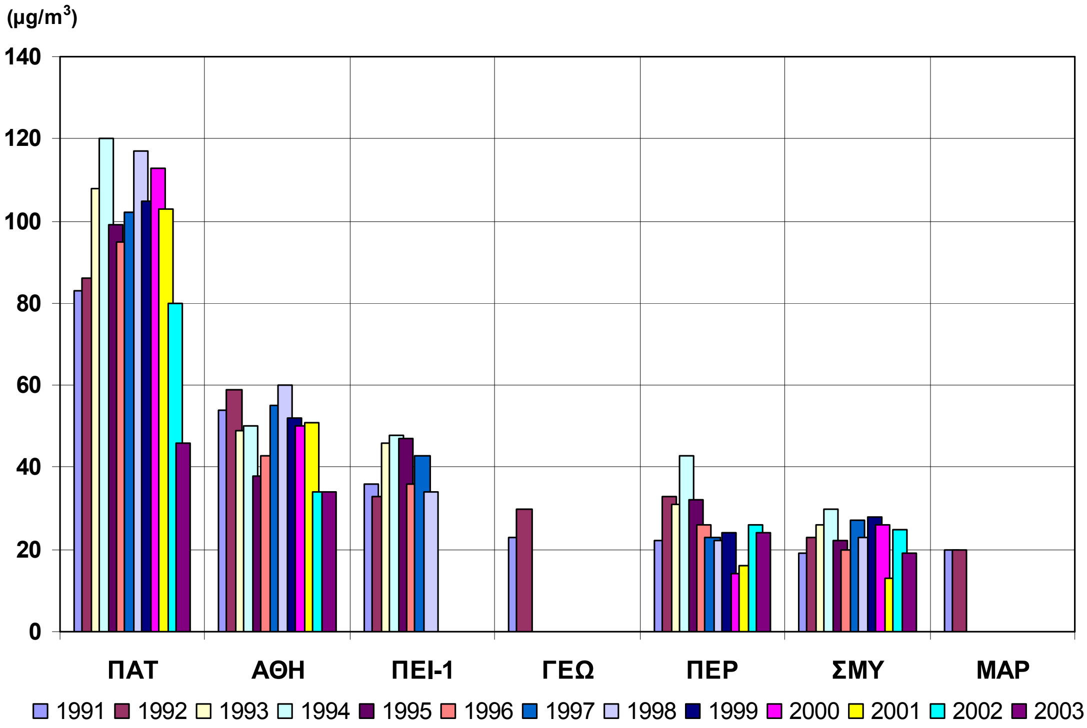


Figure 2: Evolution of the 98th percentiles of mean diurnal SO_2 (top) and mean diurnal black smoke (bottom) at seven measuring stations of the Athens monitoring network.

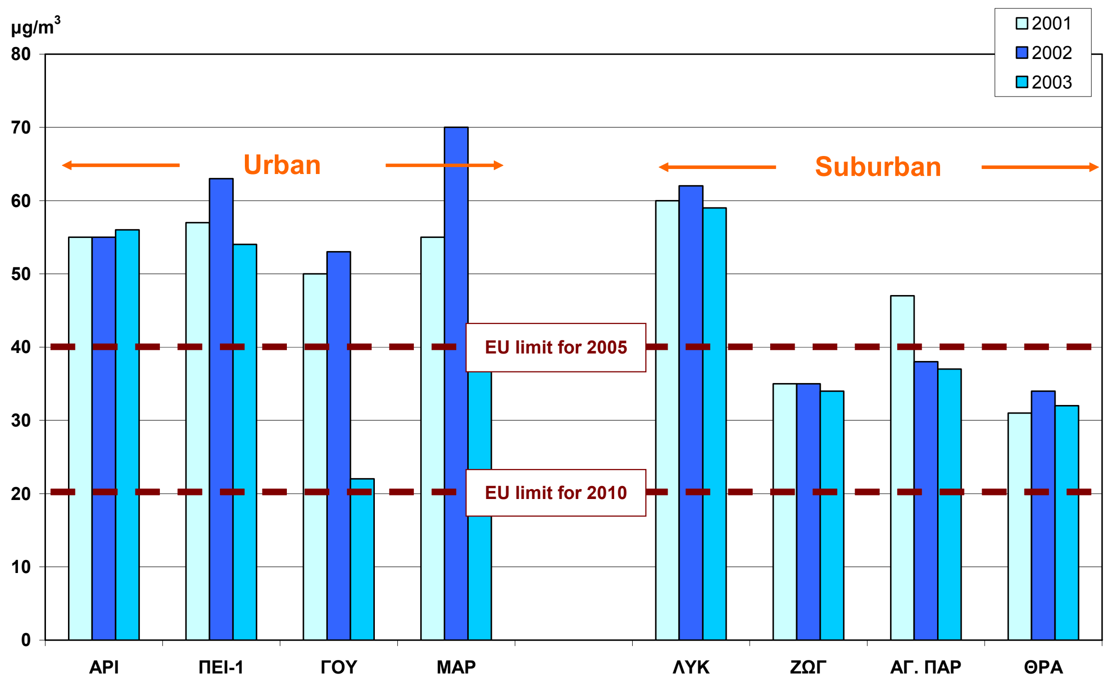


Figure 3: Evolution of the 98th percentiles of mean diurnal PM_{10} at four urban (left part) and four suburban (right part) measuring stations of the Athens monitoring network.

Regional background is determined by the Directorate of Atmospheric Pollution and Noise Control (Department of Atmospheric Quality, Greek Ministry for the Environment), using suburban- and rural-background stations. The monitoring values are compared to dispersion modelling results and EMEP background values over the Greater Athens Area.

In the frame of a recent major project, funded by the Greek Ministry for the Environment, as well as AIR4EU, ENVECO has prepared an emission inventory which was compiled for the Greater Athens Area, for the reference year 2002, taking into account emissions from:

- Stationary air pollution sources like, industry, domestic heating and oil stations,
- Mobile sources, such as, road traffic and emissions from ship, airplane and train lines.

Pollutants included were CO, NO_2, NO_x, O_3, SO_2, Benzene, PM_{10} and Pb, for most of which current EU legislation sets up specific air quality limit values that have to be met up to 2005 and 2010.

Concerning emission inventory from road traffic, the CORINAIR methodology and the COPERT software were applied. Figues 4 and 5, depict the percentage contribution of various emission sources in the Greater Athens area overall emissions, as well as the diurnal variation of PM_{10} emissions from road transport. It is important to note that although the largest percentage of PM_{10} is apparently emitted by industry, only a small fraction of these emissions affect the densely populated urban area of Athens, where emissions from road traffic play a much more important role.

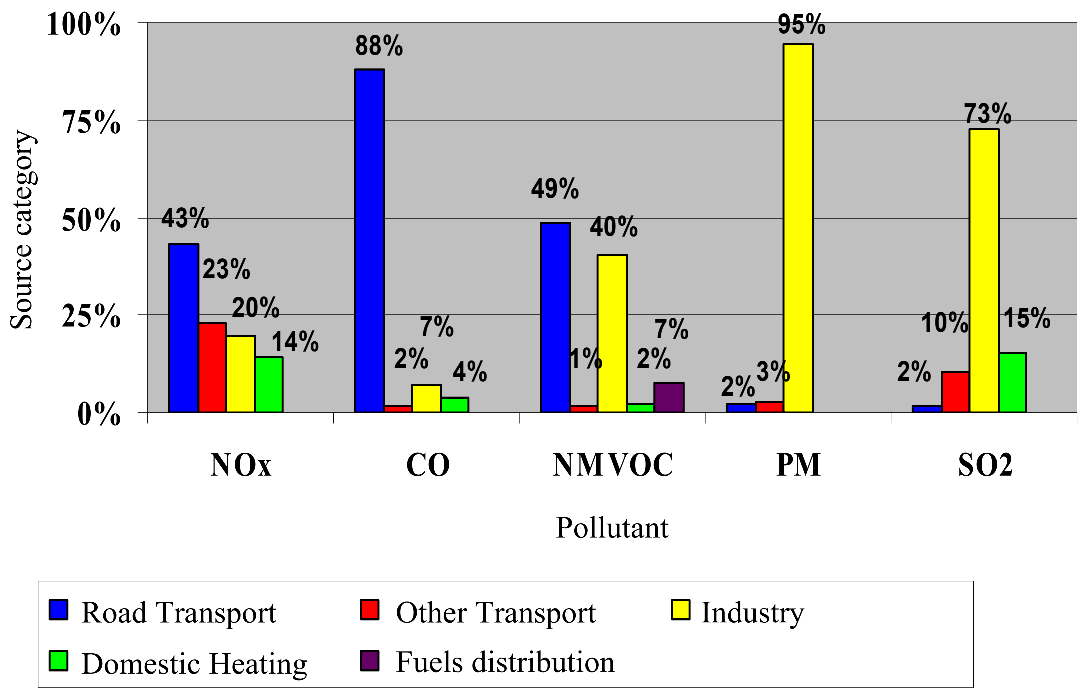


Figure 4: Percentage contribution (emissions) of source categories

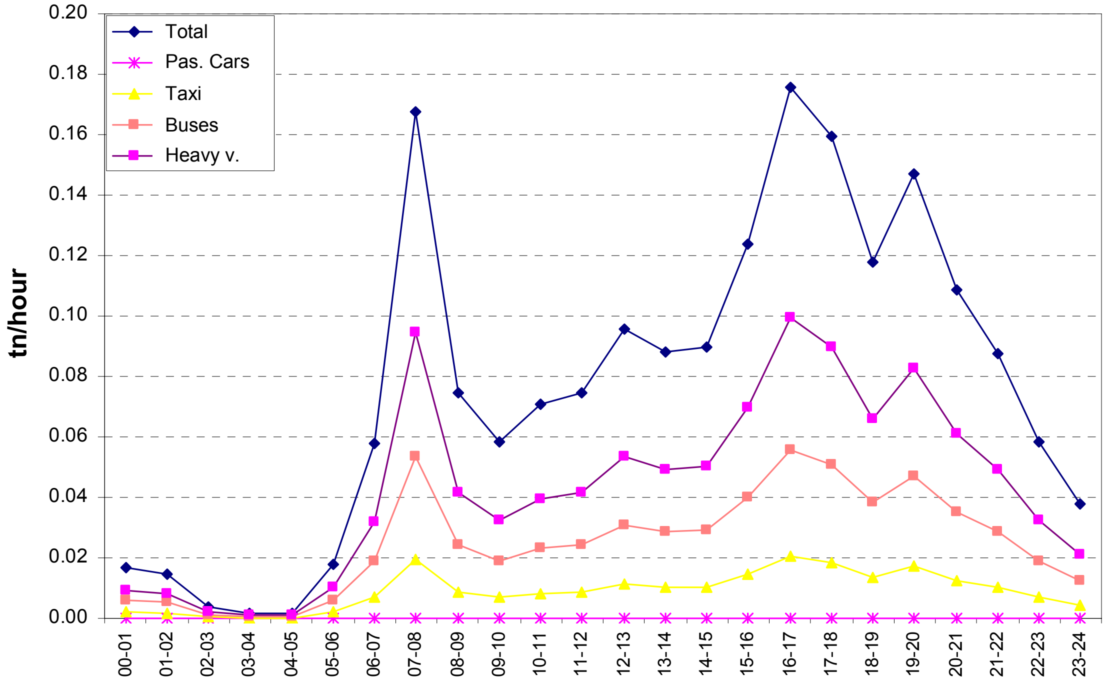


Figure 5: Emissions: Diurnal variation of PM_{10} emissions from road Transport

Figure 6: Total daily emissions from transportation (in tn/day).

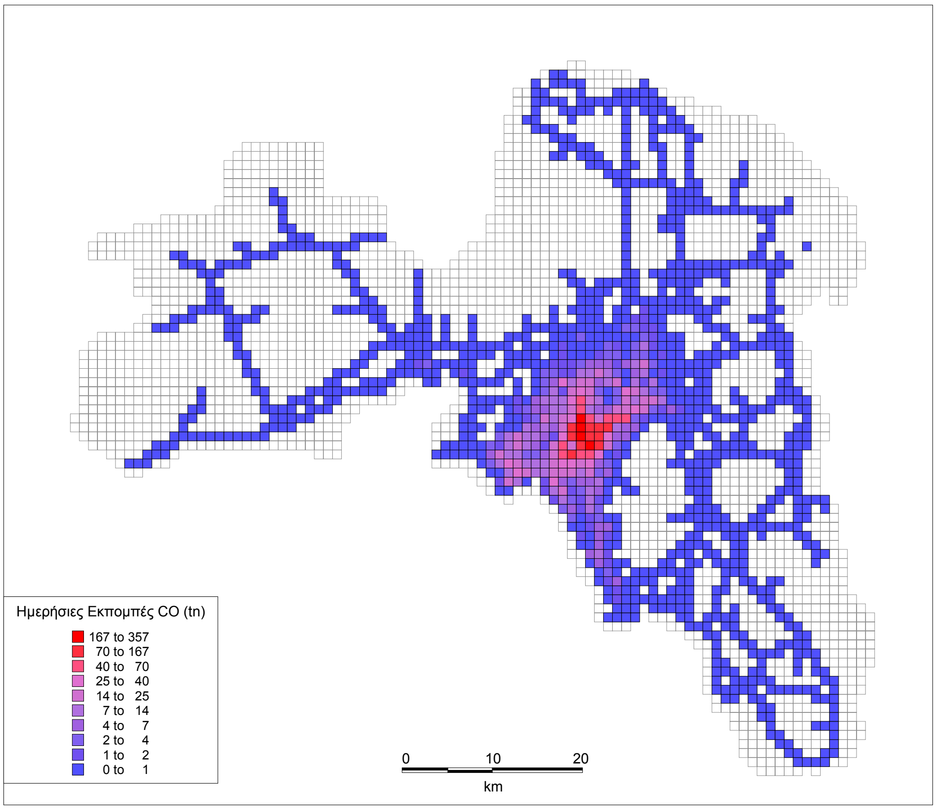


Figure 7: Spatial distribution of daily CO emissions from transportation.

2.2 Aim and description

This case study is focusing on the definition of a proper basis for the assessment of PM levels in the Greater Athens Area. This is accomplished through the investigation of issues related to source contributions (esp. natural emissions, resuspension and street increments), optimisation of the PM monitoring network (esp. with regard the siting of measuring stations based on model results), input data and the importance of background contribution to the PM levels. The case study is thus directed towards certain gaps and needs of the area under study. In particular, the following gaps and needs were identified with regard to current assessment practices:

- Resuspension of PM is usually not included in the assessment
- Although resuspension of road dust is arguably an important contributor to PM concentrations in Athens, very sparse details are known about emission characteristics
- There are significant discrepancies at some stations when comparing models to monitoring which would be quite important to explain and evaluate
- Meteorological data is insufficient as there are only a few meteorological monitoring stations in the Greater Athens Area
- Emission data PM_{10}, $PM_{2.5}$ and benzene could be improved, also taking into account natural sources (eg. Wind blown dust)
- Urban background concentrations estimation, need to be improved. Suggested methods include nested modelling approaches and more extensive “ad hoc” monitoring
- Evaluation of abatement measures on air pollution levels

The tool that is mainly used in this study is the OFIS model, which is able to incorporate parameterisations regarding natural PM sources as well as provide urban background values to smaller scale models, such as the OSPM model in this study, including non-exhaust PM emissions.

Models that include the effect of traffic induced turbulence should be used and model uncertainty should be determined and used in the AQ assessment and shown in maps. More specifically, the case study will cover the following topics:

- ❑ Investigation of sensitivity on regional background (eg. By testing various regional scale models and measurements)
- ❑ Investigation of sensitivity on initial and boundary conditions (from two different regional-scale modelling systems) and meteorological input data
- ❑ Investigation of secondary PM contribution
- ❑ Preparation of PM Maps (2003/2005)

2.3 Relevance to recommendations in Air4EU

OFIS urban scale dispersion model was used for the spatial assessment of PM levels in the study area and for the development of maps allowing the identification of heavily polluted areas within the study domain. This also serves according to the recommendations as a first step in recognising important emission sources, and the maps can be used for public information. Further research efforts for source contribution involved sensitivity simulations on PM background concentrations and natural emissions, which were performed for several future emission scenarios for the years 2005, 2008 and 2010, in order to examine future compliance with standards. As it is also suggested in the recommendations, this is an important process in identifying current problems and increased emissions and planning appropriate management strategies, so that future PM levels remain within the acceptable limits. Regarding the use of modelling to assess air pollution at the urban/agglomerate scale, the quality assurance of input data was also considered in AIR4EU to be one of the most important aspects, thus the sensitivity of OFIS to initial and boundary conditions and meteorological data was also examined in this case study.

3. Methodology

In order to address the gaps and needs mentioned previously and to improve the assessment of PM levels in the Greater Athens Area, the following tools were applied:

1) For the treatment of dispersion and relevant urban scale issues (source contribution, sensitivity analysis etc.) on PM, the OFIS model has been applied. Several simulations were performed for several future emission scenarios, for the years 2005, 2008 and 2010, in order to examine future compliance with standards.

2) The OSMP street scale model was applied.

A combination of the MEMO/MUSE and OFIS models is used to simulate air quality in Athens.

The Models used

OFIS belongs to the EZM (European Zooming Model) system (Moussiopoulos; 1995), and was developed to serve a twofold aim; (i) allowing authorities to assess urban air quality by means of a fast, simple and still reliable model and (ii) refining a regional model simulation by estimating the urban subgrid effect on pollution levels (Arvanitis and Moussiopoulos; 2006, Moussiopoulos and Douros; 2004). OFIS was derived from the more sophisticated EZM core models. Being closely related to the 3D photochemical dispersion model MARS/MUSE, it simulates concentration changes due to the advection of species and chemical transformation in each cell of its computational domain, while the concentration values outside this domain are assumed to coincide with the regional background concentrations provided by the regional scale model. The model simulates separately each day of, typically, one year.

The computational domain of the model consists of a two-layer gridded strip with a length of 240 km and a width defined by the city size, with the city in the centre. The strip is oriented along the prevailing wind direction, altering direction when the meteorological input is modified (every 3 hours). Thus, the core region lies always inside the OFIS computational domain and defines the urban area. Areas outside this region are affected to a lesser degree, depending on their distance from the centre, defining suburban and rural regions. Emission data are inserted into the model in the form of gridded emission inventories. Emissions are calculated for each OFIS cell by properly taking into account the emission density of the underlying fine-scale inventory. Due to the modular structure of OFIS, chemical transformations can be treated by any suitable chemical reaction mechanism, the default being the EMEP MSC-W chemistry (Arvanitis and Moussiopoulos; 2003).

OSPM is a combined plume and box model used for simulations of air pollution from traffic in urban streets (Hertel and Berkowicz; 1989). The formulas for concentration of pollutants in the street are derived by applying the constraint that a continuous transition must be obtained between the different flow regimes. This concerns especially the transition from the recirculating regime at higher wind speeds to the non-recirculating regime at lower wind speeds. The same applies for the case of vanishing vortex when the wind direction changes from perpendicular to parallel with the street. Expressions used for the direct contribution and the recirculation contribution are constructed to fulfil these requirements. The direct contribution is calculated using a simple plume model. It is assumed that both the traffic emissions are uniformly distributed across the canyon. The contribution from the recirculation part is calculated assuming a simple box model. The concentration in the recirculation zone is calculated assuming that the inflow rate of the pollutants into the recirculation zone is equal to the outflow rate and that the pollutants are well mixed inside the zone. The turbulence within the canyon is calculated taking into account the traffic created turbulence, which allows for the incorporation of a resuspension module in OSPM.

Several resuspension modules that exist have been reviewed, in order to select the most appropriate one for the specific case. USEPA – AP42 (URL 1) is the most widely used resuspension module and belongs to a group of widely used models for non-exhaust emissions. The AP42 provides methods to calculate emissions from brake wear, tyre wear and resuspension from paved and unpaved roads. EPA included these sources in the emission factor equation for paved roads since the field testing data used to develop the equation included both the direct emissions from vehicles and emissions from resuspension of road dust. The model has been modified for use in Germany by changing the value of constants, and further modifications in which exhaust and non-exhaust contributions were separated have also been made. MOBILE6 is another USEPA emission factor model for predicting gram per mile emissions of Hydrocarbons (HC), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Carbon Dioxide (CO2), Particulate Matter (PM), and toxics from cars, trucks, and motorcycles under various conditions. The US-EPA's Fugitive Dust Model (FDM) is a computerized air quality model specifically designed for computing concentration and deposition impacts from fugitive dust sources. The model is generally based on the well-known Gaussian Plume formulation for computing concentrations, but has adaptations for improved gradient-transfer deposition algorithm. The model incorporates meteorological information and three types of sources (point, line and area sources).

4. Results

4.1 Future scenarios

The simulations were performed for several future emission scenarios, for the years 2005, 2008 and 2010, in order to examine future compliance with standards. Year 2005 refers here as a future situation, since 2002 was the reference year based on emission availability. Emissions used for PM_{10} for those scenarios are shown in figure 10. As it is also suggested in the recommendations, this is an important process in identifying current problems and increased emissions and planning appropriate management strategies, so that future PM levels remain within the acceptable limits.

The results indicate that natural emission sources play a very important role in the calculation of PM concentrations (as clearly shown on Figures 10 and 11) and that their contribution leads to significant increase in the number of current and future exceedances. This could suggest that more strict policies regarding the anthropogenic part of PM emission need to be applied.

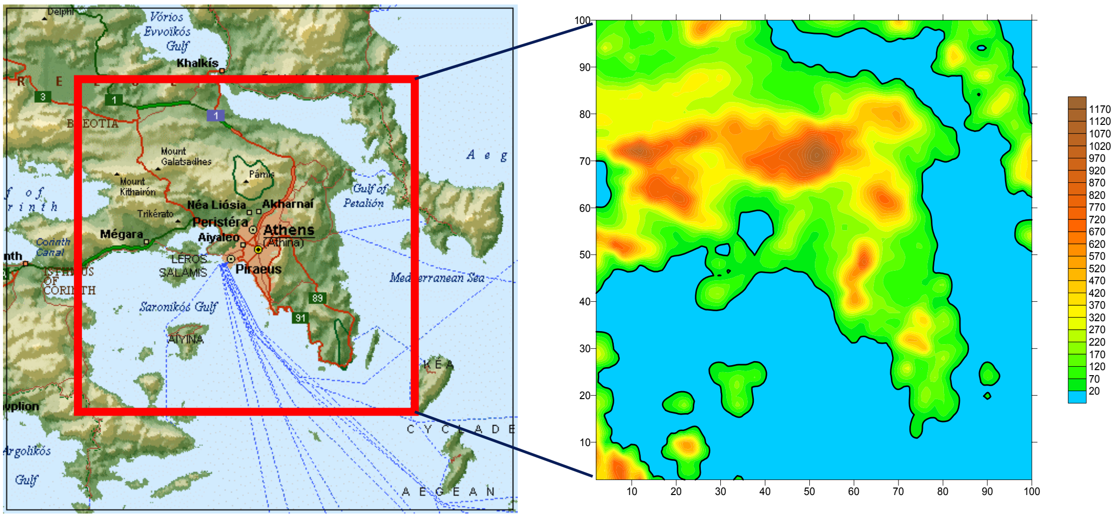


Figure 8: Computational domain of the OFIS model

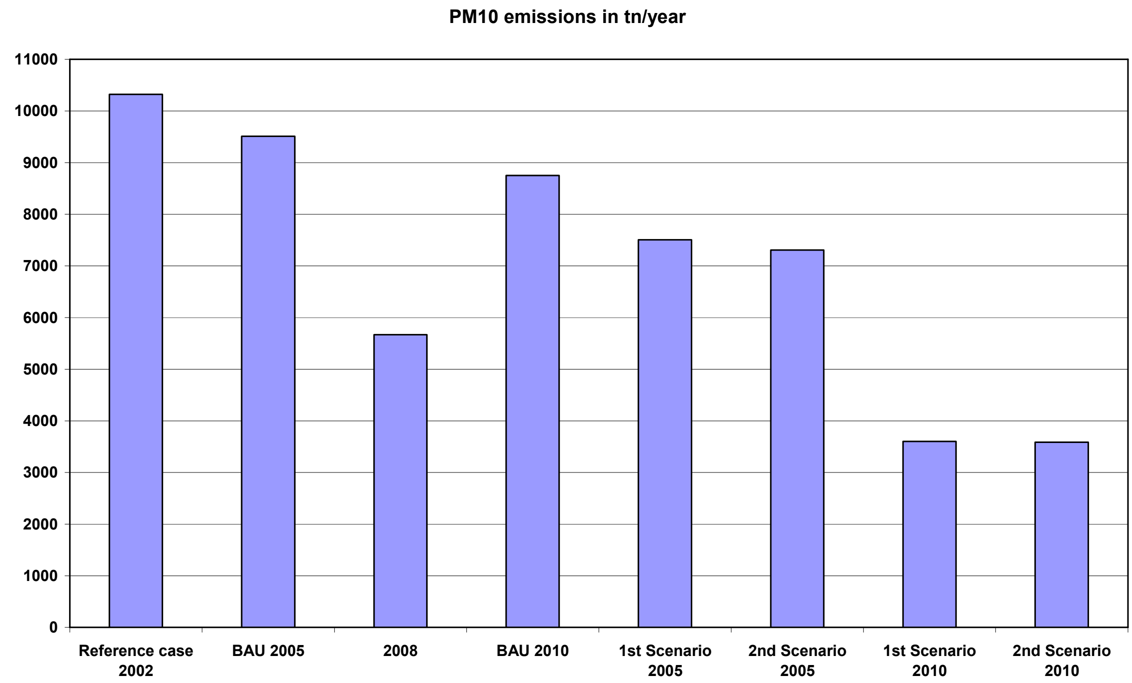


Figure 9: Total PM_{10} emissions (model input)

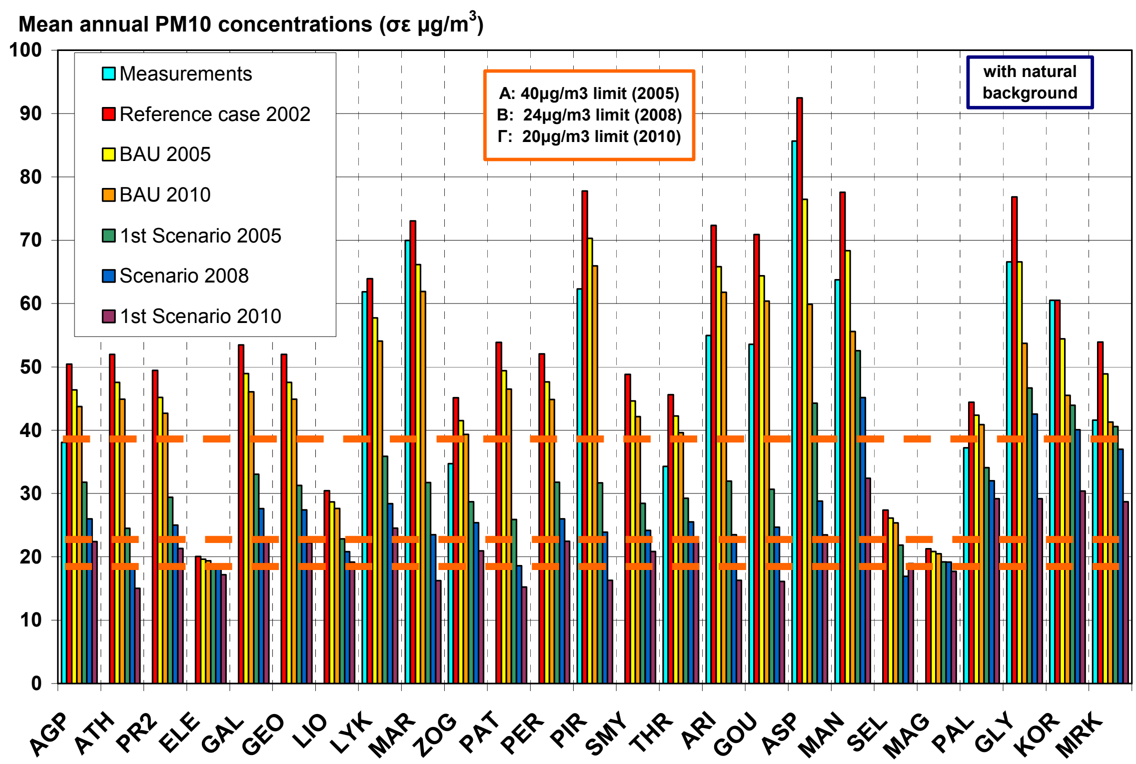


Figure 10: OFIS predicted annual PM_{10} concentrations with natural emission source contribution

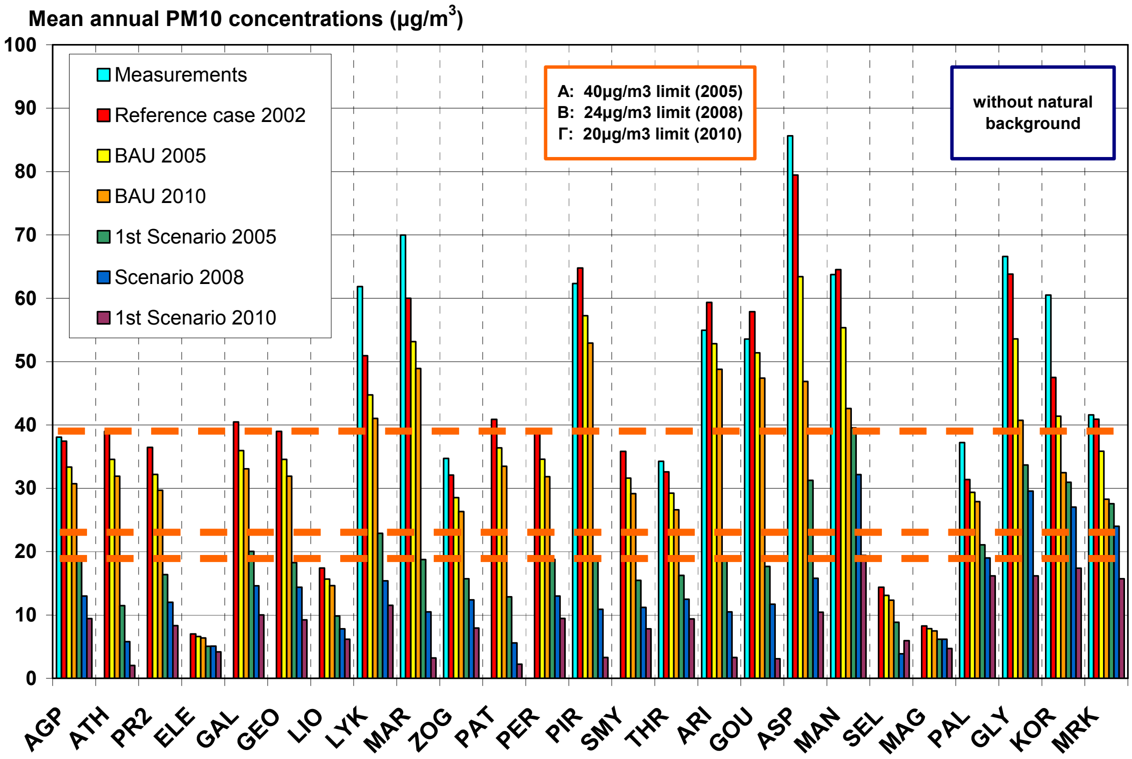


Figure 11: OFIS predicted annual PM_{10} concentrations without natural emission source contribution

4.2 Street scale contributions

Based on monitoring data after 2000, the highest concentrations in the Greater Athens Area were observed in urban “traffic” stations (Aristotelous, Piraeus 1, Goudi, Marousi), and to a lesser degree in the urban “background” stations (although no real ‘background’ PM_{10} monitoring station is in operation in Athens), while the concentration values are generally lower in the suburban stations. This result clearly indicates the detrimental effect of road transport in urban air quality. In order to achieve compliance with the 2005 and the more stringent 2010 air quality standards, emission reduction strategies for all emission sources, with particular emphasis on transport, should be implemented.

For the analysis of street scale pollution levels the OSPM model was indicatively used for Aristotelous Street. Figures 12 and 13 depicts the results of OFIS and OSPM models for the current air pollution levels in Athens compared to the available measurements for urban and suburban stations.

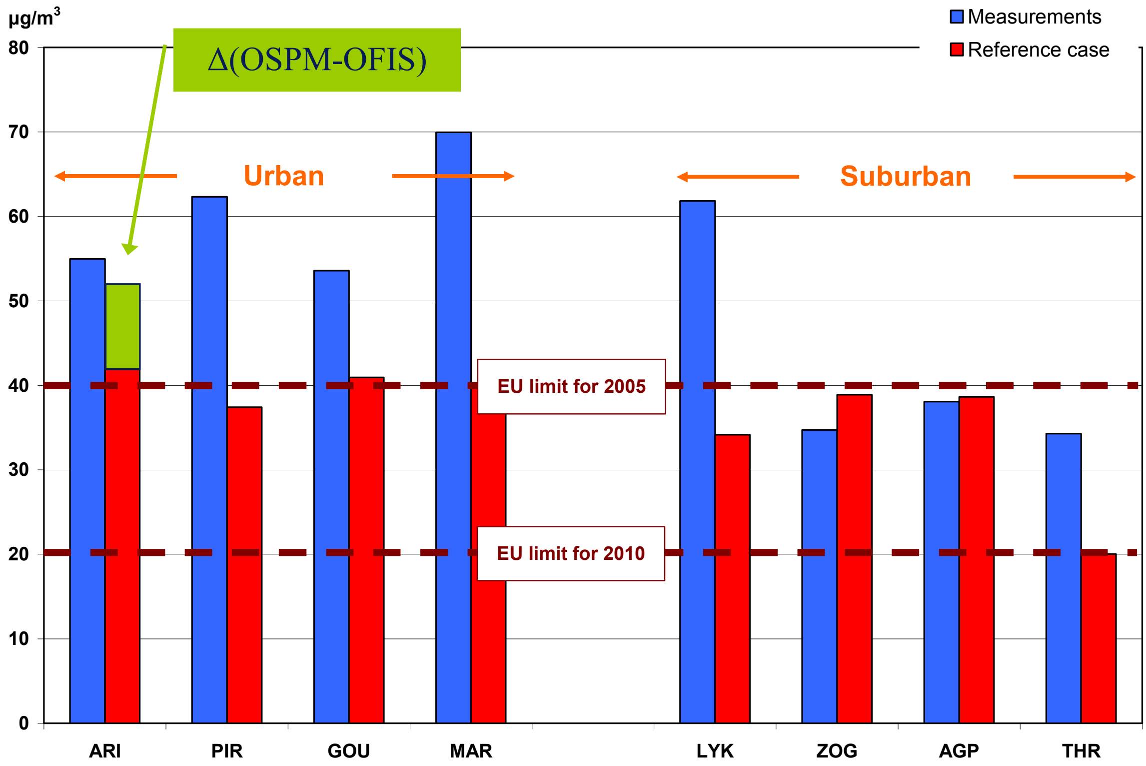


Figure 12: PM_{10} annual averages

Regarding the suburban stations, model calculation results are satisfactory for the stations of Zografos and Ag.Paraskevi. For the station of Likovrisi the concentration measurements appear to be particularly high, possibly due to the increased traffic of heavy vehicles in preparation for the Olympic Games. These are local emissions and can only be realistically represented by a local scale model incorporating detailed terrain information, such as the OSPM model that was used in the present case study. Also, as the station of Thrakomakedones appears to be considerably influenced by the suspension and transport of dust from natural sources of unknown characteristics, it is not included in this analysis. As it was mentioned before, suitable tools are necessary to realistically simulate the phenomena that lead to the characteristically high concentrations observed in the urban stations (Aristotelous, Piraeus 1, Goudi, Marousi). Indeed, the additional application of the OSPM model improved the agreement of the calculation results for PM_{10} concentration values in Aristotelous street with the measurements.

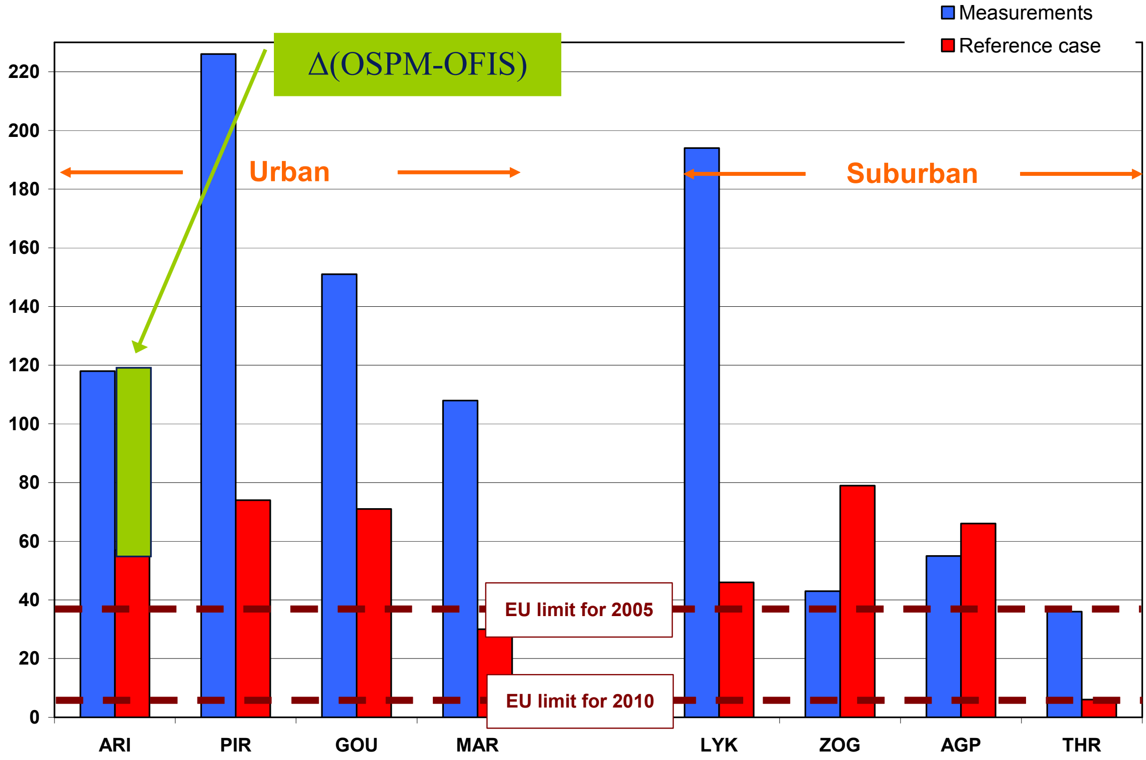


Figure 13: PM_{10} exceedances

Figure 14 depicts the average diurnal variation of PM_{10} measurements and model calculations

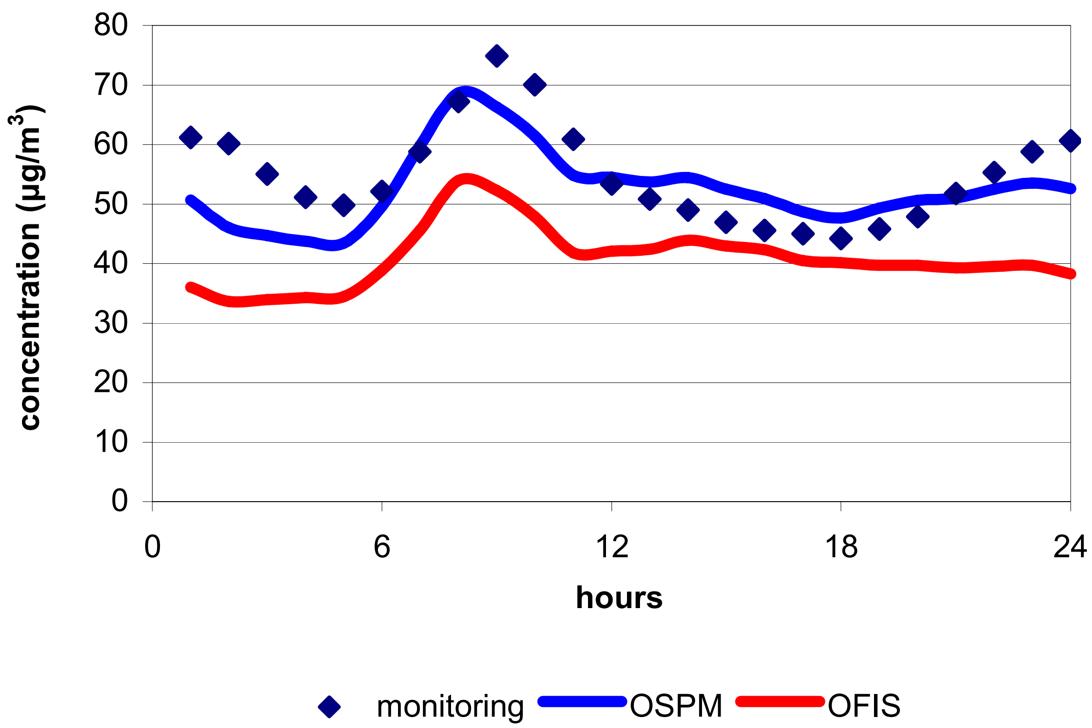


Figure 14: Average Diurnal PM_{10} concentrations for Aristotelous

A sensitivity analysis was conducted with regard to the emissions used. The impact of two reduction scenarios of primary PM_{10} emissions in the urban scale (circulation, industry, heating, waste management) on PM_{10} concentrations calculated with OFIS are presented in Figures 15 and 16. A 40% PM_{10} emission reduction results in mean annual concentrations that are in compliance with the 2010 standards (thus consequently also with the 2005 standards). However the resulting number of exceedance days was not in compliance with the 2010 standards. Only with the application of the 65% emission reduction scenario a concentration reduction was achieved so both mean annual values and number of exceedance days were in compliance with the standards. For the study of the impact of the emission reduction scenarios in the local scale, the OSPM model was applied. The results shown in Figures 17 and 18 indicate that with a 65% emission reduction compliance of the number of exceedance days with the 2010 standards could not be achieved: for this purpose a further emission reduction by 20% or an additional restriction of local emissions in Aristotelous Street by roughly 30% are required. This can be achieved with mitigation strategies at the local scale, such as pavement development and restricted access for particularly polluting vehicles.

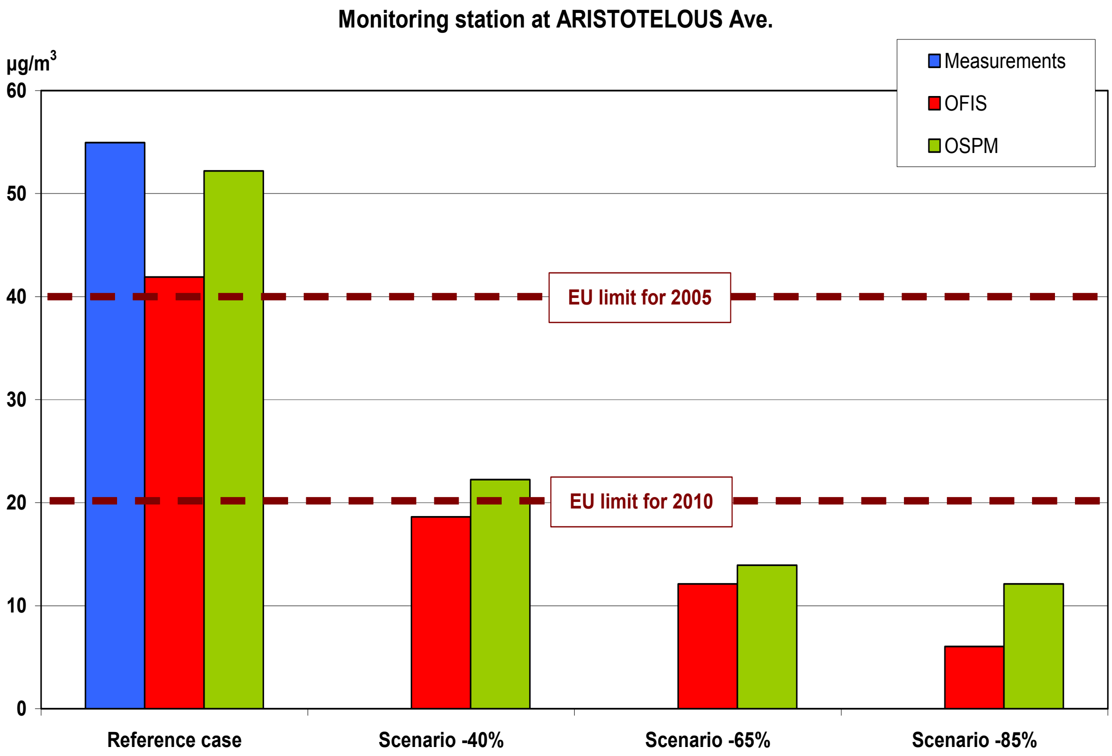


Figure 15: PM_{10} annual averages

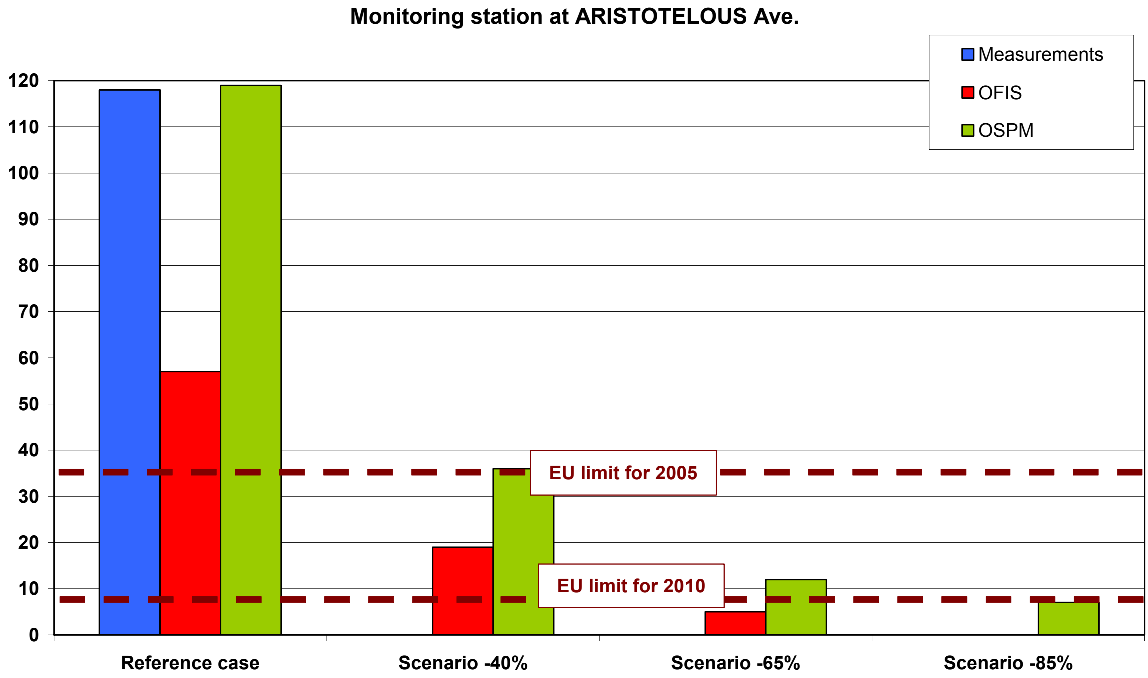


Figure 16: PM_{10} exceedances

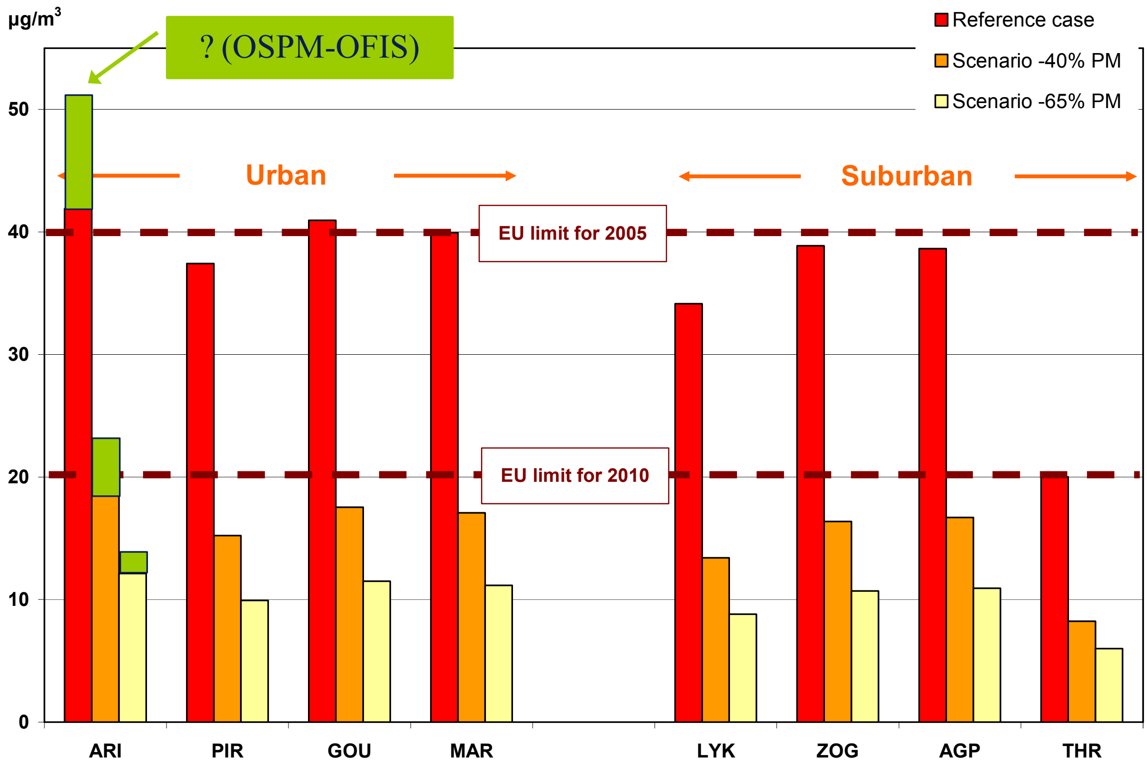


Figure 17: PM_{10} annual averages

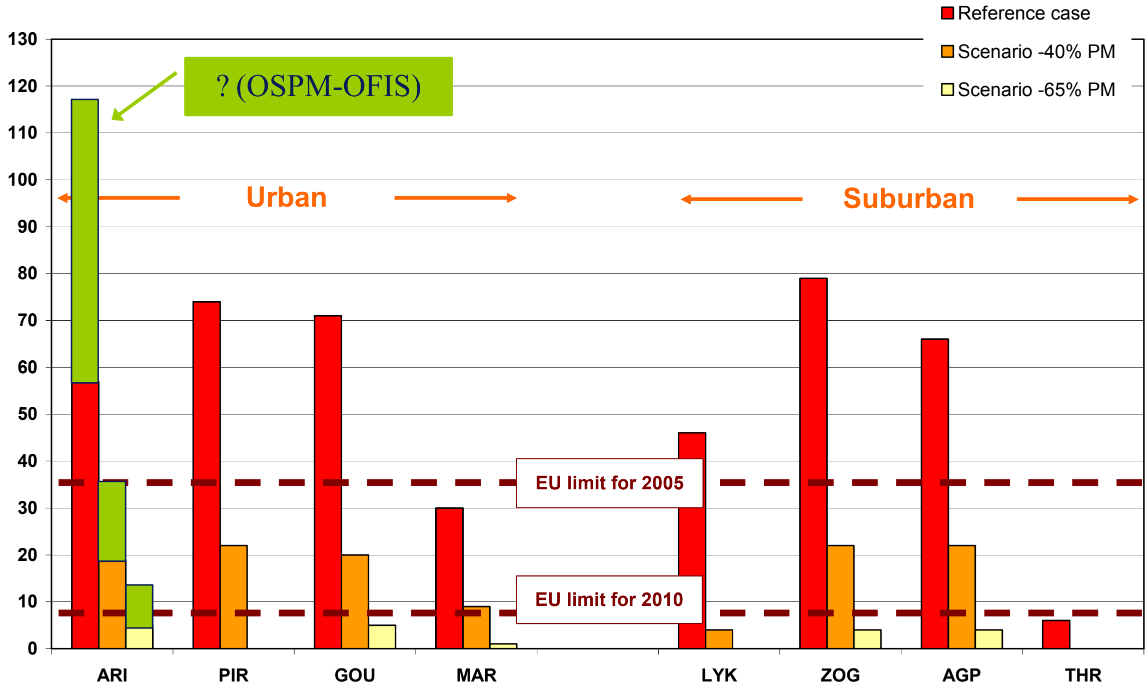


Figure 18: PM_{10} exceedances

Finally, in order to assess the source contribution of various sources, a source apportionment study was conducted by switching on and off the major activity sectors (road traffic, industry, domestic and heating). Results are shown in Figure 19.

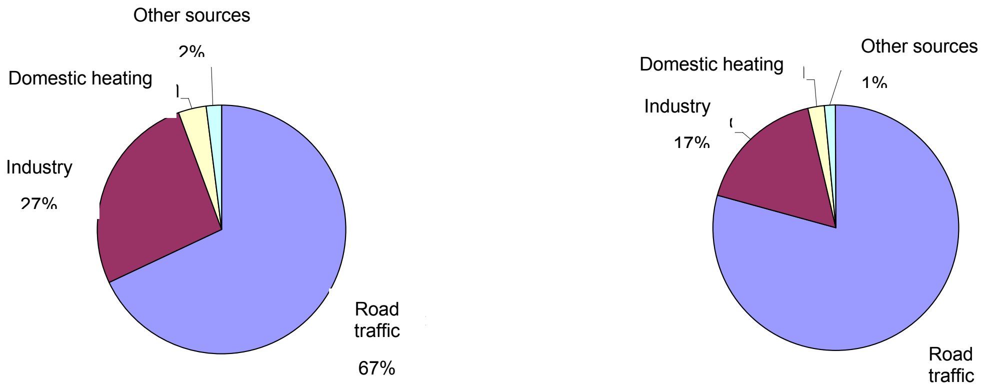


Figure 19: Percentage contribution of various sources to PM_{10} concentrations for the Aristotelous Ave. by taking into account (right) or not (left) microscale phenomena.

4.3 Sensitivity to initial and boundary conditions

Three sets of runs were performed in order to identify how different boundary conditions affect the OFIS model results. For the purposes of this analysis, boundary conditions coming from two different regional scale models systems, EMEP and LOTOS-EUROS, were used. The first two were by using the same source for boundary conditions (regarding concentrations) and meteorology, i.e. EMEP and LOTOS-EUROS respectively. As a means, however, to identify the importance of input meteorology, a third run was performed where concentration boundary conditions originated from LOTOS-EUROS, while meteorology was from EMEP (PARLAM-PS).

The EMEP Unified Model (URL 2) which has been mostly used as a source of OFIS boundary conditions is an Eulerian grid model with European coverage, using a polar stereographic projection. The horizontal grid cell size of the model is 50×50 km^2, while in the vertical the model uses 20 layers, the first of which has a thickness of approximately 90m. Meteorology for EMEP model runs originates from 3-hourly meteorological data from PARLAM-PS, a dedicated version of the HIRLAM (HIgh Resolution Limited Area Model) Numerical Weather Prediction (NWP) model (Sandnes and Tsyro; 2000). EMEP utilises various versions of the EMEP MSC-W chemical mechanism (Simpson; 1993).

LOTOS-EUROS (Schaap et al.; 2005) is also a Eulerian grid model covering Europe. In horizontal direction the model domain is divided into 140×140 grid cells with a size of 0.5ºlon.×0.25ºlat. (~25×25 km^2). The lowest 3.5 km of the atmosphere are represented by three terrain following prognostic layers for which the continuity equation is solved and an additional (diagnostic) surface layer with a thickness of 25m. The LOTOS-EUROS system is presently driven by 3-hourly meteorological data produced by the Free University of Berlin employing a diagnostic meteorological analysis system based on an optimum interpolation procedure on isentropic surfaces (Kerschbaumer and Reimer; 2003), but also, meteorological data obtained from ECMWF can be used to force the model. The model uses a slightly adapted version of the CBM-IV chemical mechanism (Adelman; 1999). This scheme contains 28 species and 66 reactions, including 12 photolytic reactions. Compared to the original scheme steady state approximations were used to reduce the number of reactions.

Several OFIS characteristics, especially its vertical structure, were selected to ensure an optimised application in conjunction with the EMEP model. This fact presented certain challenges in the formulation of boundary conditions data originating from a different regional model such as LOTOS-EUROS. More specifically, an appropriate mass-preserving interpolation scheme had to be applied to account for the different horizontal and vertical setup of the two regional models. In addition, a logarithmic law was applied in view of the different height at which wind speed was provided in each case. Finally, as the models use different chemical mechanisms, there was a need for a suitable correspondence between the chemical species available. Except for the cases where a straightforward one-to-one correspondence was possible (as in the cases of O_3, NO, NO_2, ethane, formaldehyde, xylene and various PM species), a split of the lumped CBM-IV alkanes, alkenes and aldehydes had to be performed in order to map them onto EMEP MSC-W species. This split was done following a statistical evaluation of the relative mixing ratios of the relevant EMEP MSC-W species in the output of the EMEP model.

The air quality in Athens for the year 2000 was analysed using measurements from seven urban background and suburban stations. In this way, the prevailing trends during this short time period have been revealed and they were then connected through the modelling study with the main contributing input data. Unfortunately no PM monitoring data were available for year 2000, and therefore this study was limited to gaseous species only.

The comparison between observed and modelled results for the mean annual values of NO_2 and O_3 is shown in Figure 20. Table 3 provides the correlation coefficients for the three runs.

Table 3: Correlation coefficients for the mean annual modelled vs. observed NO_2 and O_3 concentrations at seven stations of the Greater Athens Area for the three runs

	EMEP BCs & MET	**LOTOS BCs & MET**	***LOTOS BCs & EMEP MET***
NO_2	0.64	0.51	*0.66*
O_3	*0.35*	*0.23*	*0.57*

The results of this work prove the importance of scale interactive processes, by indicating a significant dependence of urban scale model results on the input boundary conditions and meteorology from regional scale models. It is evident that the runs differ substantially, most notably for O_3. This can be attributed to the steep gradient of O_3 concentrations in the first few layers of each regional model, a fact that renders OFIS very sensitive to the methodology that is used for the correspondence of vertical layers. Best results in terms of the correlation coefficient are achieved by the "mixed" run for both pollutants. The better performance of the "EMEP BCs and met" run compared to the "LOTOS BCs and met" run is not surprising if one considers the affinity of the EMEP and OFIS models, mostly reflected in the common treatment of vertical layers and chemistry.

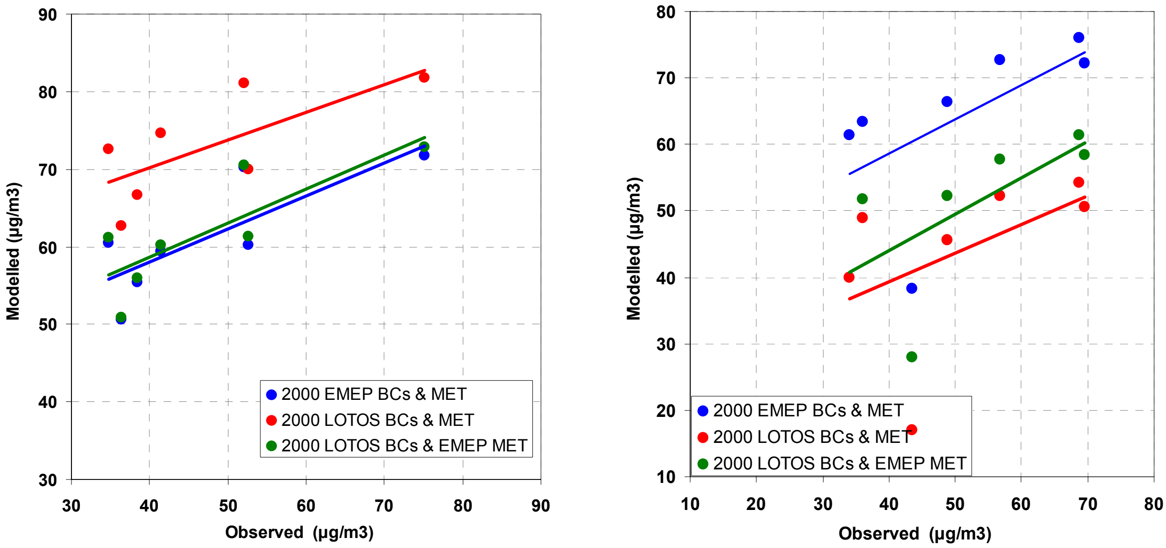
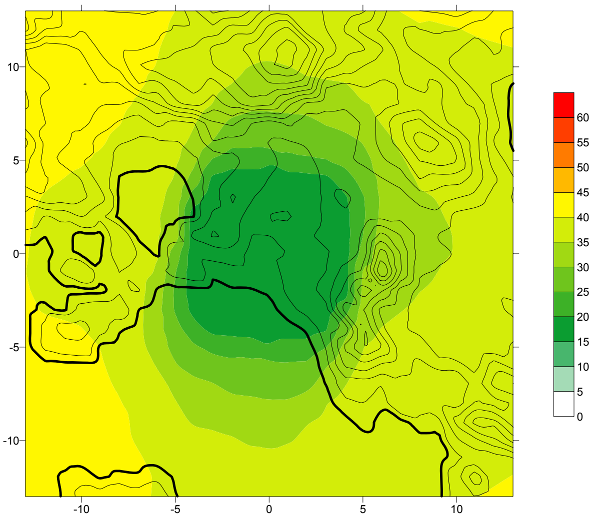


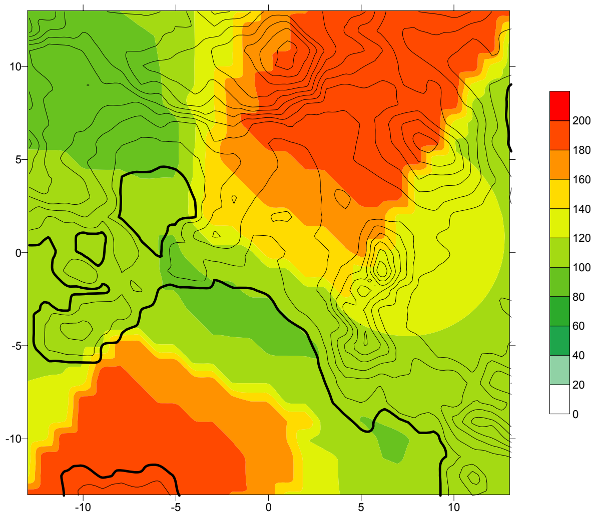
Figure 20: Scatter plot for annual mean NO_2 (left) and O_3 (right) concentrations in Athens

4.4 Spatial assessment

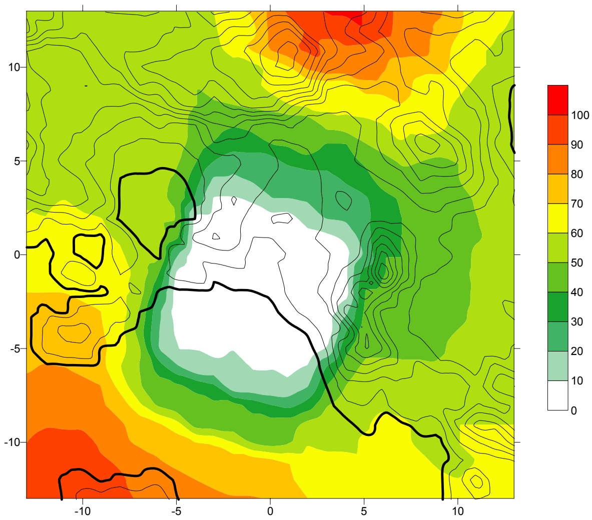
OFIS simulates concentration changes due to the advection of species and chemical reactions in each cell of the computational domain (Figures 21 and 22). The concentration values outside this domain are assumed to coincide with the regional background concentrations used for the calculation of the boundary conditions.



Mean annual values



Maximum annual values



Number of exceedance days

Figure 21: Athens maps presenting mean & maximum annual O_3 concentrations, such as the number of exceedance days, calculated by OFIS model for 2002.

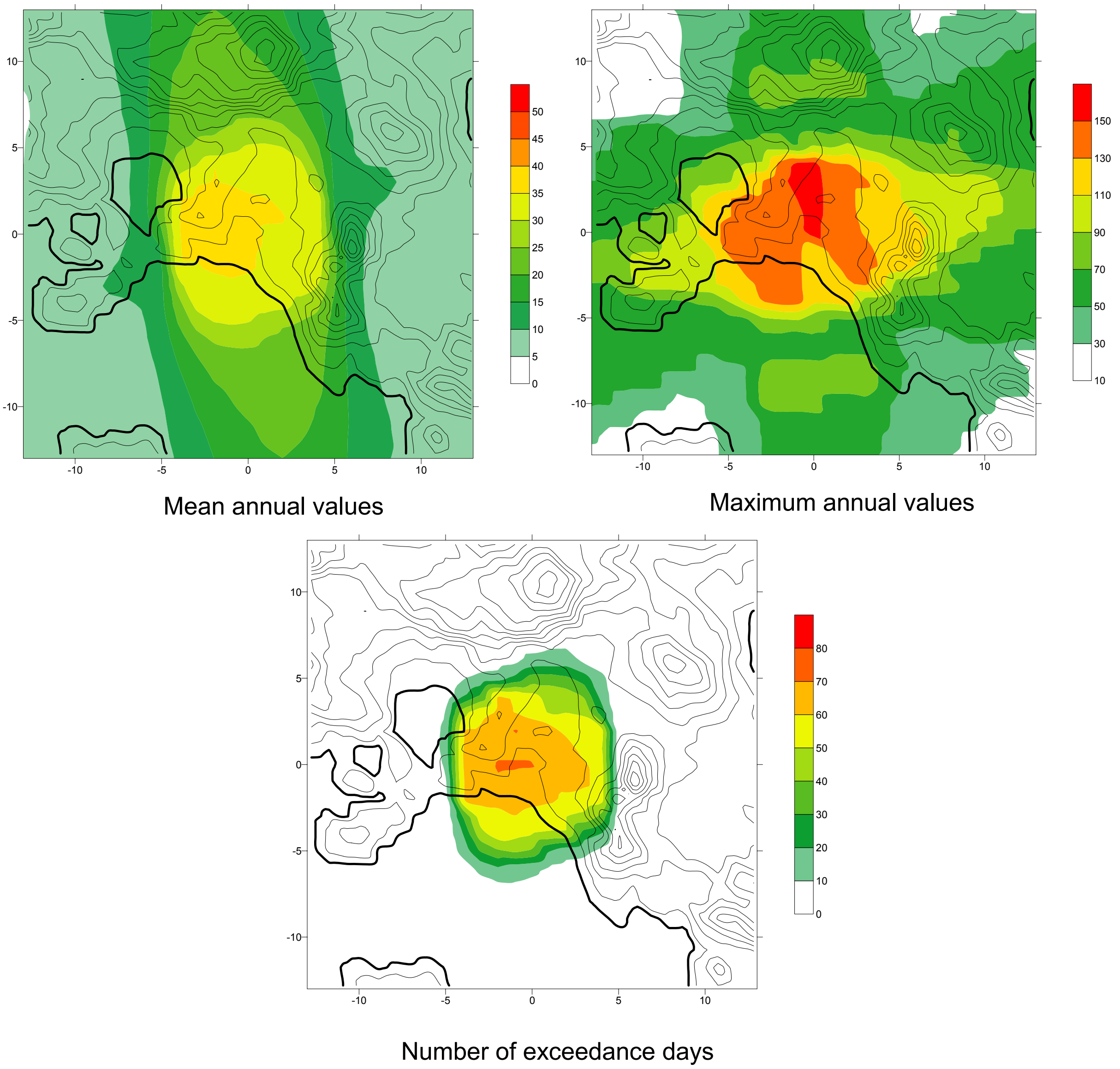


Figure 22: Athens maps presenting mean & maximum annual PM_{10} concentrations, such as the number of exceedance days, calculated by OFIS model for 2002.

5. Conclusion and discussion

5.1 Assessment of the case study

In this case study, an assessment of PM emissions in the urban area of Athens, Greece, was carried out. The US-EPA resuspension model USEPA – AP42 was used for the calculation of non-exhaust emissions. The AP42 provides methods to calculate emissions from brake wear, tyre wear and resuspension from paved and unpaved roads. EPA included these sources in the emission factor equation for paved roads since the field testing data used to develop the equation included both the direct emissions from vehicles and emissions from resuspension of road dust. Although the specific resuspension module was used in the present study due to data availability reasons, it would be interesting to investigate the performance of this module against a more recent resuspension module that will also take into account the prevailing meteorological conditions.

5.2 Improvements in assessment derived from case study

An important assessment method used in this case study was the sensitivity of the applied model to the elimination of several emission sources to examine their relative contribution. This is particularly important for the development of an effective emission control strategy, as in this way more stringent measures can be applied to the main polluting sources. Although this is a method commonly applied, an improvement in this case study was that the source contribution was related to an exposure estimate. It is particularly useful for the authorities to assess the contribution of a particular emission source not merely on its emission rates but also on the population size exposed to the source. This is because although the emission rates from a particular source in the city centre may be relatively low compared to another source within a greater distance from the centre, its emissions will affect a higher population number.

5.3 Recommendations resulting from the case study

The main recommendations resulting from this case study are:

- It is recommended for a realistic assessment of urban PM emissions that it is founded on a complete and detailed emissions inventory including:

❑ Stationary air pollution sources like, industry, domestic heating and oil stations
❑ Mobile sources, such as, road traffic and emissions from ship, airplane and train lines
❑ Natural emission sources

- It is recommended to carefully consider and select all input parameters when applying CTMs, especially in the urban and local scales.
- It is recommended to use local scale models for the estimation of the effects of local emissions on air quality, for example before any new structures or developments in an area of consideration.
- It is recommended to use a resuspension module for the estimation of non-exhaust emissions in the street canyons. This is particularly important in urban areas where the population most exposed to air pollution is located within the street canyons.

5.4 Suitability for implementation in other cities

The findings in this case study should be applicable to other cities, provided that thoroughly evaluated modelling tools are used, and a sufficient number of urban background as well as traffic stations are available.

The methodology used in this case study for the urban area of Athens can also be applied in other cities, provided that sufficient and detailed emissions data are available. However, a modification in the resuspension module according to the local emission factors of the candidate city would be advisable.

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URL1: http://www.epa.gov/ttn/chief/ap42/

URL 2: http://www.emep.int