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An overview of the PM_{10} pollution problem, in the Metropolitan Area of Athens, Greece. Assessment of controlling factors and potential impact of long range transport

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ABSTRACT

The present study analyzes PM_{10} concentration data collected by the Greek air quality monitoring network at 8 sites over the Greater Athens Area, for the period of 2001–2004. The primary objectives were to assess the degree of compliance with the EU-legislated air quality standard for PM_{10} and also provide an overall statistical examination of the factors controlling the seasonal and spatial variation of concentrations, over the wider urban agglomeration. Daily concentrations, averaged over the whole study period, ranged between 32.3 and 60.9 $\mu g\ m^{-3}$. The four-year average concentration of PM_{10} at five sites exceeded the annual limit value of 40 $\mu g\ m^{-3}$, while most of the sites surpassed the allowed percentage of exceedances of the daily limit value (50 $\mu g\ m^{-3}$), for each of the four years.

The seasonal variation of PM_{10} levels was not found to be uniform across the eight sites, with average cold-period concentrations being higher at four of them and warm period concentrations being significantly higher at three sites, which also displayed recurring annual variation of monthly concentrations. Concentration levels displayed moderate spatial heterogeneity. Nevertheless significant inter-site correlations were observed (ranging between 0.55 and 085). The determination of the spatial correlation levels relied mainly on site types rather than on inter-site distances. Monitoring sites were classified accordingly using cluster analysis in two groups presenting distinct spatiotemporal variation and affected by different particle formation processes. The group including urban sites was mainly affected by primary, combustion-related processes and especially vehicular traffic, as it was also deduced through the examination of the diurnal distribution of particulate levels and through factor analysis. On the contrary, suburban background sites seemed more affected by particle transport from more polluted neighboring areas and secondary particle formation through gaseous precursors, both processes aided from favoring meteorological conditions.

The association of the PM_{10} levels with backwards trajectories was also examined, in an attempt to account for the possible long range transport of particles in Athens. It was found that a notable part of area-wide episodic events could be attributed to trans-boundary transport of particles, with the origins of some severe dust outbreaks traced back to the Sahara desert and the Western Mediterranean.

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1. Introduction

Following a series of epidemiological studies conducted in the US in the early 90s, which categorically suggested the association of exposure to PM_{10} pollution with adverse effects on human health (Dockery and Pope 1994; Samet et al., 2000), important information on risk assessment for PM_{10} in Europe became available through multi-nation studies (Roemer et al., 1998; Brunekreef and Holgate, 2002). Elevated PM_{10} concentrations were linked with increases in mortality and hospital admissions with respiratory symptoms, especially for sensitive population subgroups. Under the growing scientific concern the European Union rendered the monitoring of PM_{10} as mandatory, promulgating annual and 24-h concentration limit values for the protection of public health, in the 1st daughter directive of the EU Air Quality Framework Directive (EC, 1999). Due to the provisions of the directive, the Greek National Air Pollution Monitoring Network initiated continuous monitoring of PM_{10} concentrations at several locations across the country, (including 8 monitoring stations in the Greater Athens Area), in 2001.

Up to that point, research studies have indicated the importance of the particle pollution problem over the Greater Athens Area, reporting high levels of PM_{10} and $PM_{2.5}$ concentrations (Chaloulakou et al., 2003) as well as the occurrence of severe episodes. Considering the geographical position and climatic characteristics, it has been suggested that natural sources could play an important role in the determination of particulate levels in Athens through processes such as dust resuspension, erosion and long range transport (e.g. Southern Mediterranean, Sahara/Sahel). Indeed, an increased abundance of coarse particles in total PM_{10} mass, in comparison to other European countries, has been reported even for traffic-impacted locations in Athens (Chaloulakou et al., 2005). Air quality was also adversely affected by the specific atmospheric circulation patterns, both synoptic-scale and mesoscale (Kassomenos et al., 1998). However, recent research has indicated the major impact of primary anthropogenic and especially mobile sources all over the area of the Athens basin (Grivas et al., 2004a,b; Manalis et al., 2005), while secondary particle formation is not a negligible parameter (Prosmitis et al., 2004).

The combination of the above factors leads to an aggravated situation. Since the beginning of the systematic monitoring of PM_{10}, fears of projected failure regarding the objectives of the relevant directive have been sounded. With the new impending directive on "Air quality and a cleaner air for Europe" it should be made clear whether the observed problem is to be attributed to non-favoring factors as climatic conditions and trans-boundary contributions and up to which extent. In the case where conformity with limit values is impeded by natural factors and a high background particulate load, then the country would be exempted from the obligation to apply these limit values up to 2009 (EC, 2005). If not, the application of stringent emission control policies is necessary.

The exposure of Athens' civilians to high levels of particle concentration is a matter of great significance for local authorities since the half of the country's population lives in the Metropolitan area of Athens. The investigated problem is of wider interest since Athens is probably the European capital city facing the most serious air pollution conditions and moreover, the relationships between air quality and the regional meteorology are expected to present similarities with other agglomerations in Southern Europe and specifically the Eastern Mediterranean.

The main objectives of this work are:

i) the assessment of the recorded levels, in monitoring stations of different characterizations, for the 4-year periods of measurements, prior to the 1st stage of the implementation of the EU PM_{10} standard.
ii) the statistical investigation of spatial and temporal variation of PM_{10} concentrations, as well as their relationships with other measured air pollutants, in order to examine the major factors contributing to observed PM_{10} concentrations in the Greater Athens Area.
iii) the assessment of the impact of long range particle transport on the recorded PM_{10} levels, in an attempt to explore the origins of severe episodes affecting the whole area.

2. Study area, data and methods

2.1. *Study area characteristics*

Sampling sites were located within the Athens Basin (450 km^2), the largest and most populated plain of the Attica peninsula (Fig. 1). The basin is surrounded by high altitude terrain in the north, which becomes lower towards the Saronic Gulf in the S–SW. Parnitha Mt. (1413 m asl) covers the northern sector of the basin, Penteli Mt. (1109 m asl) lies in the northeast and Hymettus Mt. (1026 m asl) in the east extends to the sea. The mountainous arc surrounding the basin closes with Aegaleo Mt. (468 m asl) in the N–NW. Mountains are connected with moderately high saddles, at the main exits of the basin to the Mesogeia plain in the East and the Thriassion plain in the West. It is obvious that the complex topography entails significant difficulty in the dispersion of air masses above the basin.

The Greater Athens Area (GAA) currently gathers a population exceeding 4 million inhabitants. The massive number of registered vehicles in circulation (over 2.5 million, growing at a rate of 7% yearly) is allegedly the major cause of air pollution related problems in the area, taking into account that a large proportion of these vehicles are non-catalytic (0.8 million) or are powered by old technology diesel engines (0.2 million). Although the use of natural gas for domestic heating purposes has increased lately, combustion of fuel oil is still primarily used for central heating. The industrial zones affecting the area are located westwards of the basin at the Thriassion plain (including two oil refineries, two shipyards, cement plants and a steelworks factory) and at the S–SW and northern parts of it (diversified secondary industrial operations). The detrimental effects of industrial activities of the Thriassion plain on local air quality has been discussed by Manalis et al. (2005), while the possibility of pollution intrusion to the Athens Basin and especially the western part of it has also been suggested (Kassomenos et al., 1998; Grivas et al., 2004a).

The weather conditions in GAA are mainly the results of interaction of large and local scale circulation systems. The