

6 Acknowledgements

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Estimation of the contribution to air-quality degradation in Athens from major elevated sources

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Abstract: The dispersion of air pollutants released from the major elevated sources in the Attica Peninsula has been studied extensively. An attempt was made to estimate average concentrations for some non-reactive air pollutants. These estimates were made with a two-way interactive nesting, prognostic model, RAMS, a Lagrangian particle dispersion model, LPDM, and a synoptic classification scheme developed for this purpose. Simulations were made with this complicated modelling system because of the significant variation of the physiographic characteristics in the region. Such variation was found to be responsible for the development of thermal circulations of various scales and consequently the complicated dispersion characteristics. The conclusions derived from this approach should be considered as very important for the region in general. More specifically, it was found to be very helpful for planning the expansion of the existing power production units and the development of a monitoring network.

Keywords: air pollution, atmospheric modelling, dispersion, synoptic classification scheme

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1 Introduction

Athens is located in the Attica Peninsula, which is the south-eastern part of the Greek Peninsula. There are significant topographic and land-use variations in the Attica Peninsula and the area around it. Significant topographic features include the island of Evoia to the east and the Peloponnese to the south-west and west. There are three main mountainous regions in the Attica Peninsula surrounding the city of Athens on three sides (Figure 1). These are Hymettus to the east, Penteli to the north and Parnitha to the north-west. To the west is the hilly area of Aegaleo. To the south of Athens Basin is the Saronic Gulf. The Athens Basin has an orientation from south-west to north-east. The major axis of the Basin is approximately 25 km and the minor 17 km. There are two other plains in the Attica Peninsula, the Thriassion and Mesogea Plains to the west and east of the Athens Basin, respectively.

Table 1 Some of the stack parameters for the units on each power plant.

Power plant location	Units	Stack height (m)	Load (MW)	Hours of operation
Aliveri	1	49	40	0-24
	2	49	40	0-24
	3	110	150	0-24
	4	110.5	150	0-24
Lavrio	1	150	150	0-24
	2	150	300	0-24
	3	40	86.7	7-23
	4	40	86.7	7-23
Keratsini	1	154	160	0-24
	2	154	200	0-24

2 Methodology

In order to make an estimation of the near-ground concentrations expected from the operation of the three power plants, a three-stage procedure was employed:

- 1 Development of a synoptic classification scheme (with sixteen classes) and correlation between each class and the dispersion conditions in the area;
- 2 Simulation of the atmospheric flow over the north-east Mediterranean with the Colorado State University Regional Atmospheric Modeling System (CSU-RAMS);
- 3 Simulation of the dispersion of pollutants emitted from the power plants with a Lagrangian particle dispersion model (LPDM).

2.1 Synoptic classification

A synoptic classification scheme was developed for the Attica Peninsula and the Aegean Sea (Kallos *et al.*, 1993a). In this scheme there are sixteen classes. A day-by-day analysis was performed for the years 1987-1992, and almost all the days were classified accordingly. A correlation was made between each class and the dispersion conditions in the area. In that way, the classes were set in order according to the concentrations measured.

The factors controlling dispersion from elevated sources are different from those for near-ground ones. It is also evident that, for some of the classes, local conditions and therefore dispersion characteristics are similar. Because of these facts, the sixteen classes were grouped into seven categories according to the general characteristics of the synoptic flow in the Greek territory:

- 1 Strong north-easterly winds across the Aegean during the cold period of the year
- 2 Strong north-easterly winds across the Aegean during the warm period of the year (etesians)
- 3 Weak northerly flow (north-west/north-east) during the cold period of the year

In the area around Athens there are a number of significant industrial installations emitting air pollutants from tall stacks. These installations are mainly power plants and refineries. Two of the refineries are located west of Aegaleo, at Thriassion Plain, and one west of it near the Isthmus of Corinth. The locations of these refineries are marked as R1, R2 and R3 in Figure 1.



Figure 1 The topography of south-east Greece. Contours are every 200 metres, and the distance between tick marks is 10 kilometres. The refineries R₁, R₂ and R₃ (●) and power plants P₁, P₂ and P₃ (▲) are also shown.

Three power plants are located in and around the Athens Basin, namely Keratsini, Lavrio and Aliveri, with several units and stacks on each one. Their locations are marked in Figure 1 as P₁, P₂ and P₃, respectively. Keratsini is located near the harbour of Piraeus. Lavrio is located at the south-east edge of the Attica Peninsula, and Aliveri is at the central part of the Island of Evoia on the coast of the Euboic Gulf. Their stack heights range from 40 m to 150 m.

The characteristics of each power plant are summarized in Table 1. Because of both the significant amount of air pollutants released from the stacks of these power plants and their location in and around the Athens Basin, an attempt was made to estimate their contribution to the air pollution in Athens.

- 4 Weak northerly flow (north-west/north-east) during the warm period of the year (sea breezes)
- 5 Warm advection at the lower tropospheric layers
- 6 Southerly flow (south-south-east/south-west) due to the approach of a low pressure area
- 7 Flow from west relatively strong

From the analysis and classification of the synoptic conditions during the time period 1987–1992 the frequency distribution for the seven categories was estimated. The percentage for each category is shown in Table 2.

Table 2 Percentage appearance for each synoptic category.

Synoptic category	%
1	18.65
2	10.51
3	21.10
4	12.82
5	12.93
6	6.23
7	17.76

For these seven categories, a number of typical cases were selected in order to perform model simulations. The models used are briefly described below.

2.2 Atmospheric model (CSU-RAMS)

The atmospheric model used for the simulations is the Colorado State University Regional Atmospheric Modeling System (CSU-RAMS) (Walko and Tremback, 1991; Pielke *et al.*, 1992). It is an advanced model with several capabilities, which make it one of the most appropriate models for simulations with complex flow interactions such as the present case. One of its important capabilities is the two-way interactive nesting with any number of either telescoping or parallel fine nest grids. This capability guarantees the representation of atmospheric disturbances of a wide portion of the spectrum. This is extremely useful for the purposes of this study because of the complicated interaction between the different-scale flow disturbances. The model uses terrain-following coordinate surfaces, with cartesian or polar stereographic horizontal coordinates, and cloud microphysics parametrization at various levels of complexity. Other significant capabilities of the model are the various schemes for turbulence or radiative transfer parametrizations (shortwave and longwave) through clear and cloudy atmospheres. For the boundary conditions the model uses various options for upper and lateral boundary conditions. The surface-layer parametrization (soil model, vegetation, etc.) is also detailed with various options. For initialization, it uses either horizontally homogeneous or variable (isentropic analysis) datasets as available (e.g. NMC, ECMWF, other model outputs).

2.3 Lagrangian particle dispersion model (LPDM)

It is a Lagrangian-type dispersion model (McNider *et al.*, 1988; Moran, 1992; Kallos, 1989). The motions of discrete mass elements are tracked inside the model domain as they move with the various-scale wind components. Large-scale (synoptic, regional, mesoscale) are these calculated directly from the atmospheric model, whereas the turbulent ones are deduced from the atmospheric model closure scheme. This model has been modified appropriately for use with CSU-RAMS.

3 Discussion

The atmospheric model was configured in the most appropriate way to describe accurately regional and local flow characteristics that may affect the dispersion of air pollutants released from the three power plants. More specifically, two nested grids were used for the atmospheric model CSU-RAMS. The coarse grid, with horizontal grid increments of 16 km, covers a portion of the Ionian Sea to the west and the Western part of Turkey to the east. To the south, it starts south of Crete and ends north of the Balkan Peninsula. The fine grid is shown in Figure 1. The horizontal grid increment used for the fine grid is 4 km. It covers the entire Attica Peninsula, the Saronic Gulf, the Central and Southern part of Evoia, a portion of south-east Greece and north-east Peloponnese. As was shown by Kallos and Kassomenos (1992, 1993), Kallos *et al.* (1993b), and Pilinis *et al.* (1994), it is necessary to use a model grid that covers the entire Balkan Peninsula, the Aegean Sea and at least a portion of Turkey in order to describe accurately the subregional-scale flow in the area and especially across the Aegean Sea. Test simulations using a third grid over the Attica Peninsula with 2 km horizontal grid spacing were also performed. For the purpose of this study this was not used, because the dispersion calculations are for point sources with high stacks.

For all the model simulations performed for the purpose of this study, the horizontally uniform initialization option of CSU-RAMS was used. More specifically, the radiosonde of 00 UTC (02:00 LT) from Athens airport was used. This kind of initialization is adequate for this study because emphasis is not given in very specific cases. The duration of each simulation was 36 hours.

For the dispersion calculations, the resultant meteorological fields from the atmospheric model were used. They were stored every 10 minutes. Additional input data, such as stack parameters, periods of operation, load and location of each source, were also provided. The effective stack height calculations were performed at the same time interval as the meteorological fields were available.

The concentration fields for non-reactive pollutants were estimated at constant time increments. More specifically, mean 3-, 6-, 12- and 24-hour concentrations were performed for each stack separately. The annual mean concentrations for each unit, on each power plant, were estimated from the 24-hour mean concentrations and the frequency of appearance of each synoptic category. The air pollutants taken into consideration are SO₂, total NO_x and TSP.

The annual mean concentrations were estimated for each unit separately in order to identify the areas affected from each one, because the dispersion characteristics are different. Annual mean concentrations were also estimated for each power plant and for all of them. It was found that the areas most affected are slopes of hills (or mountains)

where the plumes collide or areas around the plants during fumigation conditions. Plume impingement was observed for all the stacks, from all the plants. The distance at which they collide is a function of the stack height. Fumigation effects were found to occur under weak synoptic conditions. These characteristics can be easily identified in the figures shown here.

Figures 2-4 show the mean annual concentrations of the three pollutants estimated for the power plant at Lavrio. These are emitted from all the units of this plant, and it can be seen that the highest concentrations were estimated over the slopes of the hilly island of Macronisos during the days with relatively strong synoptic flow, because of plume impingement. This island is a few kilometres east-south-east of the plant. Secondary maxima were also observed near the plant (fumigation) and in the hilly area south-west of it (impingement). The annual concentrations estimated for the three pollutants exhibit similar spatial distribution with small variations, because of the differences in the amounts emitted from units with different characteristics.

Figures 5-7 show the mean annual concentrations of SO_2 , NO_x and TSP estimated for the power plant at Aliveri. In this case, the maximum concentrations were estimated at the hilly area of the island of Evoia and north-east Attica (impingement). Secondary maxima were estimated also over the Evoic Gulf and the slopes of Penteli and Hymettus. Smaller concentrations were also estimated over Athens, which verifies the findings of Kassomenos *et al.* (1993).

Figures 8 and 9 show the estimated annual concentrations of the total amount of air pollutants (SO_2 plus NO_x plus TSP) for the power plant at Keratsini. This power plant has not operated since 1981, but there are plans to restart it. Either diesel with low SO_2 content (up to 0.3%) or natural gas will be used. Figure 8 shows the estimated total amount of air pollutants for the case of diesel and Figure 9 shows the prediction for natural gas. The Figures show that the estimated annual concentrations in the Athens Basin are very small; the highest concentrations occur over the hilly area of Aegaleo, with secondary maxima over the south-east slopes of Mt Hymettus and at the Mesogea Plain. This is due to two factors: the high stack (the effective stack height was more than 400 m during the simulations performed) and the topographic characteristics. These simulations showed that this power plant could start operating again without significant degradation of the air quality in Athens, although the simulations for the warm period of the year showed that it might be a problem for Athens during the morning with the development of local thermal circulations. This is because of the fumigation conditions and in general because of the deep mixing height.

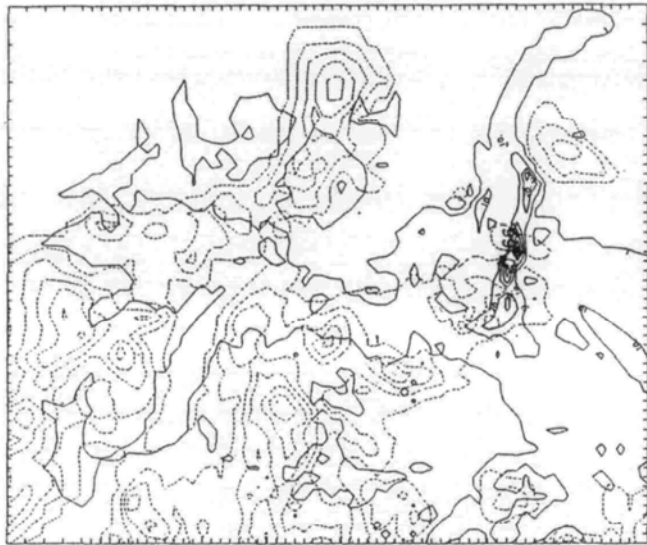


Figure 2 The mean annual concentrations ($\mu\text{g}/\text{m}^3$) of SO_2 estimated for the power plant at Lavrio.

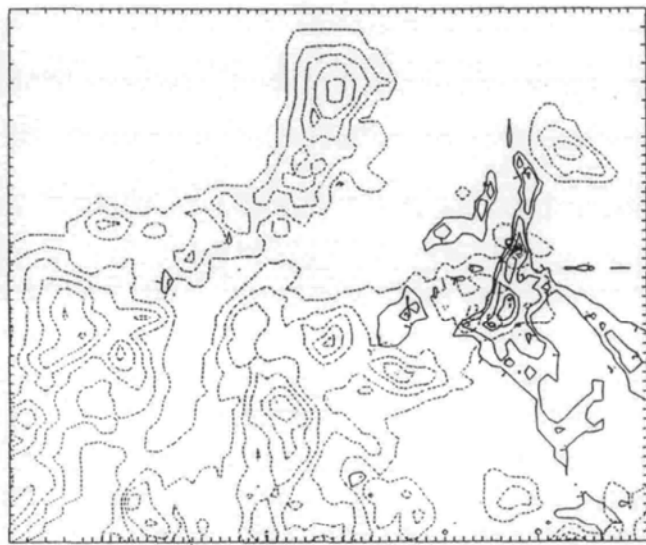


Figure 3 The mean annual concentration ($\mu\text{g}/\text{m}^3$) of NO_x estimated for the power plant at Lavrio.

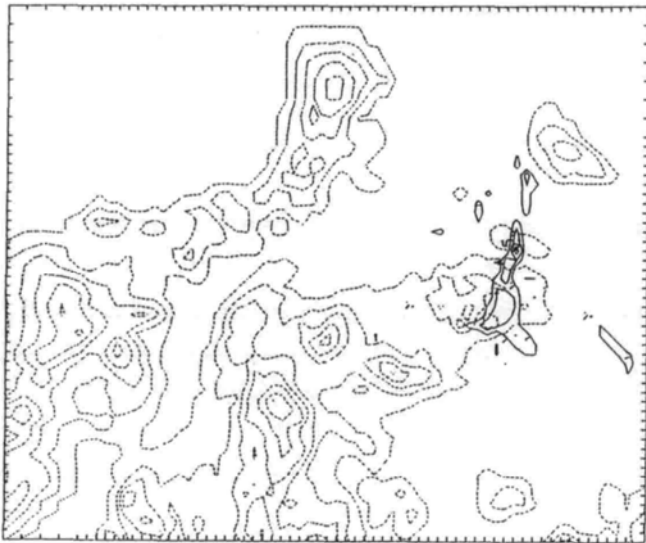


Figure 4 The mean annual concentrations ($\mu\text{g}/\text{m}^3$) of TSP estimated for the power plant at Lavrio.

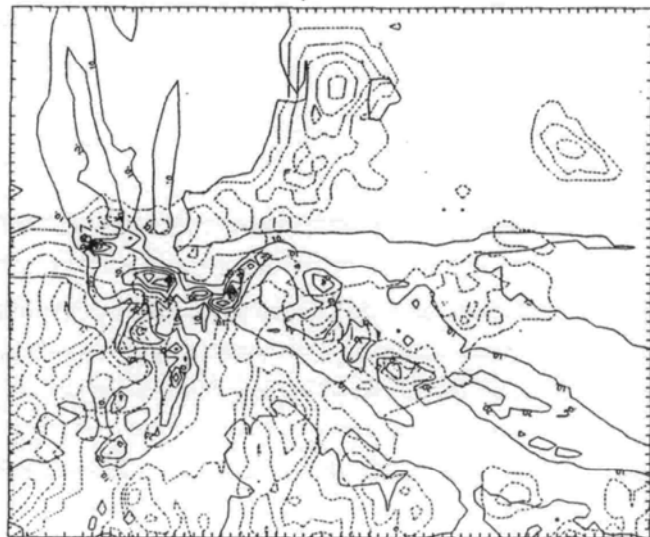


Figure 5 The mean annual concentrations ($\mu\text{g}/\text{m}^3$) of SO_2 estimated for the power plant at Aliveri.

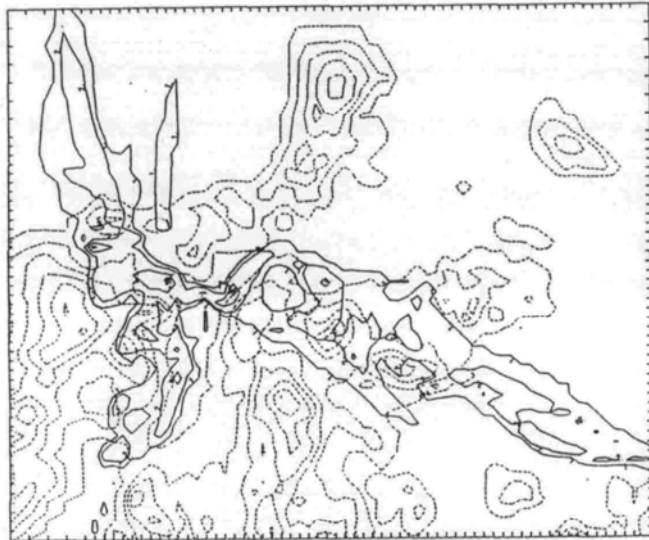


Figure 6 The mean annual concentrations ($\mu\text{g}/\text{m}^3$) of NO_x estimated for the power plant at Aliveri.

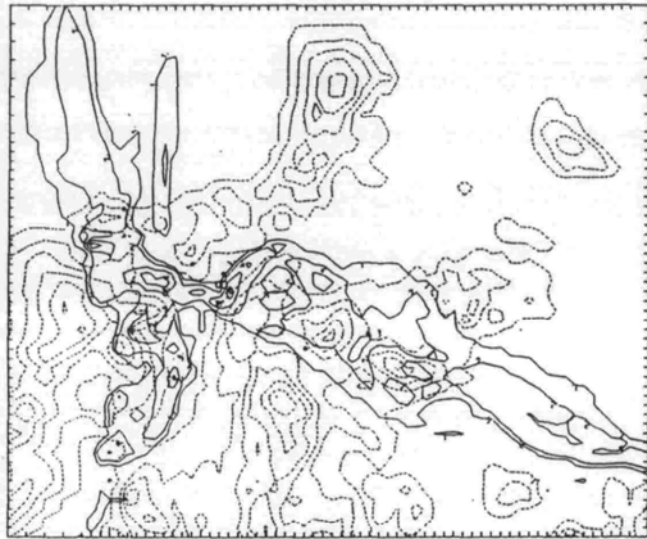


Figure 7 The mean annual concentrations ($\mu\text{g}/\text{m}^3$) of TSP estimated for the power plant at Aliveri.

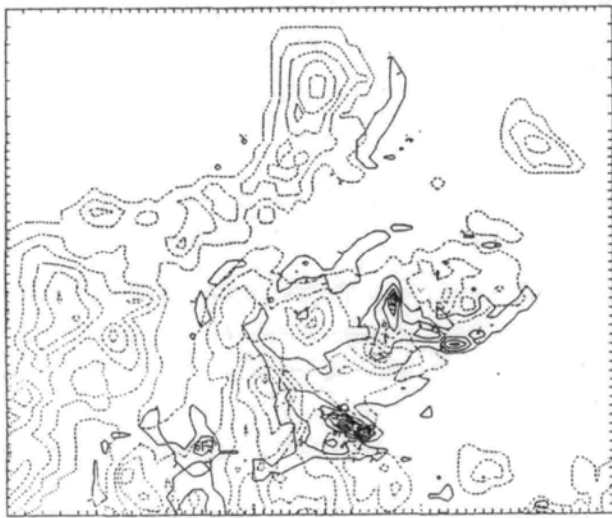


Figure 8 The mean annual concentrations ($\mu\text{g}/\text{m}^3$) for total SO_2 , NO_x and TSP estimated for a diesel-fired power plant at Keratsini.



Figure 9 The mean annual concentrations ($\mu\text{g}/\text{m}^3$) for total SO_2 , NO_x and TSP estimated for a gas-fired power plant at Keratsini.

4 Conclusions

As has been shown previously, estimated areas of peak concentration are not necessarily near the sources. In general, they tend to be either on slopes of hills or mountains facing the sources or in coastal areas where the plumes travel over the stable marine PBL and are later advected towards the land. Plume impingement is responsible for relatively high annual concentrations, even with strong wind conditions. Fumigation conditions account for peak concentrations near the source.

The methodology presented here is able to identify the areas most affected by the operation of major industrial installations. The practical significance of these results is great because the affected areas are identified within a large area around the source. The same results should be used also for the identification of the positions where a meteorological and air-quality monitoring network must be developed.

As expected, this methodology requires significant computer resources but with the powerful workstations available this is no longer a problem.

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A meteorological database for next-generation dispersion models, and a Lagrangian particle model based on kinematic simulation theory

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Abstract: The database system supports small to regional scale air pollution analysis and dispersion modelling. It provides a three-dimensional and time-dependent description of relevant meteorological scalar and vector quantities, and also trajectories and meteorological input data for commonly used dispersion models for local and regional applications. The data are visualized on a standard PC with software provided. The system contains the following modules: a statistical I/O-analysis, a boundary layer model, a short-term regional-scale forecast model (in preparation), a trajectory processor, a non-hydrostatic meteorological local model and interfaces for a variety of transport and dispersion models. Station data and gridded data are archived. Postprocessors extract archived data and process time series, profiles, sub-regions grid, etc., as required.

The new Lagrangian particle model (LPM) uses kinematic simulation theory. It calculates snapshots of concentrations rather than ensemble mean values. It can also directly provide higher moments of concentrations, $C^n(t)$, and is applicable for odour problems as well.

Keywords: kinematic simulation theory, Lagrangian dispersion modelling, meteorological input for dispersion modelling.

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