COMPARATIVE STUDY OF THE LAND USE CHARACTERISTICS IN THE GREATER ATHENS AREA (GAA) BEFORE AND AFTER 2004

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EXTENDED ABSTRACT

The purpose of the present work is to perform a comparative study of the land use changes in the rapidly developing Attica Peninsula including the Greater Athens Area (GAA) before and after 2004, the year that the Olympic Games took place, as well as of the effect of these changes on the respective pollutant emission profiles. The study of air pollution sources and characteristics is strongly dependent on the knowledge of the land use types as they influence a variety of processes that define air quality the most important one being distribution of emissions. Emission inventories consist of the most important input data that photochemical dispersion models require in order to produce realistic results. In recent years the road network has expanded while intense construction activities contributed on the radical changes of the land use, since urban areas replaced the previously free ones. As a result, a new emission distribution pattern has developed in the GAA, which is of great importance for the local air quality.

The land use data that were used in this study were provided by USGS Global Land Use/Land Cover version 2.0 Database. The data set was derived from 1-km Advanced Very High Resolution Radiometer (AVHRR) data spanning a 12-month period (April 1992- March 1993) and map projection is Lambert Azimuthial Equal Area. The USGS classification system includes 24 land cover categories such as urban land, agricultural land, rangeland, forest land, water, waterland, tundra and snow/ice. The updating process was fulfilled with the help of Google Earth. The area was divided into cells using a spatial resolution of 5x5 km^2 while Lambert Conic Conformal was used. Each cell was checked separately and correction of the LULC category was made when it was necessary. During the inventory process the methodology used was that of USGS as described in USGC Geological Survey Professional Paper 964. According to this paper, the LULC category that was finally adopted to a cell when multiple uses of land were recognized was the one that had he most coverage, with the exception of the *urban or built-up* category which took advantage over others.

Results showed that the urban grid has expanded considerably the past fifteen years while a great shift of population has been made to the eastern area of Attica (Mesogia Plain). Areas covered by low vegetation in the past are now replaced by roads, agriculture or country residences. Also, new towns were created while others expanded and many factories moved from the center of the city of Athens. Moreover, the forest land has decreased considerably in the Attica Peninsula either by continuous and extended fires or by the residential burst.

As a consequence, the concentrations of air pollutants by human activities increased and a new emission field has evolved in the Mesogia Plain (eastern Attica).

KEYWORDS: Land cover, Emission inventory, Athens.

1. INTRODUCTION

The Greater Athens Area (GAA) being the largest conurbation of Greece suffers from poor air quality due to the combination of its complex topography and high volume of traffic, industrial units, central heating, construction works and other activities. Over the past decades a great number of researchers have studied both numerically and experimentally the air pollution characteristics of the GAA, (Astitha and Kallos, 2008; Bossioli et al 2007; Martilli et al., 2003; Moussiopoulos et al., 2000). The study of air pollution sources and characteristics is strongly dependent on the knowledge of the land use types as they influence a variety of processes that define air quality, the most important one being distribution of emissions (F.-Y. Cheng et.al., 2008). Photochemical models require updated, high resolution Land Use Land Cover data (LULC). The main source for the development of reliable LULCdata is with the use of satellite imaging (M.S. Feldman et.al., 2007) which can also be used in order to update existing data.

The purpose of this study is thus to update the land use profile of the Greater Athens Area, including parts of Boeotia, NE Peloponnesus and Evvoia, with the help of a satellite imaging. The new LULC maps were introduced to the photochemical model CAMx in order to quantify the contribution of these changes on the emission patterns.

2. PHOTOCHEMICAL MODEL DESCRIPTION

The Comprehensive Air Quality Model with extensions, CAMx is a photochemical model. It simulates the emission, dispersion chemical reaction and removal of pollutants in the troposphere by solving the pollutant continuity equation for each chemical species on a system of nested three dimensional grids (CAMx v.4.40 Users Guide). The continuity equation is "solved" in time over a series of time steps. At each step, the continuity equation is replaced by a splitting method that calculates the contribution of each process (emission, dispersion, chemical reaction and removal) to the change of each cell's concentration which is then carried at the center of each cell volume. Eleven land use categories are used to describe surface characteristics, one for each cell (table 1). Default surface roughness values are assigned to each category by season.

Table 1. CAMx LULC Categories

	CAMx Landcover Classes
1.	Urban
2.	Agriculture
3.	Rangeland
4.	Deciduous forest
5.	Coniferous forest
6.	Mixed forest
7.	Water
8.	Barren land
9.	Non-forested wetlands
10.	Mixed agriculture and range
11.	Rocky

3. METHODOLOGY

3.1. Model configuration

The photochemical model CAMx v. 4.40 ran with the grid nesting method using two grids. The first one (parent domain) covered South and Central Europe, Turkey and N. Africa (fig.1) having a spatial resolution of 15x15 km^2 (200x160 cells), while the second grid (inner domain) had finer resolution of 5x5 km^2 (29x29 cells) and covered the GAA, Boeotia, part of NE Peloponnesus and NE Evvoia island (fig.2).

The simulation period started at 00.00 (UTC) on June 17th, 2006 and ended at 24.00 (UTC) on June 19th, 2006 with the first 2 days used as a spin-up period. The mild synoptic

conditions that occurred during the above period favored the development of a local circulation system (sea-breeze) which resulted in high air pollution concentrations in the Attica peninsula.
The meteorological fields (temperature, wind, pressure, water vapor, cloud/rain) used in CAMx were produced by the mesoscale meteorological model MM5. Their temporal resolution was 120 minutes for the master grid and 60 minutes for the fine grid while the spatial resolution was the same with the CAMx grids.
Hourly gridded emissions from EMEP Centre were taken for the coarse grid, while for the fine grid an emission inventory dated back to 2000 was initially used. It included hourly emission profiles for pollutants SO_2, NO_x, CO, NH_3, NMVOCs, PM_{10} and $PM_{2.5}$ for all kind of sources (point, line, area) divided in 10 different SNAP-categories (SNAP Level 1).
The CB4 chemical mechanism was used which includes 96 reactions and 37 species (25 state gases and 12 radicals).

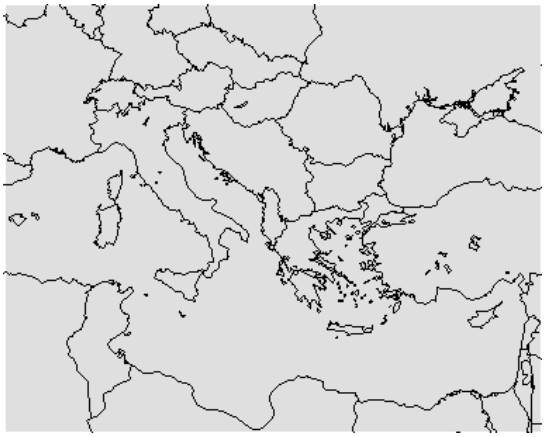


Figure 1.Coarse domain of CAMx

Figure 2. Inner domain of CAMx

3.2. Land use/ Land cover data (LULC)

The LULC data that were used in this study were provided by USGS Global LULC version 2.0 Database. The data set was derived from 1.1 km Advanced Very High Resolution Radiometer (AVHRR) data spanning a 12-month period and map projection is Lambert Azimuthial Equal Area. The USGS classification system includes 24 land cover categories (Table 2). With the help of the meteorological model MM5 these data were transformed in order to have the same spatial resolution with the CAMx grids. The initial landuse field is shown in figure 3.

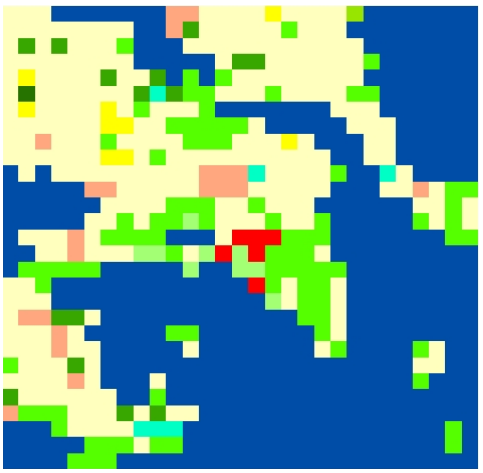


Figure 3. Initial land use field

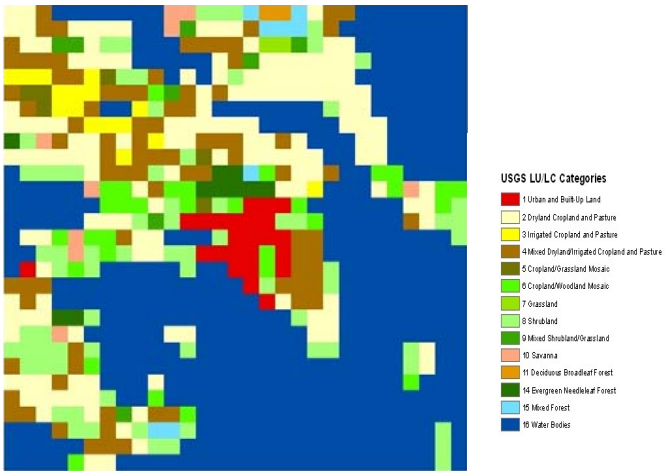


Figure 4. New land use field

The updating process was fulfilled only for the inner grid with help of a satellite image that is freely available on the internet. The area was divided into cells using a spatial resolution of 5x5 km^2 and Lambert Conic Conformal projection was used. Each cell was checked separately and correction of the LULC category was made when it was necessary. During the inventory process the methodology used was that of USGS Geological Survey Professional Paper 964, (www.usgs.gov). According to this paper, the LULC category that was finally adapted to a cell when multiple uses of land were recognized was the one that had the most coverage, with the exception of the built-up category which took advantage over others. The LULC field that was formed after the correction is shown in figure 4. Then the crosschecking of the 24 USGS land use classes to the 11 categories that CAMx uses (table1) was made and a new land use file was then created for the CAMx simulation. Figure 5 shows the new land use field for the 11 categories of CAMx.

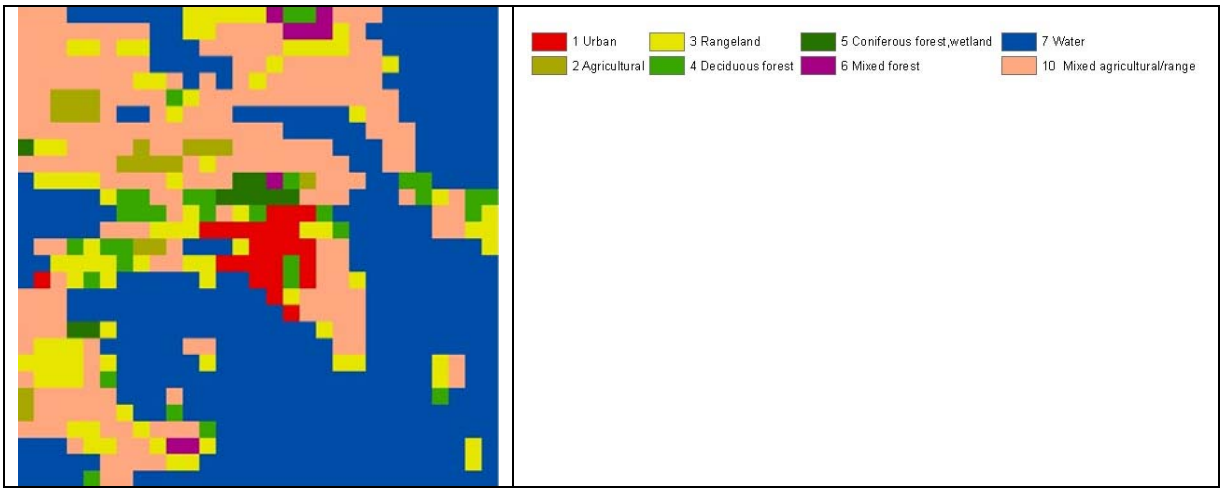


Figure 5. New CAMx land use field

Table 2. USGS LULC Categories

1.	Urban and Built-Up Land (1)*	13.	Evergreen Broadleaf Forest (5)
2.	Dryland Cropland and Pasture (10)	14.	Evergreen Needleleaf Forest (5)
3.	Irrigated Cropland and Pasture (10)	15.	Mixed Forest (6)
4.	Mixed Dryland / Irrigated Cropland and Pasture (10)	16.	Water Bodies (7)
5.	Cropland/Grassland Mosaic (10)	17.	Herbaceous Wetland (9)
6.	Cropland/Woodland Mosaic (4)	18.	Wooded Wetland (5)
7.	Grassland (3)	19.	Barren or Sparsely Vegetated (8)
8.	Shrubland (3)	20.	Herbaceous Tundra (3)
9.	Mixed Shrubland/Grassland (3)	21.	Wooded Tundra (4)
10.	Savanna (3)	22.	Mixed Tundra (6)
11.	Deciduous Broadleaf Forest (4)	23.	Bare Ground Tundra (11)
12.	Deciduous Needleleaf Forest (4)	24.	Snow or Ice (8)

*the CAMx class

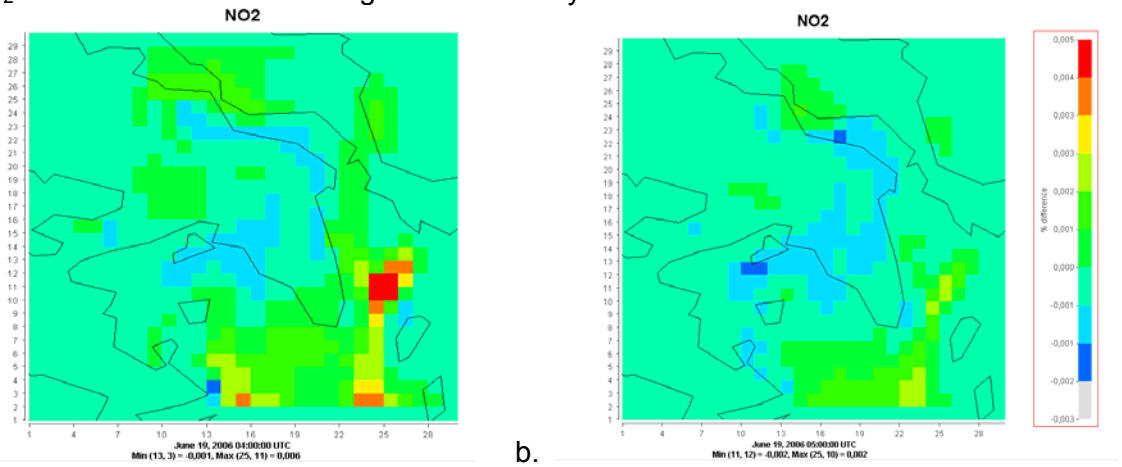
4. RESULTS

After the committing of the Olympic Games 2004 to Athens, many construction works took place that changed the landscape of the Attica peninsula. The road network was expanded (the rebuilt of national road Athinon - Lamias), as new circular roads were made (e.g., Attiki Odos) so as to serve the eastern towns of Attica and the new airport “Eleftherios Venizelos” in Spata. As a consequence, the linear residential developments along these transportation routes have extended (Mesogia Plain).

Moreover, the density of the urban area in the southern (Voula, Vari, Alimos) and eastern (Ilioupolis, Argiroupolis) suburbs of Athens has increased the recent years, so the land use class of these cells changed from 8 (shrub land) to 1 (urban and built-up land).
Many changes have also been made to the relatively open area of the Thriassio Plain. In this part, except for the refineries that existed there for many years, the past 20 years many light industries have moved from the center of Athens. As a result, the landscape of Aspropyrgos is now covered by structures (roads, plants, parking areas) and is characterized as “Industrial Park”.
Not only human activity but also fire has changed the landscape of Attica. In 2007 the fire in Parnitha mountain resulted in the reduction of 2/3 of the forest and as a consequence, the residential land in the hills has increased the recent 5 years. Similar change is seen in Penteli where former forest lands are now covered by shrubs, low vegetation and new housing areas. As can be seen in figures 3 and 4, the percentage of cells that are covered by urban and built-up land has changed from 1% to 3% for the whole daughter domain.
In Boeotia irrigated and mixed irrigated/dry land croplands have expanded because of the increase in need for agricultural products. Thanks to the improvement of the irrigation network in the areas around lake Yliki the agricultural activity is now more organized. Similar increase of the irrigated croplands has been made in Argos.
The CAMx ran for the period of the 17th - 19th of June 2006, with 2 days spin-up period, both with the old and the new land use files. Figures 6, 7 and 8 show the percent difference in the concentrations of pollutants NO, NO_2 and O_3 for the 19th of June 2006. The equation used so as to extract these results is the following:

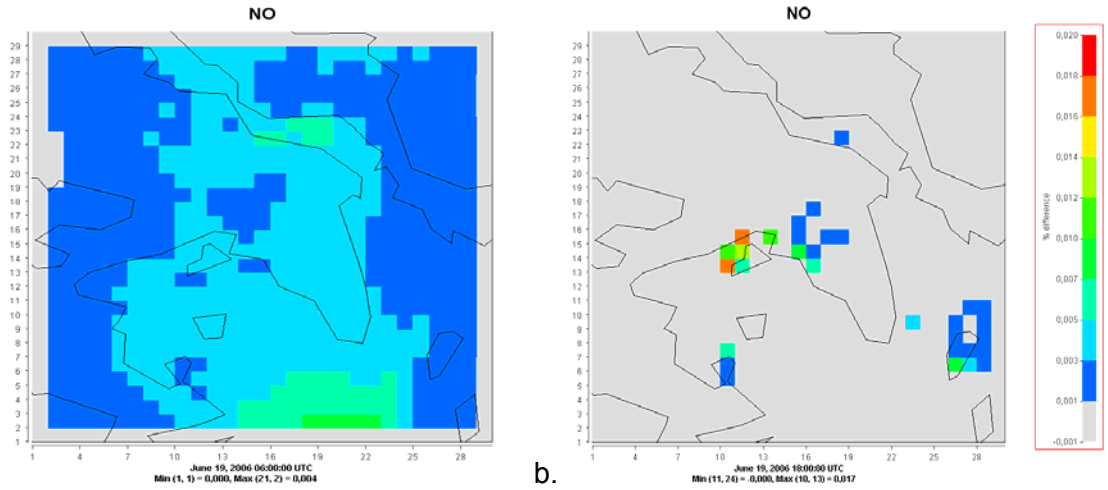
$$([X]1 - [X]2) * 100/([X]2 + .001)$$

where $[X]_1$ is the concentration of the pollutant from the simulation with the old land use field and $[X]_2$ is the concentration from the simulation with the new land use field.
From the figures it becomes evident that the percentage difference in concentration of NO is higher in the morning and evening and for the cells of which land use categories has altered to 1 (urban). These areas are Aspropyrgos, Eleusina and Perama. The change in land use has also affected the concentrations of O_3 which have increased in the above areas and in the eastern suburbs of the GAA. However, the concentrations of NO_2 do not seem to have changed considerably.



a. b.

Figures 6 a.and b. The percent concentrations of NO_2 at 4:00 UTC and 5:00 UTC



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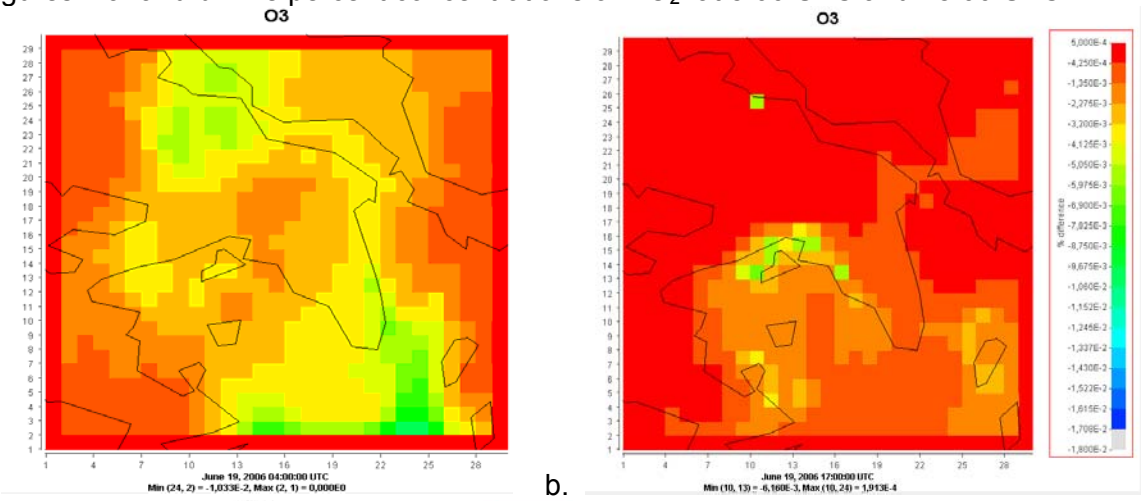
Figures 7 a. and b. The percent concentrations of NO_2 at 5:00 UTC and 18:00 UTC



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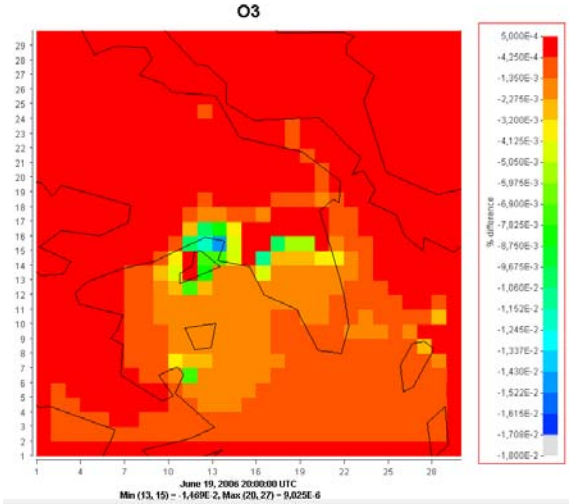

c.

Figures 8 a., b. and c. The percent concentrations of O_3 at 4:00 UTC, 17:00 UTC and 20:00 UTC

5. CONCLUSIONS

Accurate simulation data of the air quality status of the GAA are thought of importance in order to quantify the problem and study the effect of possible measures. However, due to the Athens 2004 Olympic Games the character of the GAA changed drastically in many cases because of large scale constructions works that took place. In this respect, an updated land use map was produced based on satellite imagery data from 2006. The

results of this study indicate that the land use land cover profile of the GAA and its surrounding areas has changed considerably, i.e., the percentage of the urban or built-up land has increased as a consequence of the expansion of the urban grid. New towns were created while others expanded especially in the eastern area of Attica where many constructions took place including the construction of the new Athens International Airport. The road network has expanded and many industries have moved to the Thriassio Plain. Moreover the irrigated croplands have increased in Voiotia. The percentage of land use categories 3 and 4 in the new field is 12% while in the old field was only 1%.

These changes in the land use profile have affected the emission patterns as well as the photochemical pollutants (O_3,NO_2). The most prominent changes are seen in the areas around the Industrial Park and Piraeus, the main port of the GAA. Furthermore, the North and East suburbs of the GAA, where the density of the urban area has increased have also witnessed an increase in both primary and secondary generated pollutants.

REFERENCES

1. *Astitha, M., Kallos, G. 2008: Gas-phase and aerosol chemistry interactions in South Europe and the Mediterranean region, Environmental Fluid Mechanics, pp. 1-20, Article in Press*
2. *Bossioli Elissavet, Maria Tombrou, Aggeliki Dandou, and Nikos Soulakelis, 2007: Simulation of the effects of critical factors on ozone formation and accumulation in the greater Athens area. Journal Of Geophysical Research, vol. 112, D02309.*
3. Cheng, Fang-Yi, Kim, Soontae, Byun, W. Daewon (2008), Application of high resolution land use and land cover data for atmospheric modeling in the Houston-Galveston Metropolitan area : Part II Air quality simulation results, *Atmospheric Environment 42, 4853-4869*
4. Environ, 2006 : *User's Guide to the Comprehensive Air Quality Model with Extensions (CAM_X). Version www.camx.com, www.environcorp.com.*
5. Feldman, M.S., Howard, T., McDonald-Buller, E., Mullins, G., Allen, D.T., Webb, A., Kimura, Y. (2007), Applications of satellite remote sensing data for estimating dry deposition in eastern Texas, *Atmospheric Environment 41, 7562-7576*
6. *Martilli Albetro, Yves- Alain Roulet, Martin Junier, Frank Kirchner, Mathias W. Rotach, Alain Clappier, 2003: On the impact of urban surface exchange parameterisations on air quality simulations: the Athens case. Atmospheric Environment, 37, 4217 – 4231.*
7. *Moussiopoulos N., S. Papagrigoriou, J.G. Bartzis, K. Nester, H. Van den Bergh, G. Theodoridis, 2000: Forecasting air quality in the Greater Athens area for the year 2004: an intercomparison of the results of four different dispersion models. International Journal of Environment and Pollution, 14, 343 – 353.*

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