Atmospheric Research 214 (2018) 329–337

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmosres

A meteorological analysis of PM_{10} episodes at a high altitude city and a low altitude city in central Greece – The impact of wood burning heating devices

Konstantinos Dimitriou*, Pavlos Kassomenos

Laboratory of Meteorology, Department of Physics, University of Ioannina, Greece

ARTICLE INFO

Keywords:
PM_{10}
Wood burning
Saharan dust
Central Greece
Air pollution
PSCF model

ABSTRACT

The financial crisis which struck the Greek economy since 2010 has changed significantly the profile of the country's urban particle emissions mainly due to the use of low cost fuels as wood and biomass products for residential heating. This study analyzed daily PM_{10} concentration measurements and meteorological observations collected throughout 2016 at two medium sized cities in central Greece: Karpenisi and Lamia, aiming to identify the impact of stoves and fireplaces. PM_{10} data were also analyzed along with synoptic conditions and backward air mass trajectories in order to identify atmospheric circulation patterns related to smog episodes in the two cities. Low temperatures were proven to be a key element which was associated with an increment of PM_{10} levels in both cities, however more PM_{10} episodes were observed in the high altitude city of Karpenisi, due to the more intensive wood burning in residential heating devices. Stagnant anticyclonic conditions during cold seasons were associated with the generation of exceedances of the daily PM_{10} limit set by European Union regulations, due to the accumulation of emissions. Dust aerosol intrusions from the Sahara desert were also indicated whilst PM_{10} transportation from northern directions through Balkan Peninsula is also possible.

1. Introduction

The profile of PM_{10} (particles with an aerodynamic diameter smaller than 10 μm) in the ambient air of Greek cities is determined by various sources and factors depending on each region's characteristics. According to Mavroidis and Chaloulakou, 2010, 54% of the PM_{10} fraction in the Athens conurbation is attributable to road traffic, thus the control of traffic-related particle emissions appears to be a principal objective for the confrontation of the PM_{10} pollution problem affecting the area (Grivas et al., 2004). In addition, sea-salt aerosol increases PM_{10} levels in the Athens city center up to 25% during stable onshore winds (Athanasopoulou et al., 2008). On the other hand, PM_{10} samples collected in the industrialized area of Megalopolis City (Southern Greece), located in the vicinity of two lignite fired power plants, showed that soil/road dust re-suspension from opencast mines and unpaved roads, emissions from vehicle exhausts and mining activities, lignite combustion in the lignite-fired power plants and biomass burning, are the main sources of PM_{10} in the air over Megalopolis City (Manousakas et al., 2013). The effect of long range transport of particles is also clearly observed in Greece. More specifically, northern airflows are related to the arrival of exogenous particulate matter, while southwesterly flows appear to contribute in a decisive way in the aerosol burden during Sahara dust events (Katragkou et al., 2009; Dimitriou et al., 2015).

Since 2010, the decline of the Greek economy has influenced significantly the emissions of particles in Greece, primarily due to the use of low cost fuels as wood and biomass products for residential heating (Gaidajis et al., 2014; Fourtziou et al., 2017). The most recent survey from the Hellenic Statistical Authority conducted in 2011–12, reported that the main sources of heating in Greece are: fossil fuel (oil, 64%), biomass (12%), electricity (12%) and natural gas (9%), but 32% of those who use fossil fuel, they also burn wood in fireplaces and stoves (Gratsea et al., 2017). Residential wood burning smog was estimated to comprise up to 50% of PM_{10} concentrations during the intense smog period in Athens (Athanasopoulou et al., 2017), while the results from a two-month intensive aerosol characterization campaign in Athens during wintertime 2013–2014 also indicated that wood burning episodes could be responsible for $PM_{2.5}$ (particles with an aerodynamic diameter smaller than 2.5 μm) concentrations higher than 45 μg/m^3 (Fourtziou et al., 2017). The results of Sarigiannis et al., 2015 showed that PM_1 (particles with an aerodynamic diameter smaller than 1 μm), $PM_{2.5}$ and PM_{10} fractions are higher in Thessaloniki (Greece) during the cold months of the year, mainly due to biomass use for space heating, while polycyclic aromatic hydrocarbons (PAH) and levoglucosan levels were highly correlated, indicating that particles emitted from biomass combustion are more toxic than PM emitted from other sources.

* Corresponding author at: University of Ioannina, GR-45110, Greece.
E-mail address: kdimitriou80@gmail.com (K. Dimitriou).

https://doi.org/10.1016/j.atmosres.2018.08.014
Received 27 June 2018; Received in revised form 18 August 2018; Accepted 19 August 2018
Available online 22 August 2018
0169-8095/

Various former studies in Europe have previously reported the impact of biomass burning on PM emissions. In Baena (Spain), the use of biomass resulting from the olive oil production for residential heating and industry was the most important aerosol source during the winter months (Sánchez de la Campa et al., 2018). Ambient monitoring and dispersion calculation have shown a significant influence of wood combustion for heating on ambient PM_{10} concentrations in Augsburg (Germany) (Brandt et al., 2011) whilst in Portugal, 18% of PM_{10} emissions are due to residential wood combustion, which may deeply impact the PM_{10} levels in the atmosphere (Borrego et al., 2010). Biomass burning contributions vary widely, from 14 to 24% of PM_{10} in Porto, Milan and Florence, 7% in Athens, to < 2% in Barcelona, due to the degree of penetration of biomass for residential heating (Amato et al., 2016). In Tuscany (central Italy), biomass burning accounted for 37% of the mass of PM_{10} as annual average, and > 50% during winter due to the domestic heating source, being the main cause of all the PM_{10} episodes (Nava et al., 2015). Finally, the findings of Krecl et al., 2008 revealed that residential wood combustion is an important source of PM_{10} (36–82%) and PM_1 (31–83%) in the town of Lycksele (Northern Sweden) in the winter season.

This work is focused to the possible impacts of wood burning for heating on particle related air quality. For this purpose we have studied the PM_{10} levels in two cities of central Greece, located in significantly different altitudes, in conjunction with atmospheric circulation. The combination of synoptic patterns, backward air mass trajectories, daily PM_{10} concentrations and meteorological parameters, composed a multilevel approach on the reasons which lead to PM_{10} episodes in central Greece.

2. Data and methodology

2.1. Air pollution and meteorological data

In 2016 the administration of the region of central Greece activated five urban background PM_{10} monitoring stations in five medium sized cities of central Greece namely Lamia, Halkida, Livadia, Amfissa and Karpenisi. For the needs of this paper, daily PM_{10} concentrations of the year 2016 in Karpenisi and Lamia were downloaded from the website of the Greek Ministry of Environment and Energy (www.ypeka.gr). Karpenisi is located at a mountainous and forested area (Fig. 1) at an altitude of 960 m Above Sea Level (ASL) and has a total population of approximately 10,000 people, whilst the longitude and latitude of the PM_{10} sampler are 21.79^0 and 38.91^0 respectively. Contrariwise, Lamia is a much larger city which incorporates about 50,000 inhabitants and is located at an altitude of only 84 m ASL (Fig. 1). The exact longitude and latitude of the air pollution monitoring station in Lamia are 22.43^0 and 38.90^0 respectively.

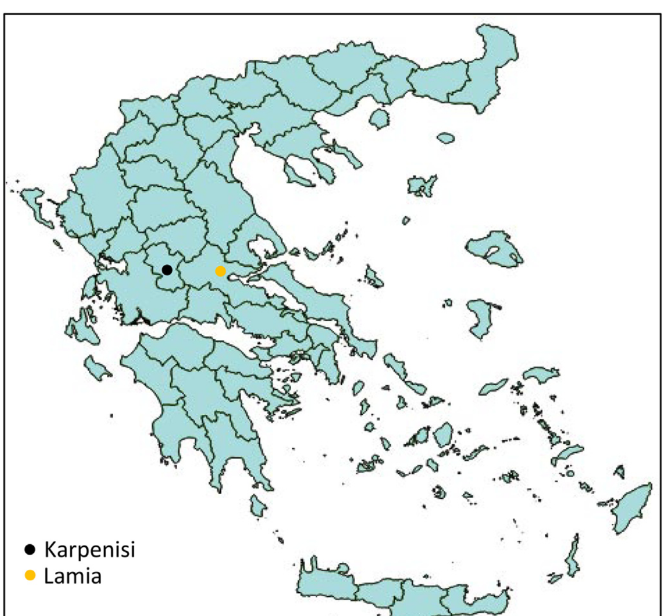

Fig. 1. The location of Karpenisi and Lamia on the Map of Greece.

Average daily temperature (°C) and wind speed (km/h) data were also obtained by two meteorological stations which belong in the network of the National Observatory of Athens (www.noa.gr). The station which was used for Karpenisi is situated in a hotel located 7 km outside the city's center whereas the station of Lamia is hosted in a school located to the eastern part of the city. Both meteorological stations are set on the ground, their temperature sensors are placed at 2 m Above Ground Level (AGL) while the anemometers are placed at 4 m and 5 m AGL at Karpenisi and Lamia respectively.

2.2. Methodology

2.2.1. Determination of atmospheric circulation patterns

To identify types of atmospheric circulation related to increased PM_{10} concentrations in Karpenisi and Lamia and reveal possible differences among the two cities a K-Means cluster analysis (Dafis et al., 2015; Kaskaoutis et al., 2014) was applied on gridded ($2.5^0 \times 2.5^0$) daily Sea Level Pressure (SLP) data from the NCEP/NCAR (National Centers for Environmental Prediction/National Center for Atmospheric Research) Reanalysis dataset (Kalnay et al., 1996) of the National Oceanic and Atmospheric Administration (NOAA) (http://www.noaa.gov). The produced mean synoptic maps for all clusters covered the area extending from 10^0W - 60°E and 20^0N - 60^0N. Daily PM_{10} concentrations and meteorological parameters had to be available at both cities in all days included in the cluster analysis method therefore only 348 days out of the 366 days of 2016 were finally used. In all clusters, the likelihood of occurrence of daily PM_{10} episodes was calculated. Daily PM_{10} episodes were defined by daily PM_{10} concentrations exceeding the daily European Union (EU) limit of 50 μg/m^3 (Directive 2008/50/EC).

2.2.2. Analysis of PM_{10} episodes with backward air mass trajectories

In order to further analyze those synoptic clusters which were characterized by increased PM_{10} concentrations and enhanced likelihood of aerosol episodes at each city, Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model of NOAA (Rolph et al., 2017; Stein et al., 2015) was used to generate 3-day (72 h) backward air mass trajectories arriving at the two cities at 500 m AGL. For each day contained in those crucial clusters, 24 trajectories reaching the receptor site from 00:00 UTC - 23:00 UTC were produced. Hourly trajectory points provided by HYSPLIT model were then allocated in a $0.5^0 \times 0.5^0$ resolution grid, covering the area from 30^0W – 60°E and 20^0N – 60^0N, and were inserted in the Potential Source Contribution Function (PSCF) model (Eq. 1) which has also been used in previous publications (Karaca et al., 2009; Polissar et al., 2001; Kong et al., 2013).

$$PSCF_{ij} = \frac{m_{ij}}{n_{ij}} \tag{1}$$

In Eq. (1), n_{ij} is the total number of trajectory points included in the ijth cell and m_{ij} is the number of trajectory points in the ijth cell which correspond to days with exceedances of the daily PM_{10} EU limit. Thus PSCF values in ij grid cells range from 0 to 1, reflecting the likelihood of occurrence of daily PM_{10} episodes at the studied area, after the approaching air masses have crossed specific grid cells. Therefore, by the implementation of PSCF model, potential regional and transboundary aerosol sources are more efficiently isolated.

However, due to the very low number of trajectory points comprised in some highly distant grid cells, possible extremely elevated PSCF