Science of the Total Environment 502 (2015) 493–501

Contents lists available at ScienceDirect

Science of the Total Environment

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

Three year study of tropospheric ozone with back trajectories at a metropolitan and a medium scale urban area in Greece

Konstantinos Dimitriou *, Pavlos Kassomenos

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

HIGHLIGHTS

- Athens metropolis emerges as an important O_3 generating area.
- SW sea-breeze flows exports O_3 towards northern suburbs of Athens.
- Potential regional O_3 sources affecting Athens and Ioannina are depicted.

ARTICLE INFO

Article history:
Received 21 August 2014
Received in revised form 22 September 2014
Accepted 22 September 2014
Available online xxxx

Editor: D. Barcelo

Keywords:
Ozone
Air mass trajectories
Conditional probability function
Potential source contribution function
Athens
Ioannina

ABSTRACT

Three years of hourly O_3 concentration measurements from a metropolitan and a medium scale urban area in Greece: Athens and Ioannina respectively, were analyzed in conjunction with hourly wind speed/direction data and air mass trajectories, aiming to reveal local and regional contributions respectively. Conditional Probability Function was used to indicate associations among distinct wind directions and extreme O_3 episodes. Backward trajectory clusters were elaborated by Potential Source Contribution Function on a grid of a 0.5° × 0.5° resolution, in order to localize potential exogenous sources of O_3 and its precursors. In Athens, an increased likelihood of extreme O_3 events at the Northern suburbs was associated with the influence of SSW–SW sea breeze from Saronikos Gulf, due to O_3 transportation from the city center. In Ioannina, the impacts of O_3 conveyance from the city center to the suburban monitoring site were weaker. Potential O_3 transboundary sources for Athens were mainly localized over Balkan Peninsula, Greece and the Aegean Sea. Potential Source Contribution Function hotspots were isolated over the industrialized area of Ptolemaida basin and above the region of Thessaloniki. Potential regional O_3 sources for Ioannina were indicated across northern Greece and Balkan Peninsula, whereas peak Potential Source Contribution Function values were particularly observed over the urban area of Sofia in Bulgaria. The implemented methods, revealed local and potential transboundary source areas of O_3, influencing Athens and Ioannina. Differences among the two cities were highlighted and the role of topography was emerged. These findings can be used in order to reduce the emission of O_3 precursors.

1. Introduction

Tropospheric ozone (O_3) is a photochemical air pollutant which is not directly emitted in the atmosphere and thus, the ecological problems related to O_3 formation from complex chemical reactions, can't be easily solved (Kolev et al, 2011). Many recent papers worldwide, have connected increased O_3 levels with elevated mortality and morbidity (Heal et al, 2013; Bell et al, 2005), primarily due to cardio-respiratory causes (Qiu et al, 2013; Hsieh and Liao, 2013). Particularly in Greece, where this paper is focused, associations among outdoor O_3 air pollution and adverse health effects have emerged from various publications (Karakatsani et al, 2010; Samoli et al, 2011). Health impacts from O_3 human exposure in Greece are also amplified during summer, due to the combination of O_3 maxima with excessive heat stress (Theoharatos et al, 2010).

The dependence of monitored O_3 levels from wind speed/direction conditions, due to short range transport, is highlighted in multiple studies (Nzotungicimpaye et al, 2014; Singla et al, 2012; Sousa et al, 2011; Permadi and Oanh, 2008; Khan et al, 2007; Tu et al, 2007). The accumulation of tropospheric O_3, due to wind blowing from specific directions, can also be determined by the use of Conditional Probability Function [CPF] (Bae et al, 2011; Masiol et al, 2014). Specifically for the case of Athens (Greece), 34 ozone pollution events within the 2000–2003 period, were associated with the prevalence of variable weak winds (Hatzianastassiou et al, 2007). In addition, it was deduced that due to sea-breeze, higher ozone concentrations are recorded to the southern and northern parts of

* Corresponding author at: Konstantinos Dimitriou, University of Ioannina, GR-45110, Greece. Tel.: +30 6976117441.
E-mail address: kdimitriou80@gmail.com (K. Dimitriou).

http://dx.doi.org/10.1016/j.scitotenv.2014.09.072

Table 1
Characteristics of the Environmental (ENVI) and Meteorological (METE) monitoring stations in Athens and Ioannina.

City	Station name (EU code)	Type	Area	Longitude/latitude		Altitude (AMSL)[a]
Athens	Agia Paraskevi (GR0039A)	ENVI-background	Suburban	23.82°	38.00°	290 m
	National Observatory of Athens	METE	Urban	23.71°	37.97°	107 m
Ioannina	Ioannina (GR0230A)	ENVI-background	Suburban	20.85°	39.65°	485 m
	University of Ioannina	METE	Suburban	20.85°	39.62°	475 m

[a] AMSL: Above Mean Sea Level.

the Athens basin (Flocas et al, 2003), whereas day-to-day O_3 accumulation is measured at the northern stations (Mavrakou et al, 2012).

Summertime tropospheric O_3 is preserved in the atmosphere for several days (Saavedra et al, 2012), hence air mass trajectories are used in numerous new publications, in order to assess the probability of long range transport contributions in O_3 episodes (Villanueva et al, 2014; Sharma et al, 2013; Saavedra et al, 2012; Bytnerowicz et al, 2013; Prtenjak et al, 2013). All these papers associated distinct atmospheric pathways with the intrusion of polluted air masses in the studied areas. Potential Source Contribution Function (PSCF) is a widely applied tool for the localization of regional air pollution sources (Dimitriou and Kassomenos, 2014a; Karaca et al, 2009; Polissar et al, 2001; Bae et al, 2011). Choi et al (2011) used the PSCF, in order to locate regional sources of O_3 precursors, influencing photochemical reactivity in Busan (Korea). Several Chinese industrial zones were identified by PSCF as O_3 potential source areas, affecting Bright Summit of Mountain Huang in SE China (Zhang et al, 2013).

In this paper, O_3 levels in a metropolitan (Athens) and a medium sized urban area (Ioannina) in Greece, located at the East and West side of Pindos mountain range respectively, were studied in order to determine local and regional contributions. Three years of hourly data were analyzed. CPF was implemented in order to signify the direction of local O_3 precursor emissions. The calculation of PSCF on a grid of $0.5° \times 0.5°$ resolution was used to localize potential transboundary O_3 sources. The different impacts of the two cities were emerged, whereas the role of topography was highlighted. The findings of this paper complement the existing bibliography on photochemical air pollution in Eastern Mediterranean and can be used for the determination of emission reduction policies.

2. Data and methodology

2.1. Data and measurement sites

Athens and Ioannina are two Greek cities with different geographical and socio-economical characteristics:

- Athens is the capital city of Greece with a total population of approximately 4 million inhabitants and is located in the region of Attica in central Greece. The Athens basin is formed by the mountains of Hymettus (E), Penteli (NNE) and Parnitha (NNW), whereas the city's Southern front is open to the sea (Pateraki et al, 2014). Hourly data of tropospheric O_3 concentrations, extending through the three year time interval 2009–2011, were obtained from Agia Paraskevi (GR0039A) suburban background station (Table 1), located NE of Athens city center at the foothills of mount Hymettus (Kassomenos et al, 2014). Hourly wind speed and wind direction data were provided by the meteorological station of the National Observatory of Athens (NOA), situated on the Pnyx Hill near the city center. The completeness of the O_3 and wind hourly datasets is 96.9% and 100% respectively.
- The medium sized city of Ioannina is localized in the region of Epirus in NW Greece and has a total population of 120,000 people. The city is situated on a plateau of a 500 m AMSL average altitude, extending around the west coast of Lake Pamvotis. Mountain Mitsikeli is located to the E–NE of the town (Koletsis et al, 2009). Hourly O_3 concentrations within the period 2009–2011 were recorded from Ioannina (GR0230A) suburban background station (Table 1), situated at the SW edge of the city. Hourly wind speed and wind direction data were obtained by the meteorological station of University of Ioannina (UOI), sited in the University Campus. The completeness of the O_3 and wind hourly datasets is 77.8% and 99.7% respectively.

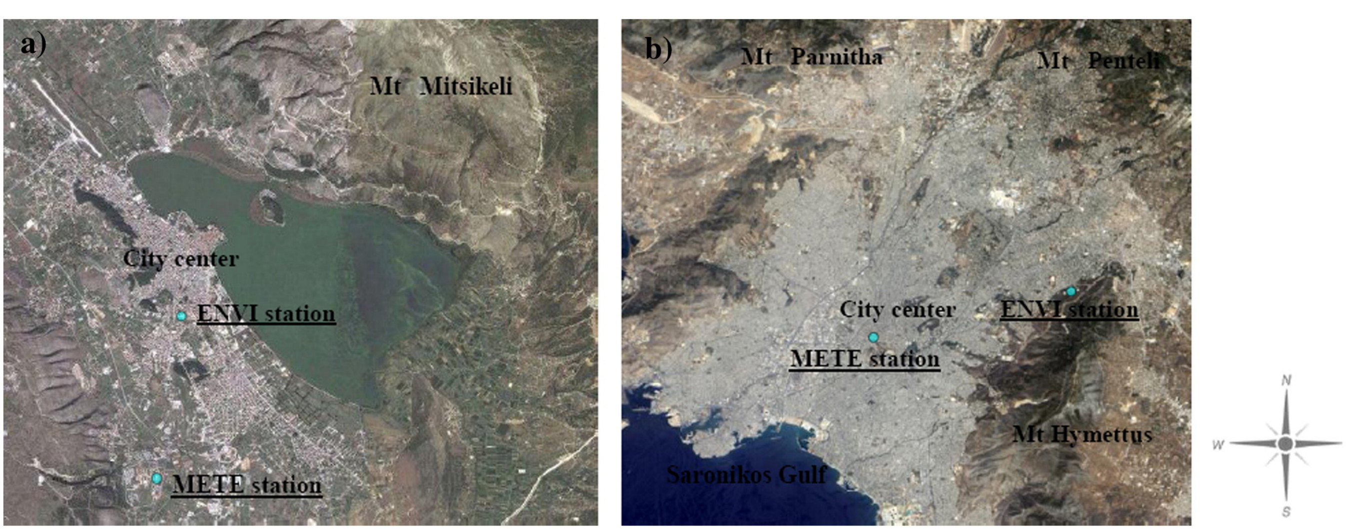

Fig. 1. Maps of a) Ioannina and b) Athens. Blue dots highlight the positions of Environmental (ENVI) and Meteorological (METE) stations. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)