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Air quality and thermal comfort levels under extreme hot weather

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ABSTRACT

Meteorological (T and RH values) and air pollution data (PM_{10}, NO_2 and O_3 concentrations) observed in Athens, Thessaloniki and Volos were analyzed to assess the air quality and the thermal comfort conditions and to study their synergy, when extreme hot weather prevailed in Greece during the period 2001–2010. The identification of a heat wave day was based on the suggestion made by the IPCC to define an extreme weather event. According to it, a heat wave day is detected when the daily maximum hourly temperature value exceeds its 90th percentile. This temperature criterion was applied to the data recorded at the cities center. Air quality was assessed at three sites in Athens (city center, near the city center, suburb), at two sites in Thessaloniki (city center, suburb) and at one site in Volos (city center), while thermal comfort conditions were assessed at the cities center. Mean pollution levels during the heat wave days and the non-heat wave days were calculated in order to examine the impact of the extreme hot weather on air quality. For this purpose, the distributions of the common air quality index and the exceedances of the air quality standards in force during the heat wave days and the non-heat wave days were also studied. Additionally, the variation of the daily maximum hourly value of Thom's discomfort index was studied in order to investigate the effect of extreme hot weather on people's thermal comfort. Moreover, the values of the common air quality index and Thom's discomfort index were comparatively assessed so as to investigate their synergy under extreme hot weather.

1. Introduction

Heat waves (HWs) induce various health, environmental, societal, and economic impacts. García-Herrera et al. (2010) discussed thoroughly the multiple impacts of the HW that occurred in Western and central Europe during the first half of August 2003. They stated that by far the most important impact was the excessive elderly mortality recorded in several countries across Europe. Other impacts included forest fires, increased pollution, loss of livestock and wilted crops. They also underlined the significant economic losses and societal consequences related to these impacts. Smoyer-Tomic et al. (2003) identified the effects of HWs on various sectors of Canadian life including agriculture, livestock, fisheries, construction, transportation, utilities, the environment, and human health. Heat stress has been linked to excess human mortality and illness, violent behavior, drought, forest fires, tornadoes, decreased agricultural and livestock productivity, construction and transportation difficulties, and reduced electrical power supply. Xu et al. (2012) reviewed the impacts of ambient temperature on another vulnerable

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group, namely the children. They stated that during HWs, the incidences of renal disease, fever and electrolyte imbalance among children increase significantly. Matzarakis and Nastos (2011) pointed out that the occurrence of a HW could lead to higher energy consumption and consequently to higher emissions of greenhouse gases, as a result of the increased need for cooling. Ciais et al. (2005) estimated a 30% reduction in the hourly fluxes of photosynthesis over Europe during 2003. They suggested that productivity reduction in Eastern and Western Europe can be explained by rainfall deficit and extreme summer heat, respectively. Koutsias et al. (2013) analyzed historical fire records and meteorological observations for the period 1894–2010 and found that fire occurrence was strongly related to the occurrence of summer HWs.

This study focuses on one of the HW impacts mentioned above, namely the degradation of the air quality. Struzewska and Kaminski (2008) studied the severe HW that affected Central and North-Eastern Europe in the first two weeks of July 2006 and found that the formation and transport of photooxidants may be favored during HWs. Theoharatos et al. (2010) found that air quality was poor during the HWs that occurred in Athens, Greece, in June and July 2007. Air pollution results from the combination of high emissions and unfavorable weather. Higher temperatures and irradiance result in enhanced biogenic VOC emission and more intensive photochemical processes which increase O_3 formation (Sillman and Samson, 1995). Mues et al. (2012) analyzed measurements of the EMEP network in Europe of the summer 2003 and found that the correlation between PM_{10} concentrations and meteorological parameters indicated that observed concentrations increased during weather conditions with high daily maximum temperature. Additionally, pollution levels can be further increased if atmospheric conditions that favor the accumulation of pollutants prevail during a HW (Tressol et al., 2008). Stagnation of air masses allows the accumulation of pollutants in the atmospheric boundary layer and in the residual layer during the night (Solberg et al., 2008). Moreover, high ambient temperatures support the production of secondary aerosols. Mangold et al. (2011) stated that the conditions of high temperatures and stagnation that prevailed during the summer HW in Europe in August 2003 favored photochemistry and secondary aerosol formation.

The combination of high pollution levels and high temperatures has been implicated to increase health risks. These conditions can trigger adverse health effects especially to the more vulnerable groups that include individuals suffering from cardiovascular or respiratory diseases and the elderly (Stafoggia et al, 2006). Many studies have verified that HWs trigger a mortality increase. Some of the deaths attributed to high temperatures are probably caused by photochemical and particulate air pollution, combined or not with high temperatures. Fischer et al. (2004) showed that 400–600 deaths occurred during the 2003 HW in the Netherlands could be attributed to O_3 and PM_{10} exposure. Fouillet et al. (2006) found that the excess risk of deaths linked to O_3 and temperature together during the August 2003 HW in France ranged from 10.6% in Le Havre to 174.7% in Paris. Stafoggia et al. (2008) estimated that a 10 $\mu g/m^3$ increase in PM_{10} concentration results in a 2.54% and 0.20% rise in risk of death in summer and winter, respectively.

The combination of high pollution levels and high temperatures has also been implicated to increase the intensity of urban heat island (UHI). An UHI develops in the three Greek cities which are studied in this paper. Giannaros et al. (2013) applied the Weather Research and Forecasting model coupled with the Noah land surface model over the city of Athens during two hot July days in 2009 and found that the city of Athens exhibits higher air temperatures than its surroundings during the night (>4 °C), whereas the temperature contrast is less evident in early morning and mid-day hours. Giannopoulou et al. (2011) analyzed the data from 25 fixed temperature stations placed in the major Athens area observed during the summer of 2009 and found that the UHI presented intensity up to 5 °C. Papanastasiou and Kittas (2012) studied the UHI intensity in Volos during the summer of 2010 and found that the maximum temperature difference between the city center and a suburb during summer was 3.1 °C, while the average maximum UHI intensity was 2.0 °C. Giannaros and Melas (2012) investigated the UHI in Thessaloniki by analyzing near surface temperature data measured at 7 sites in the greater Thessaloniki area for 1-year period (March 2008–February 2009) and found that the maximum UHI intensity ranged from 2 °C to 4 °C during the warm part of the year. They also found that the UHI had a negative impact on thermal comfort on most of the observed occasions. Poupkou et al. (2011) found that in Thessaloniki during the summer season, the poor air quality and the unfavorable comfort conditions for the majority of the population in the city center were associated with the greater frequency of a more intense UHI effect.

The interaction between air pollution and high temperatures is of great importance for the public health. Not only because of the combined adverse health effects mentioned above but also because of the fact that sensitive individuals stressed by high temperatures may respond to lower levels of air pollutants than otherwise (Katsouyanni et al., 1993; Katsouyanni, 1995). A few studies have addressed this issue (Poupkou et al., 2011) and as little is yet known about the synergetic effects of extreme heat conditions, air pollution, and other environmental factors, further research is needed (Matzarakis and Nastos, 2011). Also, countries located in the southern Europe are appropriate for the study of the synergy between air pollutants and high temperatures.

The objectives of this paper are to assess the air quality and thermal comfort levels and to examine the link between air quality and discomfort under extreme hot weather. For this purpose, air pollution and meteorological data observed in Athens, Thessaloniki and Volos, Greece, during the HWs that occurred during the summers of a 10-year period (2001–2010) were analyzed.

2. Materials and methods

2.1. Data

Air pollution data (O_3, NO_2, PM_{10}) recorded at Athens, Thessaloniki and Volos during the summers of the period 2001–2010 were used in this study. O_3 concentration was monitored at Marousi (MAR), Lykovrisi (LYK) and Panorama (PAO) stations, NO_2 concentration was monitored at Aristotelous (ARI), Agia Sofia (AGS), MAR, LYK and PAO stations, while PM_{10} concentration was monitored at ARI, AGS, MAR, LYK, PAO and Volos (VOL) stations. ARI, AGS and VOL stations are located at the center of Athens, Thessaloniki and Volos, respectively, MAR is