Seasonal Forecasts, Climatic Change and Human Health

Madeleine C. Thomson • Ricardo Garcia-Herrera
Martin Beniston
Editors

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Madeleine C. Thomson
International Research Institute
for Climate and Society
Columbia University
LDEO, Palisades
New York 10964
USA

Ricardo Garcia-Herrera
Departamento Fisica de la Terra II
Facultad de Ciencias Fiscas
Universidad Complutense de Madrid
Ciudad Universitaria 28040
Madrid, Spain

Martin Beniston
University of Geneva
Site de Battelle/D7 chemin de Drize
CH-1227 Carouge
Geneva, Switzerland

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Madeleine C. Thomson
Ricardo Garcia-Herrera

Contents

Contributors

Bas Amelung
International Centre for Integrative Studies, University of Maastricht

Joan L. Aron
Science Communication Studies, Columbia, MA 21045, USA

Martin Beniston
University of Geneva, Climate Change and Climate Impact – Battelle, Building D, 7 route de Drize, CH 1227 Carouge, Switzerland

Laurent Braak
MEDES, Toulouse, France

Eliane Coëffier
Institut Pasteur, Paris, France

Stephen J. Connor
International Research Institute for Climate and Society, The Earth Institute at Columbia University, Lamont Campus, Palisades, NY 10964-8000, USA

Luis E. Cuevas
Liverpool School of Tropical Medicine, Pembroke Place, Liverpool, L3 5QA UK

Antonio Güell
CNES, Toulouse, France

C. Anthony Hart
Department of Medical Microbiology and GU Medicine, University of Liverpool, Liverpool, UK

Chris D. Hewitt
Met Office, Hadley Centre for Climate Prediction and Research, Fitzroy Road, Exeter EX1 3PB, UK

Christian Hogrefe
State University of New York, Albany, NY, USA

Louise Kelly-Hope
Liverpool School of Tropical Medicine, Pembroke Place, Liverpool, L3 5QA UK

Patrick Kinney
Department of Environmental Health Sciences, Mailman School of Public Health, Columbia University, New York, USA

Jean Pierre Lacaux
MEDIAS-France, 18 Avenue Edouard Belin, B.P. 2102, FR-31401 Toulouse Cedex 9, France

Barry Lynn
Goddard Institute for Space Studies, New York, USA

Gilma C. Mantilla
National Institute of Health, Ministry of Social Protection, Bogota, Colombia

Simon J. Mason
International Research Institute for Climate and Society, The Earth Institute at Columbia University, Lamont Campus, Palisades, NY 10964-8000, USA

Andreas Matzarakis
Meteorological Institute, University of Freiburg, Freiburg, Germany

Panagiotis Th. Nastos
Laboratory of Climatology and Atmospheric Environment, University of Athens, Greece

Joyce Rosenthal
Graduate School of Architecture, Planning & Preservation, Columbia University, New York, USA

Cynthia Rozenzweig
Goddard Institute for Space Studies, New York, USA

Daniel Ruiz
Escuela de Ingeniería de Antioquia, Calle 25Sur No. 42–73, Envigado, Antioquia, Colombia

Philippe Sabatier
INRA/Veterinary School of Lyon, France

Madeleine C. Thomson
International Research Institute for Climate and Society, The Earth Institute at Columbia University, Lamont Campus, Palisades, NY 10964-8000, USA

Yves M. Tourre
MEDIAS-France, 18 Avenue Edouard Belin, B.P. 2102, FR-31401 Toulouse Cedex 9, France

Chapter 10
Weather, Ambient Air Pollution and Bronchial Asthma in Athens, Greece

Panagiotis Th. Nastos

Abstract The associations between various meteorological parameters, concentrations of PM_{10}, SO_2, and O_3 pollutants and bronchial asthma of residents of the wider region of Athens are examined in this study. For this purpose, 1,288 patients' admissions (412 males and 876 females) recorded in 13 pneumonological clinics of Sotiria Hospital, which is the major Hospital for respiratory diseases in Athens, were analyzed for the period 1/1/2001–31/12/2002. The meteorological data were available by the National Observatory of Athens and the concentrations of PM_{10}, SO_2, and O_3 pollutants were obtained by the air pollution network of 10 stations of the Ministry of Environment (Directorate of Air and Noise pollution Control).

The evaluation of the possible relationship between the bronchial asthma admissions (BAA) and the meteorological variables was achieved by the application of Generalized Linear Models with Poisson distribution, because the medical dataset presents large divergence from a Gaussian distribution. The results showed that a statistically significant ($p<0.01$) negative correlation between all examined air temperature variables, water vapor pressure, evaporation, sunshine, total solar irradiance, and BAA exists. Moreover, the findings of the analysis showed that a statistically significant relationship between the examined pollutants and BAA on the same day does not exist, with the exception of O_3, which is correlated negatively ($p<0.01$) with BAA. Nevertheless, there is a statistically significant lag effect (7–8 days) between the increase in BAA and the peak in the concentrations of PM_{10}, SO_2, and O_3 pollutants. During the cold period of the year (October–April), BAA is significantly associated with O_3 lag 2 day.

The interannual variation of bronchial asthma admissions (BAA) reveals peaks within the transitional seasons of the year (spring and autumn), while the main minimum is apparent during summer period and especially in August.

Keywords Weather variability, ambient airpollution, bronchial asthma, Generalized Linear Models, Athens, Greece

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Laboratory of Climatology and Atmospheric Environment, University of Athens, Greece

10.1 Introduction

The influence of weather conditions and air pollution on health is a major focus of research. IPCC (Technical Summary, 2001) highlights that global climate change will have various impacts on human health; some of which are positive, but mostly negative. Changes in the frequencies of extreme heat and cold, the frequencies of floods and droughts, and the profile of local air pollution and aeroallergens would directly affect population health.

Increased bronchial asthma admissions (BAA) is associated with low air temperature (Greenburg et al. 1966; Yuksel et al. 1996; Grech et al. 2002; Bartzokas et al. 2003). Altitude and the annual variation of temperature and relative humidity outdoors were negatively associated with asthma symptoms (Weiland et al. 2004). Admissions to emergency room for asthma count were negatively correlated with ambient temperature and strong wind existence on previous days. They were also positively correlated with ambient relative humidity (Berktas and Bircan 2003). Hashimoto et al. (2004) suggest that childhood asthma increases when climate conditions show a rapid decrease from higher barometric pressure, from higher air temperature and from higher humidity, as well as lower wind speed while the presence of mist and fog causes the exacerbation of asthma in children (Kashiwabara et al. 2002). Furthermore, a study by Goldstein (1980) showed that almost every asthma epidemic in both New Orleans and New York City was preceded by the passage of a cold front (by 1–3 days) followed by a high pressure system.

Several recent studies have reported associations between ambient pollutants and BAA (Bascom 1996; Delfino et al. 1997; Jaffe et al. 2003; Trasande and Thurston 2005). More specifically, Dockery and Pope (1994) have found 3.4% increase in emergency department visits for asthmatics per 10 $\mu g/m^3$ PM_{10} and 1.9% increase in hospital admissions for asthmatic attacks per 10 $\mu g/m^3$ PM_{10}, while the daily counts of emergency room visits were significantly associated with PM_{10} exposure on the previous day (Schwartz et al. 1993) or on the previous 3 days (Galán et al. 2003). Besides, Walters et al. (1994) showed that during winter a rise of 100 $\mu g/m^3$ in SO_2 might result in four more asthma admissions each day, for residents of Birmingham. With respect to ozone, positive and statistically significant associations were found between hospital respiratory admissions and both ozone recorded on the day of admission and up to 3 days prior to the date of admission (Burnett et al. 1994; Galán et al. 2003). On the contrary, many researchers did not find any significant associations between ambient ozone concentrations and doctor asthma visits (Jalaludin et al. 2004; Braun-Fahrlander et al. 1992; Hoek and Brunekreef 1995; Ostro et al. 1999).

The goal of this study is to examine whether an association between BAA, meteorological variables and the concentrations of SO_2, O_3 and PM_{10} pollutants could be observed in Athens.

10.2 Data and Analysis

The medical dataset analyzed consists of 1,288 patients' admissions recorded in 13 pneumonological clinics of Sotiria Hospital, which is the major hospital for respiratory diseases in Athens, were analyzed for the period 1/1/2001–31/12/2002. The age distribution of the patients is depicted in Fig. 10.1.

The children and the adolescents comprise the minority of the recorded patients while the elderly people (age >70 years) dominate in the upper level of the BAA. Therefore, there is a remarkable plateau in the age distribution regarding the registered patients with age from 20 to 70 years. The number of females are twofold the number of males within each age class after 40 years. There has not been found any reason for this evidence, possibly it is due to females' sensitivity and modern way of living. The meteorological data were available by the National Observatory of Athens and concern daily values of:

– Mean Air Temperature (T_{mean}, °C)
– Day-to-Day Change of Mean Air Temperature (ΔT_{mean}, °C)
– Maximum Air Temperature (T_{max}, °C)
– Day-to-Day Change of Maximum Air Temperature (ΔT_{max}, °C)
– Minimum Air Temperature (T_{min}, °C)
– Day-to-Day Change of Minimum Air Temperature (ΔT_{min}, °C)
– Diurnal Air temperature Range (T_{range}, °C)
– Day-to-Day Change of Diurnal Air temperature Range (ΔT_{range}, °C)
– Mean Water Vapor Pressure (e, mm Hg)
– Day-to-Day Change of Mean Water Vapor Pressure (Δe, mm Hg)

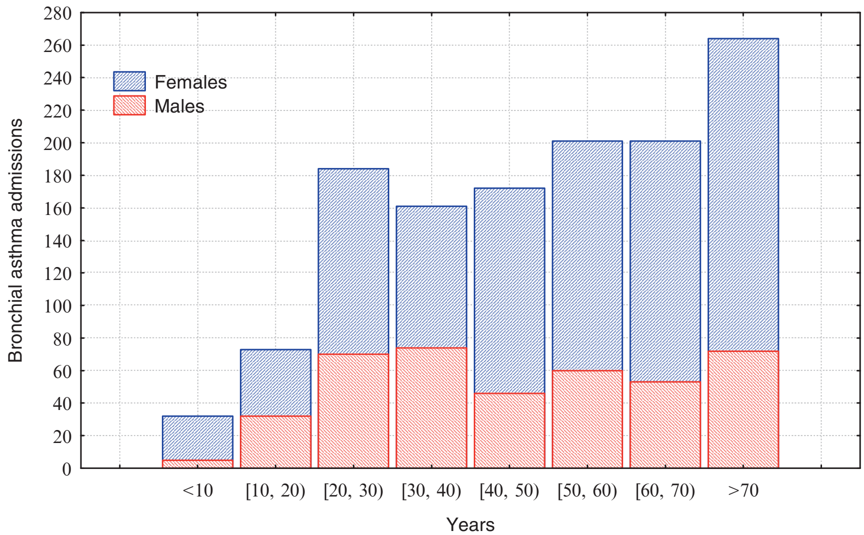

Fig. 10.1 Age distribution of the patients with bronchial asthma in Athens

- Mean Atmospheric Pressure (P, hPa)
- Day-to-Day Change of Mean Atmospheric Pressure (ΔP, hPa)
- Total Evaporation (E, mm)
- Day-to-Day Change of Total Evaporation (ΔE, mm)
- Total Sunshine (S, h)
- Day-to-Day Change of Total Sunshine (ΔS, h)
- Mean Total Solar Irradiance (I, W m^{-2})
- Day-to-Day Change of Mean Total Solar Irradiance (ΔI, W m^{-2})

The air pollution data measured by the air pollution network of 10 stations of the Ministry of Environment (Directorate of Air and Noise pollution Control) include daily values of:

- Mean Concentration of Particulate Matter diameter <10 μm ($PM_{10\,mean}$, μg m^{-3})
- Day-to-Day Change of Mean Concentration of Particulate Matter diameter <10 μm ($\Delta PM_{10\,mean}$, μg m^{-3})
- Maximum Concentration of Particulate Matter diameter <10 μm ($PM_{10\,max}$, μg m^{-3})
- Day-to-Day Change of Maximum Concentration of Particulate Matter diameter <10 μm ($\Delta PM_{10\,max}$, μg m^{-3})
- Mean Concentration of Sulphur Dioxide ($SO_{2\,mean}$, μg m^{-3})
- Day-to-Day Change of Mean Concentration of Sulphur Dioxide ($\Delta SO_{2\,mean}$, μg m^{-3})
- Maximum Concentration of Sulphur Dioxide ($SO_{2\,max}$, μg m^{-3})
- Day-to-Day Change of Maximum Concentration of Sulphur Dioxide ($SO_{2\,max}$, μg m^{-3})
- Mean Concentration of Ozone ($O_{3\,mean}$, μg m^{-3})
- Day-to-Day Change of Mean Concentration of Ozone ($\Delta O_{3\,mean}$, μg m^{-3})
- Maximum Concentration of Ozone ($O_{3\,max}$, μg m^{-3})
- Day-to-Day Change of Maximum Concentration of Ozone ($\Delta O_{3\,max}$, μg m^{-3})

In order to determine the relationship between the admissions of BAA and the aforementioned meteorological and ambient air pollution variables, Generalized Linear Models (GLM), described by McGullagh and Nelder (1997), were applied. The class of models known as Generalized Linear Models, or GLMs, was formally introduced by Nedler and Wedderburn (1972). The components of a GLM are as follows:

- The aim is to model the distribution of a stochastic response variable, *y*, in terms of stimulus variables $x_1, x_2, \ldots, x_p$, or known mathematical functions of them.
- The distribution of y depends on the stimulus variables through a single *linear predictor*: $\sum_{j=1}^{p} x_j \beta_j$ where, in general, the x_j,*s* are known mathematical function functions of the stimulus variables, not necessarily simply the variables themselves.
- The mean of *y* is related to *n* by a known function called the *link* function: $E[y] = m = l^{-1}(n)$, $n = l(m)$.

Note that the link function transforms the mean into the linear predictor and not the other way round. Hence it acts in the same direction as a transformation of the response itself, from which the idea arose.

– The variance of y is a function of the mean: Var[y] = $\varphi\upsilon(\mu)/A$ where φ is a possibly unknown, positive *scale parameter*, A is a known *prior weight*, and $\upsilon(\mu)$ is a known function of μ called the *variance function*.
– The distribution of y has a density of known form, namely

$$f_Y(y;\mu,\varphi)=\exp\left[\frac{A}{\phi}\{y\theta(\mu)-\gamma(\theta(\mu))\}+\tau\left(y,\frac{\phi}{A}\right)\right]$$

This distributional form can be shown to include the normal, gamma, Poisson and binomial distributions, as well as several others such as beta, inverse Gaussian and negative binomial. Note that the relationship between the canonical parameter θ, and the mean, μ, will depend on the particular distribution, and the relationship between μ and n is defined by the link function. The link function establishes the connection between the linear predictor, n, and the mean of the distribution μ. There is a ‘natural link’ for each distribution. It is important to note that although the link function is in some way similar to a transformation function, it only establishes a mathematical connection between the mean and the response variables. A transformation function when applied to observations may be intended to simplify the connection between the mean and the response variables. It may also achieve other goals such as to stabilize the variance. The natural link for the Poisson distribution is the log link: $n = log(\mu)$, $\mu = e^n$, the variance function is $\upsilon(\mu) = \mu$ and as in the case of the binomial distribution, the scale parameter is 1. Poisson models with log links are often called *log-linear models* and are used for frequency data.

The evaluation of the possible relationships between meteorological parameters, concentrations of PM_{10}, SO2, O_3 pollutants and BAA was achieved by the application of Generalized Linear Models with Poisson distribution, because the medical dataset presents large divergence from a Gaussian distribution. In the models fitting procedure the dependent variable was the daily totals of the BAA, filed by the Hospital and the independent covariates were the aforementioned meteorological parameters and ambient air pollutants. Models’ goodness-of-fit was evaluated through deviance residuals (McGullagh and Nelder 1997).

10.3 Results and Discussion

Table 10.1 depicts the mean and maximum daily values of the pollutants’ concentrations and the meteorological parameters examined. With respect to the Air Quality Guidelines of the World Health Organization (WHO2000) [Ozone: 120 μg/m^3 per 8 h, SO_2: 125 μg/m^3 per 24 h and 50 μg/m^3 per year, PM_{10}: no guideline values were set for particulate matter because there is no evident threshold for effects on morbidity and mortality], there were some days with exceeding values for ozone, mainly during the summer time. This is mainly due to the geographical location and to the climatological conditions (high sunshine and air temperature favor the O_3 formation). Nevertheless, the national threshold for undertaking extraordinary measures (360 μg/m^3 in 1 h) was not exceeded in any station of the network.

According to the WHO and national thresholds for the pollutants, there are no exceedances for the SO_2 concentrations during the examined period, in any station of the network. There is an important decrease trend of the SO_2 concentrations, which is associated with the reduction of the sulfur content in diesel petroleum since 2000. The particulate matter PM_{10} is one of the new pollutants, which began to be measured recently in the European Union, and constitute an important problem for the majority of the countries, especially the southern ones of the European Union. This pollutant is considered being at high levels. The national threshold is 70 μg/m^3 averaged over 24 h and for 35 days within the year. The mean daily PM_{10} concentrations of all the stations of the air pollution network exceeded the national threshold for 186 days during the 2 examined years.

Furthermore, the Environmental Protection Agency (EPA) uses its Air Quality Index (EPA 2006) to provide general information to the public about air quality and associated health effects. An Air Quality Index (AQI) of 100 for PM_{10} corresponds to a PM_{10} level of 150 μg/m^3 averaged over 24 h, and people with respiratory disease, such as asthma, should limit outdoor exertion.

The annual evolution of the pollutants concentrations is illustrated in Fig. 10.2. The primary pollutant SO_2 show high values during the cold period of the year, and this is mainly due to central heating of the buildings, while O_3 presents high concentrations during summer time, because of the increased sunshine and high air

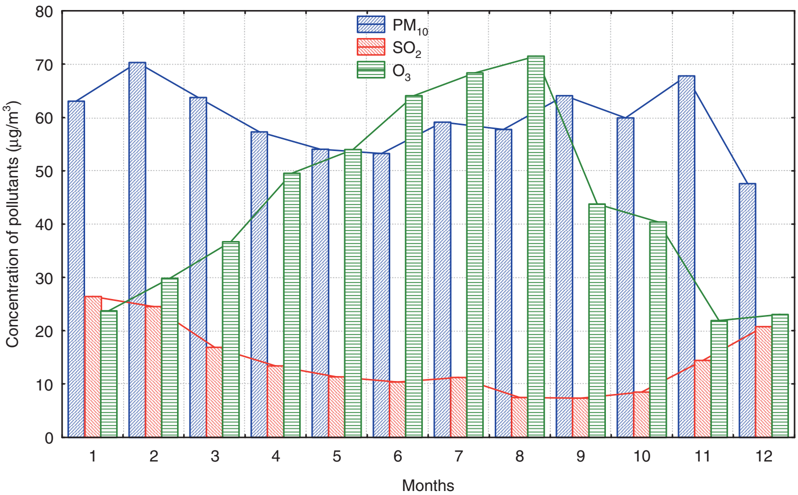

Fig. 10.2 Mean annual evolution of the pollutants concentrations, for the period 2001–2002, in Athens

temperature, which play a determinative role in the photochemical procedures. Particulate matter includes both solid particles and liquid droplets found in air and many man-made and natural sources produce PM_{10} directly or emit other pollutants that react in the atmosphere to form PM_{10}. There is no remarkable seasonal variation because the sources emitted PM_{10} exist all over the year.

The Generalized Linear Models were applied individually to every considered variable, in such a way that the dependent variable, within the constructed univariate model, was the daily totals of the BAA and the independent variable was each meteorological or pollutant variable.

The results (Table 10.2) showed that a statistically significant ($p < 0.01$) negative correlation exists between all examined air temperature parameters, water vapor pressure, evaporation, sunshine, total solar irradiance, and BAA (shaded parameters in Table 10.2). No statistically significant correlations exist between the BAA and the day-to-day changes of the meteorological parameters. More specifically, on the same day, a decrease of 10 units in daily mean, maximum and minimum air temperature, diurnal air temperature range, mean water vapor pressure, total evaporation, total sunshine and total solar irradiance links to an increase 14%, 12%, 16%, 19%, 26%, 38%, 18% and 0.9% of the probability having BAA, respectively. These results are in agreement with the findings of other researchers (Yuksel et al. 1996; Grech et al. 2002; Berktas and Bircan 2003; Hashimoto et al. 2004; Hajat et al. 2004).

A brief description of the prevailing synoptic conditions in Greece is considered useful, in order to understand the covariability of the meteorological parameters examined and their effect to BAA. During the cold period of the year (October–April)

Table 10.1 Mean and maximum daily values for PM_{10}, SO2, O_3, and meteorological variables in Athens for the period 1/1/2001–31/12/2002

Meteorological parameters	Mean daily values	Maximum daily values	Air pollutants	Mean daily values	Maximum daily values
T_{mean} (°C)	19.2 ± 7.4	34.1	$PM_{10\ mean}$ (μg/m^3)	59.75 ± 23.32	171.96
ΔT_{mean} (°C)	0.0 ± 1.6	5.6	$\Delta PM_{10\ mean}$ (μg/m^3)	0.01 ± 20.88	95.45
T_{max} (°C)	23.9 ± 8.4	40.2	PM_{10max} (μg/m^3)	128.14 ± 61.08	521.75
ΔT_{max} (°C)	0.0 ± 2.3	7.7	ΔPM_{10max} (μg/m^3)	−0.04 ± 61.93	458.50
T_{min} (°C)	15.6 ± 6.8	29.3	$SO_{2\ mean}$ (μg/m^3)	14.34 ± 9.56	64.76
ΔT_{min} (°C)	0.0 ± 1.7	7.4	$\Delta SO_{2\ mean}$ (μg/m^3)	0.03 ± 6.96	29.45
T_{range} (°C)	8.3 ± 2.6	17.0	SO_{2max} (μg/m^3)	35.81 ± 26.16	151.29
ΔT_{range} (°C)	0.0 ± 2.3	7.9	ΔSO_{2max} (μg/m^3)	0.03 ± 24.22	98.87
e (mm Hg)	10.2 ± 3.4	18.6	$O_{3\ mean}$ (μg/m^3)	44.00 ± 21.05	97.60
Δe (mm Hg)	0.0 ± 1.5	5.6	$\Delta O_{3\ mean}$ (μg/m^3)	−0.02 ± 11.77	53.78
P (hPa)	1,003.1 ± 5.6	1,021.3	O_{3max} (μg/m^3)	83.69 ± 32.01	210.00
ΔP (hPa)	0.0 ± 3.5	12.1	ΔO_{3max} (μg/m^3)	−0.01 ± 19.58	81.17
E (mm)	3.2 ± 2.1	10.0	–	–	–
ΔE (mm)	0.0 ± 1.0	3.4	–	–	–
S (h)	8.0 ± 4.3	14.1	–	–	–
ΔS (h)	0.0 ± 3.5	10.7	–	–	–
I (W m^{-2})	188.2 ± 94.2	352.0	–	–	–
ΔI (W m^{-2})	0.1 ± 51.4	193.0	–	–	–

northern winds prevail in Greece because of the existence of anticyclones over Europe and Siberia and low barometric pressure over Mediterranean Sea. The blow of these winds is interrupted by the blow of southern winds due to passage of troughs in Mediterranean Sea and Europe. Polar continental air masses cover frequently the whole the country, producing a cold regime, which combines low air

Table 10.2 Results of the application of Generalized Linear Models (GLM) with Poisson distribution (dependent variable is the daily number of outpatients with bronchial asthma, while independent covariate is each one of the aforementioned meteorological parameters and the ambient air pollutants). The shaded parameters indicate statistically significant relationships with BAA

Meteorological parameters	b coefficient ± standard error	Significance level *p*	Ambient air pollutants	b coefficient ± standard error	Significance level *p*
T_{mean} (°C)	−0.0153 ± 0.0039	0.000092	$PM_{10\,mean}$ (μg m^{-3})	0.0005 ± 0.0012	0.697836
ΔT_{mean} (°C)	−0.0064 ± 0.0167	0.701445	$\Delta PM_{10\,mean}$ (μg m^{-3})	0.0001 ± 0.0013	0.947794
T_{max} (°C)	−0.0131 ± 0.0034	0.000138	$PM_{10\,max}$ (μg m^{-3})	0.0001 ± 0.0005	0.892464
ΔT_{max} (°C)	−0.0042 ± 0.0118	0.724132	$\Delta PM_{10\,max}$ (μg m^{-3})	−0.0001 ± 0.0004	0.885435
T_{min} (°C)	−0.0169 ± 0.0043	0.000080	$SO_{2\,mean}$ (μg m^{-3})	0.0040 ± 0.0029	0.165814
ΔT_{min} (°C)	−0.0076 ± 0.0157	0.626525	$\Delta SO_{2\,mean}$ (μg m^{-3})	−0.0015 ± 0.0042	0.720442
T_{range} (°C)	−0.0213 ± 0.0108	0.049104	$SO_{2\,max}$ (μg m^{-3})	0.0012 ± 0.0010	0.261381
ΔT_{range} (°C)	0.0002 ± 0.0122	0.989784	$\Delta SO_{2\,max}$ (μg m^{-3})	−0.0012 ± 0.0012	0.295670
e (mm Hg)	−0.0302 ± 0.0083	0.000263	$O_{3\,mean}$ (μg m^{-3})	−0.0036 ± 0.0014	0.008275
Δe (mm Hg)	0.0162 ± 0.0186	0.382841	$\Delta O_{3\,mean}$ (μg m^{-3})	−0.0019 ± 0.0024	0.427757
P (hPa)	0.0036 ± 0.0050	0.467488	$O_{3\,max}$ (μg m^{-3})	−0.0033 ± 0.0009	0.000354
ΔP (hPa)	−0.0038 ± 0.0076	0.620220	$\Delta O_{3\,max}$ (μg m^{-3})	−0.0021 ± 0.0015	0.164866
E (mm)	−0.0479 ± 0.0138	0.000525			
ΔE (mm)	−0.0253 ± 0.0277	0.361491			
S (h)	−0.0194 ± 0.0062	0.001839			
ΔS (h)	−0.0055 ± 0.0076	0.471294			
I (W m^{-2})	−0.0009 ± 0.0003	0.003225			
ΔI (W m^{-2})	−0.0006 ± 0.0005	0.239556			

temperature, low vapor pressure and evaporation and short duration of sunshine. These weather conditions seem to be responsible for worsening the BAA.

The prevailing weather type during warm period of the year (May–September) is that of Etesians winds (periodical winds of the north section). This type is established in Greece, when a North Atlantic anticyclone extends over Europe covering the Balkans simultaneously with the Indian low over Asia Minor and the Eastern Mediterranean Sea. The blow of Etesians winds transfers polar continental air masses to Northern Greece and the result is the appearance of precipitation and frontal thunderstorms. Another effect of the Etesians regime is the summer drought and the uniform weather conditions in Greece. More specifically, the weather is identified by high air temperature, high absolute humidity and evaporation, high total solar radiation and sunshine (Karalis 1969; Kotinis-Zambakas 1983).

Regarding the effect of the aforementioned pollutants on BAA on the same day, the findings of the analysis showed that a statistically significant relationship between these pollutants and BAA does not exist, with the exception of O_3, which is correlated negatively ($p<0.01$) with asthma. One reason for the lack of effects between air pollution and BAA may be the low levels of ambient air pollution measured within the studied period, which ranged between low to medium levels. Another possible explanation is the public response to early warnings by the local authorities once the concentrations of the pollutants cross a particular threshold. People respond to this alert by decreasing their exposure to outdoor air pollution (or increasing their avoidance behavior), and this leads to fewer hospitalizations than would have otherwise occurred. Jalaludin et al. (2004) came to the same conclusions, studying acute effects of urban ambient air pollution on BAA in a cohort of Australian children. They found no association between ambient ozone concentrations and BAA, but there was, however, an association between PM_{10} concentrations and BAA. Also, in another study conducted in Finland where ambient air pollution levels were similarly low, Timonen and Pekkanen (1997) did not remark any consistent associations between PM_{10}, NO_2 and SO_2 concentrations and respiratory symptoms in a group of children with asthma or cough. Furthermore, even in conditions with high levels of PM_{10} and O_3, Hoek and Brunekreef (1995) did not find a positive association between these pollutants and respiratory symptoms. None the less, epidemiological and clinical studies have shown that O_3 exposure is associated with worsening of athletic performance, reductions in lung function, shortness of breath, chest pain with deep inhalation, wheezing and coughing, and asthma exacerbations among those with asthma (Bates and Caton 2002).

Taking into account the clear seasonality of the O_3 concentrations within the year, with peak during the warm period (Fig. 10.2), an investigation of a possible relationship between O_3 concentrations and BAA, only during the cold periods of the years examined, is performed. As it is mentioned before the prevailing synoptic conditions do not favour the incidence of ozone episodes, but there are some spells with high sunshine and high air temperature. The results of the GLM application pointed out a statistically significant positive relationship between BAA and O_3 lag 2 day. More concretely, an increase of 10 $\mu g/m^3$ in daily mean concentrations is associated with an increase 5% of the probability of having BAA ($p=0.04$).

This evidence shows that even low to medium concentrations of O_3 are responsible for worsening BAA. No relationships were found between the other examined pollutants (PM_{10}, SO_2) and BAA, during the cold period of the year. The investigation for possible relationships within the warm period of the year results in no evidence of significant correlations between BAA and all the pollutants.

The age distribution of the patients manifests that the most vulnerable are the elderly people (age > 70 years), so the application of Logistic analysis, taking into account the WHO thresholds of the pollutants, is considered the most appropriate to reveal relative risks. Regarding SO_2 threshold (125 μgr/m^3), no relative risk was found, but PM_{10} exceedances of the threshold of 70 μgr/m^3 seems to double the risk (odds ratio = 1.70, 95% CI 1.20–2.40, significant level = 0.003) of observing the daily number of outpatients at age 70 years and older compared to all others. Relevant results were extracted for the O_3 concentrations above 120 μgr/m^3 (odds ratio = 1.70, 95% CI 1.01–2.89, significant level = 0.048).

In the process, the delays between pollutants maxima and BAA were examined with the following results (statistically significant at $p = 0.05$): we found that BAA were lagged on PM_{10}, SO_2 and O_3 by 7–8 days. An increase of 10 μgr/m^3 on lagged daily mean PM_{10} concentrations is associated with an increase of 3% for BAA, while an increase of 10 μg/m^3 on lagged daily mean SO_2 concentrations links to an increase of 9% for BAA. As far as the O_3 concentrations are concerned, an increase of 10 μg/m^3 on lagged daily mean O_3 concentrations is associated with a decrease of 4% for BAA and vice versa. As it is mentioned before, ambient ozone is not a primary pollutant and is positively correlated to sunshine and air temperature, climatic factors that play a determinative role in the photochemical procedures. Besides, decreases of BAA are significantly associated to increases in air temperature. Consequently, ambient ozone is negatively associated to BAA. Gratziou et al. (2001), investigating the relationship between ambient air pollution and respiratory health in children, found that 7-day mean of PM_{10} was associated with upper respiratory symptoms, while Neuberger et al. (2004), observed an increase of respiratory diseases after a lag of 10–11 days of $PM_{2.5}$, in Vienna, Austria. Besides, a lag of up to 5 days for asthma visits is associated with an increased risk from exposure to air pollution (Lipfert 1993; US EPA 1996).

A more descriptive analysis is shown in Figs. 10.3–10.5 where the relative frequency (%) of the BAA per 10-Days Intervals as a function of the minimum air temperature and the water vapor pressure percentiles (Fig. 10.3), the atmospheric pressure and sunshine percentiles (Fig. 10.4) and the PM_{10}, SO_2 and O_3 percentiles (Fig. 10.5), along with the variation of the total number of admissions per 10-Days Intervals (yellow line) and the polynomial fitting (brown line) are depicted. The stacked bars shown in each interval represent the percentages of BAA associated with the particular parameters' percentiles. This section is considered useful to demonstrate in a more tangible way the impact of the percentiles distribution of the meteorological and air pollution variables to the total counts of BAA for the whole study period, within 10-Days Intervals. For instance, it is clear from Fig. 10.5 that even in cold periods of the examined years the so rarely appeared maximum values of O_3 seem to exacerbate BAA. The construction of the stacked bar for the 3rd

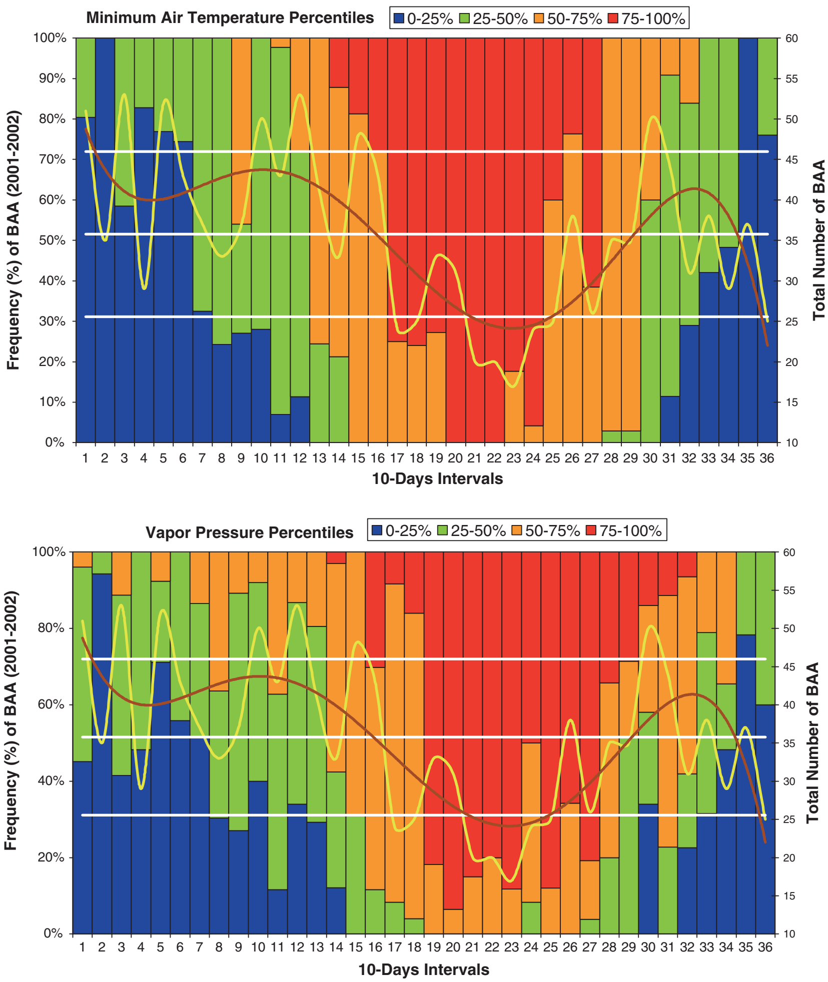

Fig. 10.3 Frequency (%) of the BAA per 10-Days Intervals (2001–2002) as a function of the minimum air temperature and water vapor pressure percentiles, along with the variation of the total number of BAA per 10-Days Interval (yellow line) and the polynomial fitting (brown line). Three reference lines (white lines) concerning the mean, the mean + SD and the mean – SD are also depicted (*see* Appendix 2)

interval concerning the impact of O_3 (Fig. 10.5) is briefly described. During the whole study period, 53 BAA are aggregated for the two 3rd 10-Day Intervals (20–31 January) from which 37 counts are associated with the first percentile of O_3, 7 counts with the second percentile, 3 counts with the third percentile and 6 counts with the forth percentile. In the process the relative frequencies are evaluated and these are the components of the stacked bar in the graph.

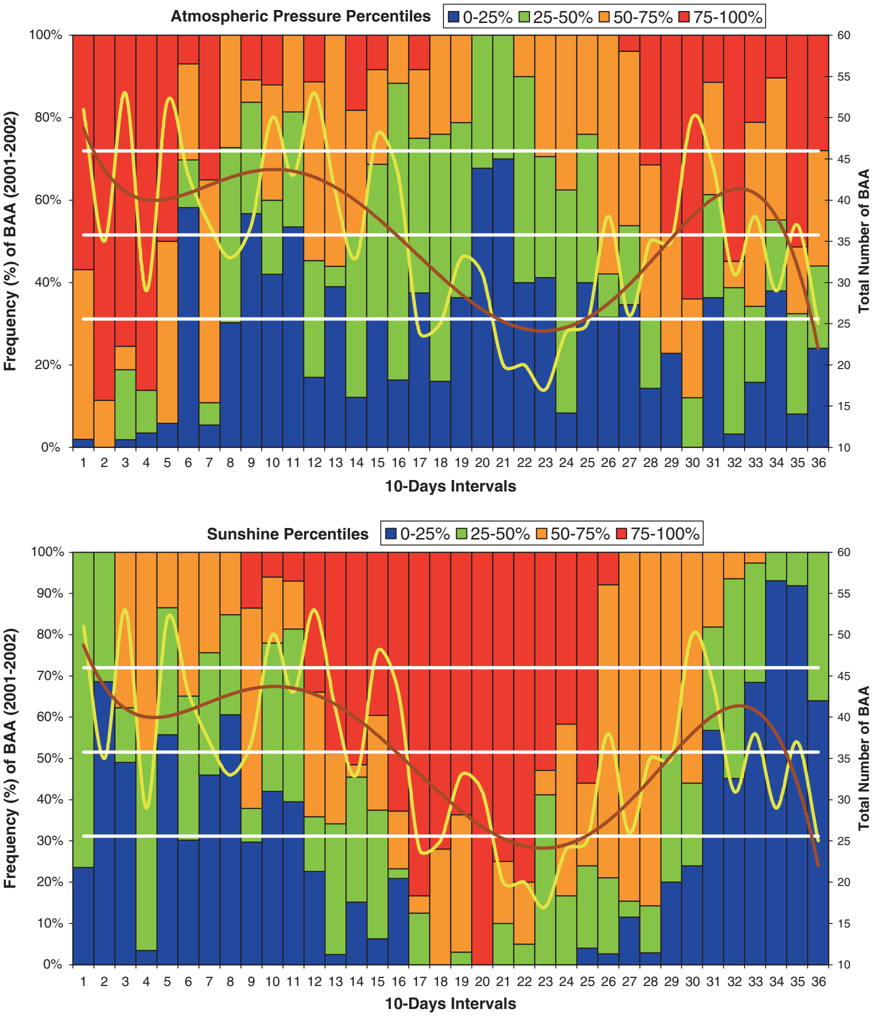

Fig. 10.4 The same as in Fig. 10.3 but for atmospheric pressure and sunshine percentiles (*see* Appendix 2)

The total numbers of BAA are higher in winter months, April and October, while a trough is appeared in August. This pattern is similar to the seasonality of asthma admissions in Malta (Grech et al. 2002) and in Ankara, Turkey (Berktas and Bircan 2003). The air temperature, the water vapor pressure and the sunshine within the highest percentile is well associated with the trough of BAA during summer time, while the highest percentile of the atmospheric pressure coincides with the winter peak of BAA. As far as ambient air pollutants are concerned, there is no clear association between BAA and PM_{10} concentrations, on 10-Days analysis. On the other hand, the highest percentile of SO_2 is in agreement with the peak of BAA during

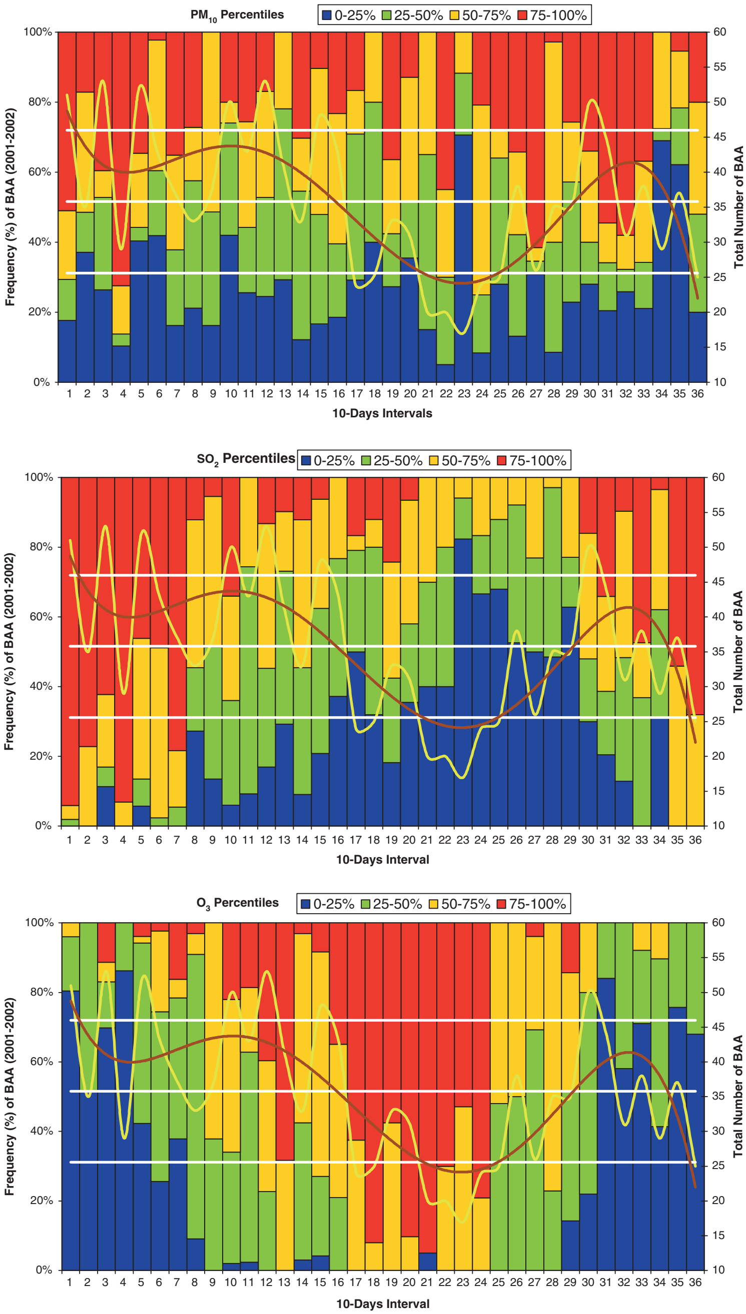

Fig. 10.5 The same as in Fig. 10.3 but for PM_{10}, SO_2 and O_3 percentiles (*see* Appendix 2)

January and February and the minimum of BAA occurs within the highest percentile of O_3. The application of Generalized Linear Models on the basis of 10-Days Intervals revealed that an increase of 10 units in 10-Days mean concentration of SO_2 links to an increase 16% of the respective totals of BAA.

The findings of the above analysis show evidence that weather and air pollution influence BAA, but a further investigation will be carried out since only 2 years were available for the medical datasets.

10.4 Conclusions

The bronchial asthma admissions in the major hospital of Athens for respiratory diseases, during the period 1/1/2001–31/12/2002, show a clear pattern with peaks in winter months, April and October and minimum in August.

The application of GLM analysis to the meteorological and medical datasets revealed that there is a statistically significant negative relationship among daily mean, maximum and minimum air temperature, diurnal air temperature range, mean water vapor pressure, total evaporation, total sunshine, mean total irradiance and BAA. On the other hand, there is no statistically significant association between PM_{10}, SO_2 concentrations and BAA on the same day while a weak negative relationship between O_3 concentrations and BAA is extracted. Nevertheless, a statistically significant positive relationship between BAA and O_3 is revealed when the cold periods of the examined years were considered. Besides, increases in PM_{10} and SO_2 concentrations were associated with increases in BAA, while increases in O_3 concentrations were associated with decreases in BAA, which become evident after lag 7–8 days. However, there is a need for further research to explain the mechanisms for the observed associations between BAA, weather and ambient air pollution.

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