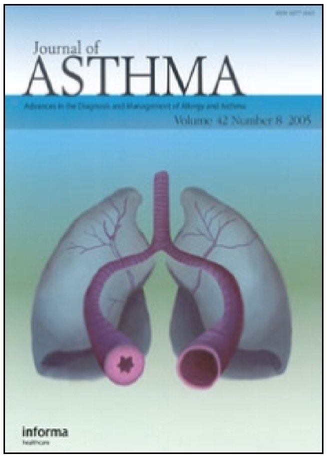

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ORIGINAL ARTICLE

The Effect of Weather Variability on Pediatric Asthma Admissions in Athens, Greece

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The aim of this study was to determine whether there is any association between weather variability and asthma admissions among children in Athens, Greece. Medical data were obtained from hospital registries of the three main Children's Hospitals in Athens during the 1978–2000 period; children were classified into two age groups: 0–4 and 5–14 years. The application of Generalized Linear Models with Poisson distribution revealed a significant relationship among asthma hospitalizations and the investigated parameters, especially for the children aged 0–4 years. Our findings showed that Hospital admissions for childhood asthma in Athens, Greece, is negatively correlated with discomfort index, air temperature and absolute humidity whereas there is a positive correlation with cooling power, relative humidity and wind speed.

Keywords childhood asthma, weather, Generalized Linear Models, Athens

INTRODUCTION

The association of asthma morbidity with weather conditions has been pointed out even at the 5th century BC by Hippocrates (1). There is evidence that changes in temperature, barometric pressure and relative humidity have some influence on the worsening of asthmatic symptoms (2–7).

In Korea, relative humidity was found to be a more important factor than temperature to exercise induced bronchospasm in patients with perennial asthma (8). In Athens, it has been shown that the weather types associated with high incidence of Childhood Asthma Admissions (CAA) are established during the cold period of the year (9). More specifically, the cold anticyclonic conditions are the most accountable for worsening CAA. On the contrary, weather types characterized by high air temperature, high absolute humidity, high total solar radiation and sunshine, are related to low CAA. Besides, a constant seasonal variability in asthma admissions among children in Athens was found, whereas the more implicated meteorological variables for younger asthmatic children were relative humidity and atmospheric pressure (10).

Observations in Tokyo suggest that childhood asthma symptoms increase when climate conditions show a rapid decrease from higher barometric pressure, higher air temperature and higher humidity (11); asthmatic children frequently visited the emergency department on misty or foggy nights, especially during midnight to dawn periods with high atmospheric temperature (6). Furthermore, in both New Orleans and New York City almost every asthma epidemic was preceded by the passage of a cold front (by 1 to 3 days) followed by a high pressure system (12).

Athens, the capital of Greece, being a city of about 4,000,000 inhabitants, is situated in a small peninsula located in the south-eastern edge of the Greek mainland. The metropolitan area is mainly located in a basin surrounded by high mountains on three sides and open to the sea from the south. The extensive building of Athens, the rapid increase of population and the number of motor vehicles mainly after 1970, resulted in the formation of an Urban Heat Island (UHI), which affects the biometeorological regime of the city. The urbanization effect referred mainly to maximum air temperature and to the warmer seasons of the year, causes discomfort to the inhabitants, and mostly to the sensitive groups in the population (13).

In order to evaluate the direct and indirect influence of the weather conditions on humans in a more holistic approach biometeorological indices are used. Weather services in addition to their traditional activity of climate analysis and weather forecasts have focused their activity on the development of several indices to provide information on human discomfort conditions (14).

We hypothesized, therefore, that biometeorological indices are associated with childhood asthma morbidity and consequent admission rates for acute asthma. To test this hypothesis we investigated if there is any association between specific biometeorological indices and the most commonly used meteorological parameters with asthma admissions among children in Athens, Greece.

METHODS

The medical data were obtained from the hospital registries of the three main Children's Hospitals of Athens for

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the 1978–2000 period, covering approximately 78–80% of the paediatric beds of Metropolitan Area of Athens (MAA). All children admitted with the diagnosis of “asthma,” “asthmatic bronchitis” or ”wheezy bronchitis,” aged 0–14 years, living in the above-mentioned region were included. They were classified into two age groups: 0–4 and 5–14 years. Monthly CAA rates, after adjusting for paediatric beds that are not accounted for (approximately 20–22% of total number), were expressed per 10^5 populations aged the same as the studied groups. The estimation of the population for each year of the study period was based upon the 1981 and 1991 national census (10).

The monthly values of the meteorological parameters were calculated using the meteorological data (air temperature, relative humidity, absolute humidity and wind speed) recorded at the station of the National Observatory of Athens for the aforementioned period.

Two biometeorological indices were used in the analysis; the first was Thom’s discomfort index (THI), given by the formulae (15):

$$\mathrm{THI} = \mathrm{T_a} - 0.55\,(1 - 0.01\,\mathrm{RH})\,(\mathrm{T_a} - 14.5)^{\circ}\mathrm{C}$$

where $\mathrm{T_a}$ is the monthly value of the mean air temperature (°C) and RH is the corresponding monthly value of the relative humidity (%). Regarding the population of the metropolitan area of Athens, there is no discomfort when THI $< 21^{\circ}$C, less than 50% of the total population feels discomfort when $21^{\circ}\mathrm{C} \leq \mathrm{THI} < 24^{\circ}\mathrm{C}$, more than 50% of the total population feels discomfort when $24^{\circ}\mathrm{C} \leq \mathrm{THI} < 27^{\circ}\mathrm{C}$, most of the population suffers from discomfort when $27^{\circ}\mathrm{C} \leq \mathrm{THI} < 29^{\circ}\mathrm{C}$, while the discomfort is very strong and dangerous when $29^{\circ}\mathrm{C} \leq \mathrm{THI} < 32^{\circ}\mathrm{C}$ (14). In the last case, a prescribe state of medical emergency must be taken.

The other biometeorological index we used is cooling power (CP) given by the empirical formulae (16):

$$\mathrm{CP} = (0.412 + 0.087\,\mathrm{v})\,(36.5 - \mathrm{T_a})\,\mathrm{mcal\,cm^{-2}\ sec^{-1}}$$

where v is the monthly mean wind speed (m/sec) and $\mathrm{T_a}$ is the monthly mean air temperature (°C). The CP has been related to sensation scale, which can be classified as follows: hot environment when $\mathrm{CP} \leq 5$, pleasant or mild when $5 < \mathrm{CP} \leq 10$, cool when $10 < \mathrm{CP} \leq 15$, cold when $15 < \mathrm{CP} \leq 22$, very cold when $22 < \mathrm{CP} \leq 30$ and extreme cold when $\mathrm{CP} > 30$ (17).

The relationship between CAA and the aforementioned environmental parameters was calculated by the application of: (a) Pearson χ^2 test, the most widely used method of independence control of groups in lines and columns in a table of frequencies and (b) Generalized Linear Models with Poisson distribution. In the first step of the detailed statistical analysis, the values of each environmental parameter and CAA, were grouped in five quintiles, so that the first quintile contain the lowest 20% and the fifth quintile, the highest 20% of the values. In the process, the number of months for the quintiles of CAA was calculated for each quintile of the parameters and then a contingency table was constructed for every parameter.

The Pearson χ^2 test was applied in each 1 of the 12 constructed contingency tables (six contingency tables for each one of the age groups with respect to the 6 environmental parameters examined) checking the null hypothesis that the quintiles of each environmental parameter are not related (hence they are independent) to the quintiles of CAA. The use of contingency tables instead of Pearson correlation was considered more accurate, because the medical data shows a large divergence from a Gaussian (regular) distribution.

In the second step of the performed analysis, the statistical importance of the correlation between the frequency of CAA and the examined parameters was examined by the application of Generalized Linear Models with Poisson distribution (18), a method of analysis which has been performed satisfactory in previous studies (19, 20). Poisson models with log links are often called *log-linear models* and are used for frequency data. In the model’s fitting procedure we used as a dependent variable the monthly number of CAA in the Children’s hospitals of MAA, while as independent covariates the aforementioned environmental parameters. Models’ goodness-of-fit was evaluated through the deviance residuals (18).

In order to keep the experiment error rate to a specified level (usually $\alpha = 0.05$) a simple way of doing this (Bonferroni adjustment) is to divide the acceptable α-level by the number of comparisons we intend to make. In our study, if 6 pairwise comparisons are to be made and we want to keep the overall experiment-wise error rate to 5% we will evaluate each of our pairwise comparisons against 0.05 divided by 6. That is, for any comparison to be considered significant, the obtained p-value would have to be less than 0.008 ($0.05/6 = 0.008$) and not 0.05.

Results

The annual variations of the mean monthly number of CAA and the mean monthly values of biometeorological parameters we studied for the period 1978–2000 are depicted in Figure 1 The annual march of THI values is inverse to the hospitalizations for childhood asthma in both age groups, whereas the annual march of CP values is in parallel to the admissions. During summer months, the presence of minimum CAA corresponds with maximum of THI. Concerning the asthma admissions for the 5–14 year age group, two maxima appear, the main one occurs in May and the secondary one in September; the minimum happens in August.

The scatter plots depicted in Figure 2 reveal the combined influence of low air temperatures and high relative humidity, mainly appeared within the cold period of the year, in maximizing the incidence of CAA. Furthermore, increased wind speed and low air temperature favour increased number of CAA as well.

The numbers of months for each quintile of monthly asthma admissions for the younger age group and for each quintile of the THI, after Pearson chi square test on the constructed contingency tables was applied, are presented in Table 1; the same information regarding CP is given in Table 2. The first quintile of CAA ($\mathrm{CAA} \leq 22.6$) in Table 1 is related to the last quintile of THI ($\mathrm{THI} > 22.5^{\circ}\mathrm{C}$), and this is statistically significant (at $p = 0.05$). On the contrary, Table 2 shows that the first quintile of CAA ($\mathrm{CAA} \leq 22.6$) is also significantly related (at $p = 0.05$) to the first quintile of

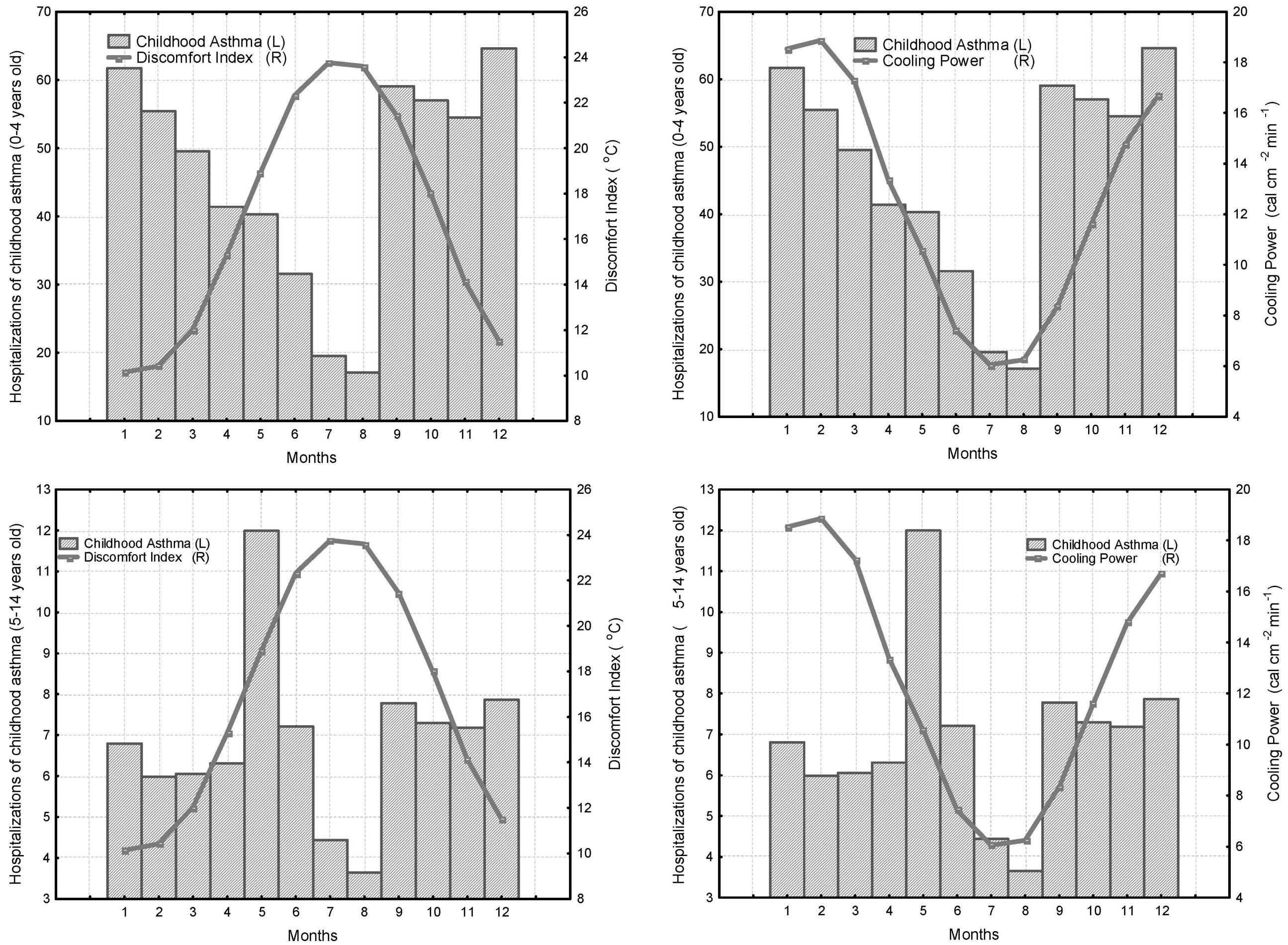

FIGURE 1.—The annual variation of the mean monthly number of childhood asthma admissions and the biometeorological parameters during the period 1978–2000, for 0–4 years age group (upper graphs) and for 5–14 years age group (lower graphs).

CP ($CP \leq 7.2$ cal cm^{-2} min^{-1}). Similar results were found with respect to the older age group (tables are not shown for brevity's sake).

With respect to the plain meteorological parameters, we found that the first percentiles of air temperature ($T \leq 10.9°C$) and absolute humidity ($e \leq 7.1$ g/m^3) are related significantly (at $p = 0.05$) to the last percentile of CAA, while the first percentiles of relative humidity ($RH \leq 52\%$) and wind speed ($v \leq 2.0$ m/sec) link to the first quintile of CAA (tables are not shown). These findings refer to both the age groups examined with an exception of relative humidity and absolute humidity that are not related to CAA, for the 5–14-year age group.

The results extracted after the application of Generalized Linear Models with Poisson distribution both to the clinical and environmental data are tabulated in Table 3. Regarding the biometeorological parameters for the 0–4-year age group, a significantly negative correlation was found between THI and CAA. The interpretation of the result is that, a 10-unit increase in the THI links to 38% decrease in the probability of having CAA. A positive correlation was also found between CP and hospital admissions. A 10-unit increase in the CP yields a 78% increase in the likelihood of hospitalization for asthma. For the 5–14 year age group, a positive correlation was found between CP and CAA whereas a 10-unit increase in the CP is associated with an 18% increase in the probability of having CAA.

With respect to the examined meteorological parameters and for the younger age group, a positive relationship was found between mean monthly relative humidity and CAA, and between mean monthly wind speed and CAA. A 10% increase in the relative humidity is related with a 31% increase in the probability of having CAA, while an increase of 1 m/sec in the mean monthly wind speed links to a 23% increase in CAA.

A negative relationship between mean monthly air temperature, mean monthly absolute humidity and CAA for the younger age group was also detected. We found out that a decrease of 10°C (10 g/m^3) in air temperature (absolute humidity) corresponds to an increase 31% (57%) of having CAA, respectively.

There was no affect of the meteorological parameters to the older ones with an exception of the wind speed, which influences positively the asthma admissions. An increase of 1 m/sec in the mean monthly wind speed is associated with a 20% increase in CAA.

DISCUSSION

The association between weather variability and monthly hospitalization rates for acute exacerbations of asthma in

TABLE 1.—Number of months for the quintiles of monthly number of childhood asthma admissions (CAA) for each quintile of the discomfort index (THI) for the younger age group.

		Quintiles of CAA (0–4 yrs)				
Quintiles of THI (°C)		CAA ≤ 22.6	22.6 < CAA ≤ 36.7	36.7 < CAA ≤ 52.8	52.8 < CAA ≤ 69.5	CAA>69.5
1	THI ≤ 11.4	2	8	12	17	17
2	11.4 < THI ≤ 14.4	6	10	10	17	12
3	14.4 < THI ≤ 18.9	10	8	14	11	12
4	18.9 < THI ≤ 22.5	7	12	14	8	14
5	THI > 22.5	*30*	17	6	2	0

Pearson Chi Square: 83.114, Degrees of Freedom: 16.

TABLE 2.—Number of months for the quintiles of monthly number of CAA for each quintile of the cooling power (CP), for the younger age group.

		Quintiles of CAA (0–4 yrs)				
Quintiles of CP (cal cm^{-2} min^{-1})		CAA ≤ 22.6	22.6 < CAA ≤ 36.7	36.7 < CAA ≤ 52.8	52.8 < CAA ≤ 69.5	CAA>69.5
1	CP ≤ 7.2	*32*	18	6	2	1
2	7.2 < CP ≤ 10.5	9	14	15	5	11
3	10.5 < CP ≤ 13.9	9	10	14	12	9
4	13.9 < CP ≤ 17.5	3	10	8	20	14
5	CP > 17.5	2	3	13	16	20

Pearson Chi Square: 105.202, Degrees of Freedom: 16.

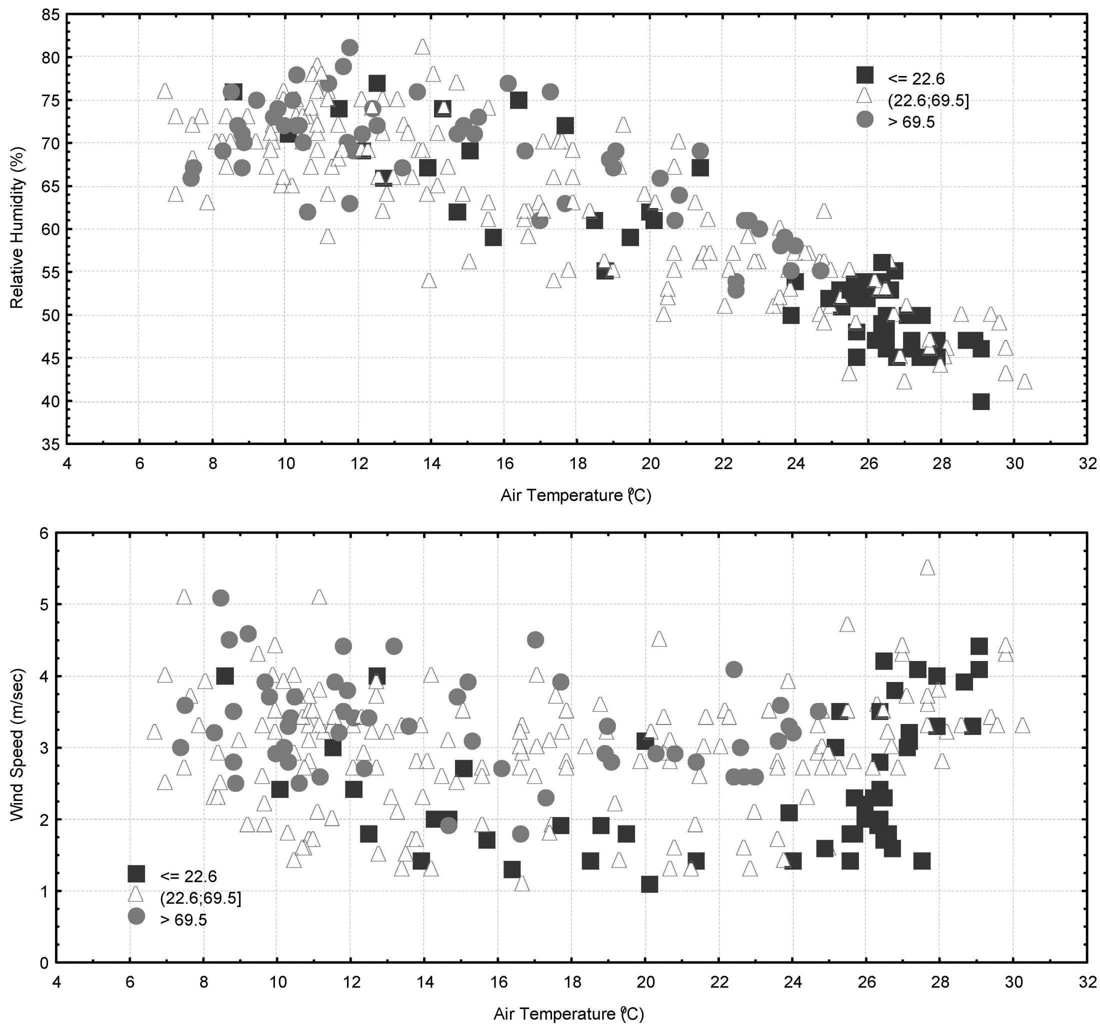

FIGURE 2.—Bivariate scatter plot for asthma admissions among children 0–4 years old as a function of air temperature and relative humidity (upper graph), air temperature and wind speed (lower graph). The squares denote asthma admissions within the first quintile (<22.6), the circles within the fifth quintile (>69.5) and triangles between the first and fifth quintiles.

TABLE 3.—Results of the application of Generalised Linear Models (GLM) with Poisson distribution (dependent variable the monthly number of asthma admissions, independent covariates the meteorological parameters).

	Asthma Admissions			
	(0–4 yrs)		(5–14 yrs)	
Meteorological parameters	**β-coefficient ± S.E.**	***p***	**β-coefficient ± S.E.**	***p***
THI (°C)	***−0.0481 ± 0.0018***	***0.000000***	−0.0067 ± 0.0045	0.136687
CP (cal cm^{-2} min^{-1})	***0.0578 ± 0.0018***	***0.000000***	***0.0167 ± 0.0047***	***0.000362***
T (°C)	***−0.0376 ± 0.0014***	***0.000000***	−0.0058 ± 0.0034	0.089990
RH (%)	***0.0273 ± 0.0009***	***0.000000***	0.0057 ± 0.0023	0.012739
e (g/m^3)	***−0.0834 ± 0.0036***	***0.000000***	−0.0121 ± 0.0093	0.190283
v (m/sec)	***0.2040 ± 0.0103***	***0.000000***	***0.1818 ± 0.0266***	***0.000000***

Figures in bold and italics are statistically significant ($p < 0.008$).

children was investigated during a 23-year period, in Athens, Greece.

This study shows that a pronounced seasonal variation of CAA among children in Athens does exist, rising during the cold damp period in the 0–4 year age group, but peaking around May in the 5–14-year group; mean monthly THI values are inversely related to the hospitalizations in both age groups while CP values are in parallel to the admissions.

The pattern of asthma admissions distribution is similar to the seasonality reported by others (21–25); the spring asthma peak tends to be associated with tree and grass pollen (26), the second peak in early autumn probably is due to respiratory infections often seen at the beginning of the school year (24, 27, 28). The deep troughs in July and August should also be related to the summer holiday. However, weather conditions influence directly or indirectly most of the aforementioned triggers of asthma exacerbation (i.e., pollen production and transport, survival and infectivity of respiratory viruses, air pollution concentration) (29–31).

It is of interest that during summer months the minimum of asthma admissions is associated with the maximum of THI values and the minimum of CP. The performed analysis also revealed a negative relationship between mean monthly air temperature, absolute humidity and asthma admissions; no association with relative humidity was detected. The vapor pressure or the absolute humidity is considered as the most important parameters for the estimation of the effect of humidity on the human body (32). In summer months high air temperature and vapor pressure that reach their maximum (increased evaportranspiration), combined with low wind speed, create a stable environment where the water vapors do not disperse; these conditions are beneficial for asthmatic children whereas the opposite conditions are asthmogenic.

There is an increasing body of evidence supporting the role of humidity, low temperature and high wind speed as triggers for asthma symptoms manifestation (4, 7, 20, 33–38). Weiland et al. (7) investigated the association between climate and atopic diseases using worldwide data from 146 centres of the International Study of Asthma and Allergies in Childhood (ISAAC). They found that, in Western Europe, the prevalence of asthma symptoms increased by 2.7% with an increase in the estimated annual mean of indoor relative humidity of 10%. The altitude and the annual variation of temperature and relative humidity outdoors were negatively associated with asthma symptoms. In another report (34), the occurrence of fog or liquid precipitation was associated with an increased number of emergency department visits for asthma in a children's hospital in Ottawa, Canada.

Furthermore, higher wind speed was observed on days with high asthma counts from April to June, and September to November, but not during the other periods examined. First preliminary results obtained in a Mediterranean region have demonstrated a negative impact of metereologic events like passages of cold weather fronts or increase of wind velocity on the course of asthma disease (35). Stephen and Corbett (36) investigated the relationship between Santa Ana wind conditions and visits for asthma at a southern California emergency department. These northeasterly winds are common during fall and winter in southern California and belong to a class known as Foehn winds. They are characterized by gusty winds, decreased relative humidity, warm temperatures, and decreased levels of airborne pollutants. During a 4-year period, the emergency department visits for asthma increased during Santa Ana winds compared with other weather conditions.

Wind speed is considered to be of interest because higher wind speed, especially combined with cold existence could result in asthma exacerbation (Figure 2, lower graph). A possible explanation of this finding is that asthma attacks occur when children get respiratory infections. Cold weather associated with windy conditions may facilitate viral infections as the virus spreads more rapidly among children in closed or overcrowded conditions.

On the other hand, windy days especially during thunderstorms, may trigger asthma attacks by increasing the number of fungal spores and pollen grains in the air. D'Amato et al. (39) studied the link between thunderstorms and asthma epidemics, especially during the pollen seasons, in several cities in Europe (Birmingham, London, Napoli) and Australia (Melbourne, Wagga Wagga). They concluded that under wet conditions or during thunderstorms, pollens grains may, after rupture by osmotic shock, release into the atmosphere part of their content, including respirable, allergen-carrying cytoplasmatic starch granules (0.5–2.5 μm) that can reach lower airways inducing asthma reactions in pollen sensitive patients. The thunderstorm-asthma outbreaks are characterized, at the beginning of thunderstorms by a rapid increase of visits for asthma.

Windy days of appeared more often during the months of January, February and March, when synoptic systems approach and affect Greece. Greece covers the southern edge of Balkan Peninsula, being in the eastern basin of the

Mediterranean Sea. During the cold period, because of the anticyclones in Europe and Siberia and low pressure in the Mediterranean Sea, the dominant wind blowing in Greece is from the north, being occasionally interrupted as the wind blows from the south according to the passage of the depressions in the Mediterranean Sea and Europe. In the warm period, Greece is under the Etesians climate, which are winds of the north (40).

A potential limitation of the study may be the fact that admission rates were given on a monthly basis and not weekly or daily. In that way, any short-term effect of short duration weather changes could be lost, but not of changes for longer duration. The very prolonged study period (23 years) eliminates that weakness and allows for possible detection of repeated specific weather conditions affecting asthma symptoms. Monthly changes have already been used as a reliable tool in the literature (10, 23).

Conclusions

The results indicate that there is a well-established relationship between weather conditions and hospitalizations of asthmatic children. This impact is more intense with respect to the children aged 0–4 years. The wind speed from the meteorological parameters and the cooling power from the biometeorological indices examined could be the precursors of worsening the health of asthmatic children. In addition, the air temperature and the absolute humidity strongly influence the incidence of asthma exacerbations among children, and more concretely, the lower the air temperature and the absolute humidity the higher the hospitalizations. Cold weather associated with windy conditions could be the precursor of childhood asthma exacerbations.

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