THE EFFECT OF WEATHER TYPES ON THE FREQUENCY OF CHILDHOOD ASTHMA ADMISSIONS IN ATHENS, GREECE

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Presented at the 13th International Symposium on Environmental Pollution and its Impact on Life in the Mediterranean Region (MESAEP), Thessaloniki, Greece, 08 – 12 Oct. 2005

SUMMARY

The aim of this study was to investigate the influence of weather conditions on the number of admissions for childhood asthma in Athens, Greece. Daily counts of childhood asthma admissions (2764) of the three main Children's Hospitals in Athens, from hospital registries during a 3-year period (2001-2003), were obtained. The meteorological data reviewed consists of daily values of 20 parameters recorded at the National Observatory of Athens during the study period: maximum temperature (T_{max}); minimum temperature (T_{min}); mean temperature (T_{mean}); diurnal temperature range ($T_{range} = T_{max} - T_{min}$); day-to-day change in maximum temperature (ΔT_{max}); day-to-day change in minimum temperature (ΔT_{min}); day-to-day change in mean temperature (ΔT_{mean}); day-to-day change in diurnal temperature range (ΔT_{range}); mean relative humidity (RH); day-to-day change in mean relative humidity (ΔRH); mean water vapor pressure (e); day-to-day change in mean water vapor pressure (Δe); mean atmospheric pressure at sea level (P); day-to-day change in mean atmospheric pressure (ΔP); mean irradiance (I); day-to-day change in mean irradiance (ΔI); mean sunshine (S); day-to-day change in mean sunshine (ΔS); mean wind speed (v) and day-to-day change in mean wind speed (Δv).

The performed statistical methods were: (i) Pearson's χ^2 test, using contingency tables and (ii) Factor and Cluster analysis. The application of this 2-part analysis revealed the relationship between the extracted weather types and the frequency of childhood asthma admissions in Athens. The results showed that weather conditions with low temperature, low water vapor pressure and cold anticyclonic presence were significantly correlated with an increase in the number of asthma admissions among children in Athens. The impact of these specific weather conditions on asthma exacerbation should be interpreted either by the asthmogenic effect of humid weather per se or the association with respiratory viral infection, mold's and mites' allergy.

KEY WORDS:
Childhood asthma, weather types, Athens.

INTRODUCTION

Childhood asthma is a common health problem associated with high morbidity burden. The worldwide increase in the incidence of asthma suggests that environmental factors may influence the seasonal variations in pediatric asthma. The weather conditions have been reported by several studies as risk factors in childhood asthma admissions (CAA).

Acute asthma and acute laryngitis, are correlated with the afternoon gradients of air temperature, heat content (the thermal energy of the ambient air), and modified heat content factor (the energy required to heat the air water vapor to the ambient temperature), but not correlated with the absolute values of air temperature and water content [1]. Low air temperature is associated with increased CAA [2-5]. Also, the asthma epidemic was significantly associated with a drop in air temperature six hours previously and a high grass pollen concentration nine hours previously. Non-epidemic asthma was significantly associated with lightning strikes, increase in humidity or sulphur dioxide concentration, a drop in temperature or high rainfall the previous day, and a decrease in maximum air pressure or changes in grass pollen counts over the previous two days [6]. Altitude and the annual variation of temperature and relative humidity outdoors were negatively associated with asthma symptoms [7], as well as admission to emergency room for asthma count was negatively correlated with ambient temperature and strong wind existence on previous days. It was also positively correlated with ambient relative humidity [8]. Hashimoto et al. [9] 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 [10]. The occurrence of fog or liquid precipitation was associated with an increased number of asthma visits, while snow was associated with a reduced number ($P<0.05$) [11-12], as well as CAA found to be associated with high atmospheric pressure [13]. Furthermore, a study by Goldstein [14], showed that almost every asthma epidemic in both New Orleans and New York City, was preceded by the passage of a cold front (by one to three days) followed by a high pressure system.

Very large sferic densities are associated with moderate rises in hospital admissions for acute asthma. However, typical thunderstorm days are not associated with spectacular asthma epidemics of the scale previously reported in the literature. Thunderstorm-associated excesses are amplified after a run of high pollen counts [15]. In most patients symptoms began at the time of sudden climatic changes associated with a thunderstorm [16].

In this study, we try to find out the manner in which weather and childhood asthma are related. The first step is to determine the appropriate weather types in Athens and the second to examine the influence of these weather types to the incidence and severity of childhood asthma.

DATA AND ANALYSIS

The medical data were obtained from the hospital registries of the three main Children's Hospitals of Athens for the 2001-2003 period. All children admitted with the diagnosis of "asthma", "asthmatic bronchitis" or "wheezy bronchitis", aged 0-14 years, living in the metropolitan area of Athens were included. There were 2764 asthma admissions in total during the entire study period. The males' admissions are almost 2fold the females' and there is an exponential decrease of the admissions as children grow up. Children's admissions at the age of one-year old come up to 556 (male) and 300 (female), while at the older age of fourteen, they count 16 (male) and 7 (female), as it is depicted in Figure 1. Also, this pattern was found by Crighton et al. [17] studying asthma hospitalizations in Ontario, Canada. They suggest that young males (0-4 years) were hospitalized at two or three times the rate of females of the same age and rates were much lower in the older age groups.

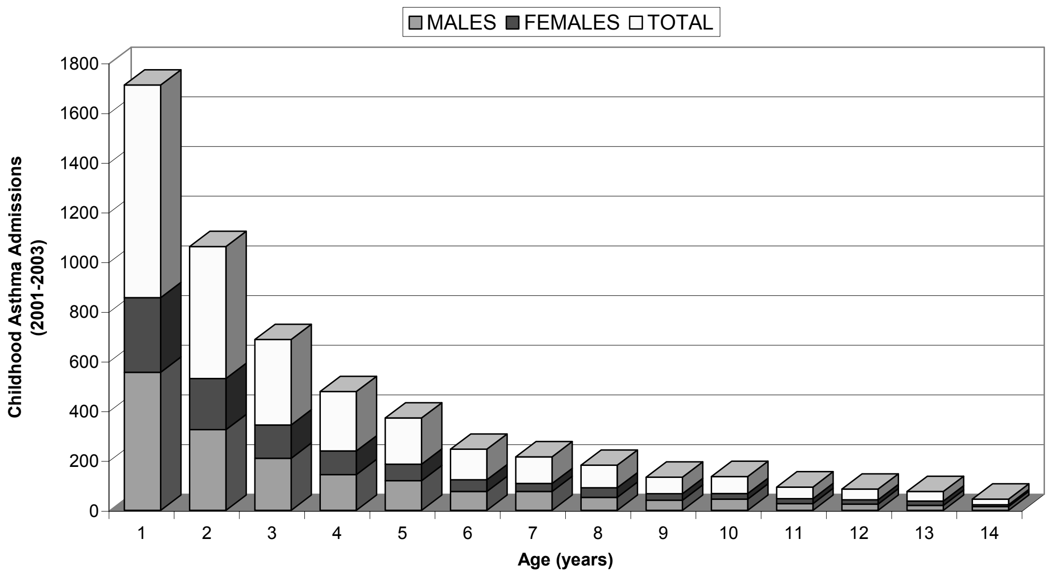

FIGURE 1 - The number of Childhood Asthma admissions per age for the males, the females and the total.

The meteorological variables analysed, included daily values of 20 parameters recorded at the National Observatory of Athens during the period 2001-2003 and they are the following: maximum temperature (T_{max}); minimum temperature (T_{min}); mean temperature (T_{mean}); diurnal temperature range ($T_{range} = T_{max} - T_{min}$); day-to-day change in maximum temperature (ΔT_{max}); day-to-day change in minimum temperature (ΔT_{min}); day-to-day change in mean temperature (ΔT_{mean}); day-to-day change in diurnal temperature range (ΔT_{range}); mean relative humidity (RH); day-to-day change in mean relative humidity (ΔRH); mean water vapor pressure (e); day-to-day change in mean water vapor pressure (Δe); mean atmospheric pressure at sea level (P); day-to-day change in mean atmospheric pressure (ΔP); mean irradiance (I); day-to-day change in mean irradiance (ΔI); mean sunshine (S); day-to-day change in mean sunshine (ΔS); mean wind speed (v) and day-to-day change in mean wind speed (Δv).

The relationship between CAA and the aforementioned meteorological 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) Factor Analysis (FA) and Cluster Analysis (CA). In the first step of the detailed statistical analysis, the values of each meteorological parameter 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 days with 0, 1, 2, 3, 4 and 5 or more events of CAA in the Hospitals was calculated for each quintile and then a contingency table was constructed for every parameter. The Pearson χ^2 test was applied in each one of the 20 contingency tables, checking the null hypothesis that the quintiles of each meteorological parameter are not related (hence they are independent) to the number of CAA. The use of contingency tables instead of Pearson correlation considered more accurate, because the medical data present large divergence from a Gaussian (regular) distribution. In the second step of the performed analysis, the application of FA and CA to meteorological parameters resulted in seven weather types, which were examined for impacts to CAA. Table 1 presents the contingency tables for the mean air temperature and the mean water vapor pressure. It is clear that many days with 1 event of CAA appear within the fifth quintile of the mean air temperature and water vapor pressure (shaded values in the Table 1). These findings are statistically significant (T_{mean}: χ^2= 247.15, df =20, p<0.001 and e: χ^2: 151.781, df=20, p<0.001).

The main applications of FA are to reduce the number of variables and to detect structure in the relationships between variables that is to classify variables. Therefore FA is applied as a data reduction or structure detection method. The data should have a bivariate normal distribution for each pair of variables, and observations should be independent. Therefore each of the p initial variables $X_1, X_2, \ldots, X_p$ can be expressed as a linear function of m $(m<p)$ uncorrelated factors: $X_i = a_{i1}F_1 + a_{i2}F_2 + \ldots + a_{im}F_m$ where $F_1, F_2, \ldots, F_m$ are the factors and $a_{i1}, a_{i2}, \ldots, a_{im}$ are the factor loadings which express the correlation between the factors and the initial variables. The values of each factor are called factor scores and they are presented in standardized form, having zero mean and unit variance [18, 19]. The number m of the retained factors has to be decided, by using various rules (eigenvalue ≥ 1, scree plot) and considering the physical interpretation of the results. Another important point of the analysis is the rotation of the axes, which maximizes some factor loadings and minimizes some others and in that way a better separation among the initial variables is succeeded. Varimax rotation is generally accepted as the most accurate orthogonal rotation, which maximizes the sum of the variances of the square factor loadings, keeping the factors uncorrelated [20].

TABLE 1
Number of days with 0, 1, 2, 3, 4 and 5 or more Childhood Asthma admissions in relation to the mean air temperature (T_{mean}) and mean water vapor pressure (e) over 3-years period (2001-2003).

Childhood Asthma Admissions/day						
T_{mean} (°C)	**0**	**1**	**2**	**3**	**4**	**≥5**
1	22	38	43	32	41	43
2	15	43	44	40	26	53
3	24	29	39	44	26	55
4	47	53	41	39	10	33
5	94	75	28	14	1	3
Childhood Asthma Admissions/day						
e (mm Hg)	**0**	**1**	**2**	**3**	**4**	**≥5**
1	24	40	43	36	39	40
2	17	37	44	42	24	52
3	28	47	36	47	24	42
4	49	54	41	25	13	36
5	84	60	31	19	4	17

Cluster Analysis is a way of grouping cases of data based on the similarity of responses to several variables. In our analysis we applied the average linkage cluster analysis based on the calculation of the Euclidean distances of already standardized data [21]. It seems the most appropriate for our case as it has been proven that it gives the most realistic results in climatological studies [22].

The Euclidean distance between two values i and j is defined as:

$$D(i,j) = [\Sigma_\kappa(M(\iota,\kappa) - M(j,k))^2]^{1/2}$$

where M is the original matrix, $k = 1,\ldots, N$ are the different variables characteristics for the values to be classified and D the similarity matrix.

RESULTS AND DISCUSSION

The medical dataset included 1736 male and 1028 female children within the age 1-14 years old. The mean monthly distribution of CAA (Figure 2) showed that increased admissions appear during the cold period of the year (October to March) with a peak in March. Afterwards, the CAA decreased rapidly towards the minimum appeared in August. This pattern is similar to the seasonality of asthma admissions in Malta [4] and in Ankara, Turkey [8].

In order to reveal the relationship between CAA and each one of the examined meteorological parameters the χ^2 test was applied in each one of the 20 contingency tables, checking the null hypothesis that the quintiles of each meteorological parameter are not related (hence they are independent) to the number of CAA. The interpretation of the results suggests that many days with minimum CAA (1 event) coincide with the high (fifth percentile) values of T_{mean}, T_{max}, T_{min}, T_{range}, e, I, S and v. This relationship is statistically significant ($p<0.01$) and is in agreement with other researchers' findings [3, 9, 23]. Furthermore, on the days with maximum CAA (>5 events), the mean atmospheric pressure was higher (fifth percentile) and the relative humidity was lower (first percentile) than on days with minimum admissions and this is statistically significant ($p<0.01$). A relevant study by Ehara eta al. [24], revealed the same relationship in Hakodate, Japan.

Regarding the effects of the day to day changes in the examined meteorological parameters to CAA, no statistically significant relationship was found, with an exception of day-to-day changes in T_{min}, which influence CAA in such a way that high changes (Fifth percentile) in T_{min} are related to minimum CAA (1 event) and this is statistically significant ($p<0.01$).

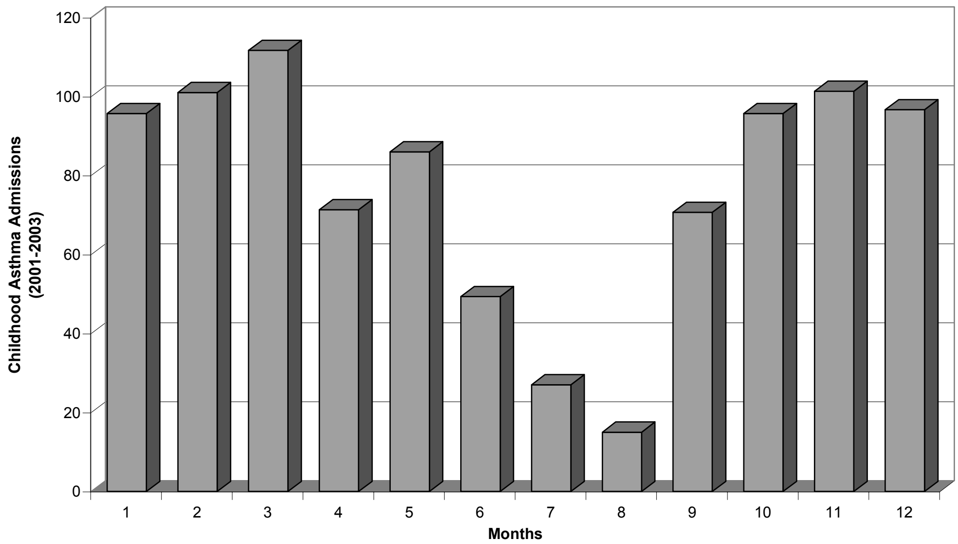

FIGURE 2 - Mean monthly distribution of childhood asthma admissions during the years 2001-2003.

TABLE 2 - Mean values of the meteorological parameters for each weather type (cluster).

Meteorological	Weather Types						
Variables	1	2	3	4	5	6	7
T_{max} (°C)	23.37	32.46	17.77	21.15	17.07	18.91	18.37
ΔT_{max} (°C)	-2.23	.33	-2.42	2.83	1.28	-1.60	.62
T_{min} (°C)	16.14	22.17	11.34	12.53	9.11	12.73	12.45
ΔT_{min} (°C)	-.47	.15	-2.59	-.23	-.25	.59	2.18
T_{mean} (°C)	19.21	26.65	14.28	16.31	12.43	15.30	15.02
ΔT_{mean} (°C)	-1.32	.22	-2.29	1.22	.38	-.35	1.38
T_{range} (°C)	7.23	10.28	6.42	8.62	7.96	6.18	5.92
ΔT_{range} (°C)	-1.75	.18	.17	3.06	1.53	-2.19	-1.56
RH (%)	50.06	50.08	73.95	67.86	65.10	69.70	72.52
ΔRH (%)	-8.34	.55	3.19	-6.30	-.27	6.86	1.37
e (mm Hg)	8.27	12.66	9.24	9.48	7.15	9.13	9.43
Δe (mm Hg)	-2.11	.29	-.77	-.29	.14	.79	.93
P (hPa)	1004.85	1001.19	997.36	999.77	1008.63	1006.75	1001.42
ΔP (hPa)	2.72	-.18	-1.57	-2.00	1.75	.17	-3.57
I (W m^{-2})	213.13	276.80	94.23	174.72	148.98	107.95	101.76
ΔI (W m^{-2})	16.11	.21	-19.27	79.21	19.30	-66.67	-19.39
S (hrs)	8.48	11.62	2.92	7.63	7.51	3.51	3.52
ΔS (hrs)	.52	.08	-1.08	5.29	1.80	-4.68	-1.90
v (m sec^{-1})	5.53	3.04	3.91	3.03	2.59	2.83	4.14
Δv (m sec^{-1})	1.79	-.19	.33	.01	-1.14	-.41	1.34

TABLE 3 - Weather properties of the seven types (clusters) extracted for Athens.

Weather Type	Weather properties	Incident
1	Low relative humidity, decrease of relative and absolute humidity, high wind speed, increase of barometric pressure and wind speed, decrease of daily air temperature range	Mostly during warm period of the year
2	High air temperature, high absolute humidity, high total solar radiation and sunshine	
3	Low pressure, low total radiation and sunshine, decrease of air temperature, increase of relative humidity	
4	Increase of daily air temperature range, increase of total solar radiation and sunshine	
5	High pressure, low air temperature, low absolute humidity and wind speed, decrease of wind speed	Mostly during the cold period of the year
6	Increase of relative humidity, decrease of total solar radiation and sunshine	
7	Increase of air temperature and absolute humidity, low daily air temperature range, decrease of pressure	

In the process, FA was applied to the 20 meteorological parameters and resulted in 5 factors, which explained 80% of the the variability of the weather in Athens. Subsequently, CA was applied to the 1095 factor scores cases (days) in order to group them into classes of days with a characteristic type of weather and this procedure led to 7 clusters (Table 2 and 3). These steps of analysis have been considered necessary by many researchers [25-27].

In order to reveal which weather type influences more the CAA, the χ^2 test was applied to a contingency table constructed by the number of days with 0, 1, 2, 3, 4 and 5 or more events of CAA in the Hospitals for each weather type (Table 4).

TABLE 4 - Number of days with 0, 1, 2, 3, 4 and 5 or more Childhood Asthma admissions related to the weather types over 3-years period (2001-2003).

	Childhood Asthma Admissions/day					
Weather Types	**0**	**1**	**2**	**3**	**4**	**≥5**
1	14	25	28	19	12	17
2	118	109	53	47	13	34
3	14	15	12	8	12	22
4	7	11	14	20	9	15
5	23	34	36	42	33	44
6	9	26	22	20	18	33
7	10	18	29	12	7	21

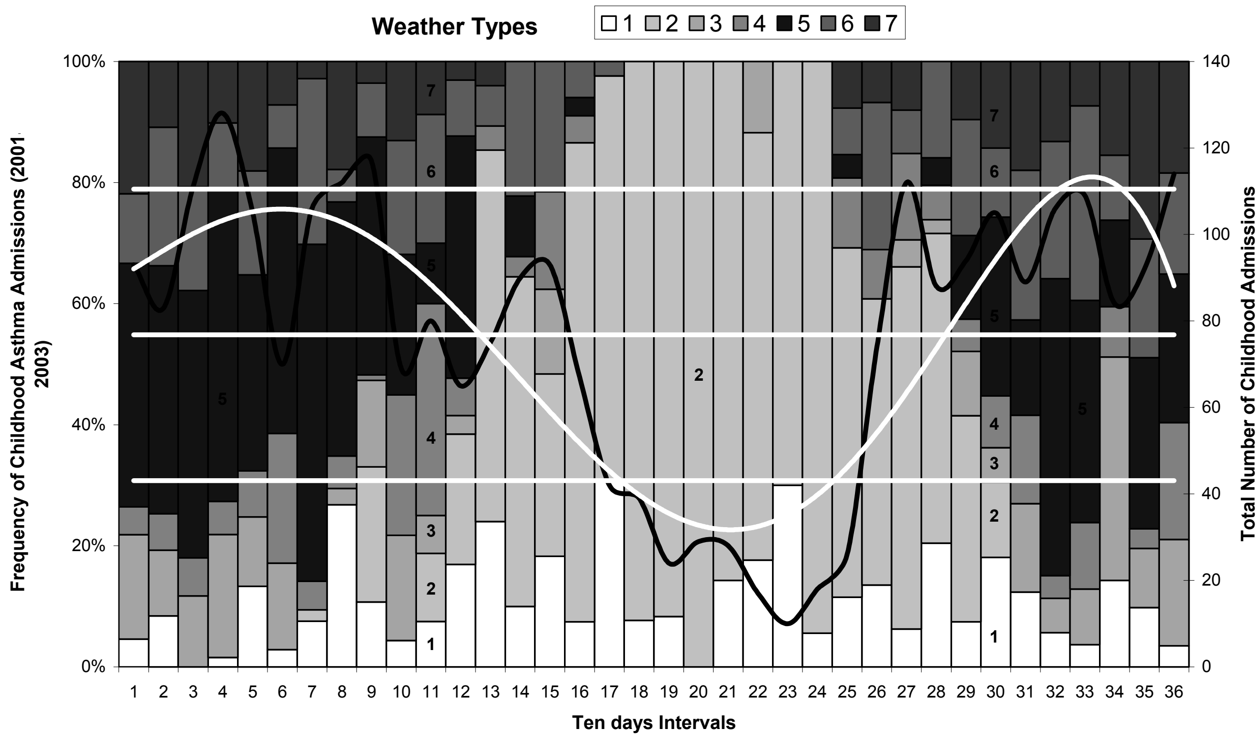

FIGURE 3 - Relative frequency (%) of the Childhood Asthma admissions per Ten-Days Intervals as a function of the weather types (clusters) along with the variation of the total number of admissions per Ten-Days Interval (black curve) and the polynomial fitting (white curve). Three reference lines (white lines) concerning the mean, the mean+SD and the mean-SD are also depicted.

Weather types 1 and 2, occurred mainly during the warm period of the year, seem to be associated with low CAA. On the other hand, weather types 3-7, prevailed mainly during the cold period of the year, are responsible for worsening CAA. More specifically, the weather type 2, which is identified by high air temperature, high absolute humidity, high total solar radiation and sunshine, minimizes CAA, while the weather types 5 and 6, characterized by cold anticyclonic conditions after the passage of a cold front, are the drivers for the onset of high CAA. These findings are statistically significant ($p<0.01$), using the χ^2 test ($\chi^2=159.53$, df=30). Furthermore, Goldstein [14] studying the weather patterns and asthma epidemics in New York City and New Orleans, USA, concluded that a cold front (by one to three days) followed by a high pressure system was associated with asthma epidemics.

A more descriptive analysis is appeared in Figure 3 where the relative frequency (%) of the CAA per 10-Days Interval as a function of the 7 weather types (clusters) along with the variation of the total number of admissions per 10-Days Interval (blue line) and the polynomial fitting (black line) are depicted in Figure 3. The bars appeared in each interval represent the percentages of CAA associated with the particular weather types. It is well depicted that the weather type 2 (red colour) is associated with low CAA and weather types 5-6 (light green and orange) are mainly related with high CAA.

CONCLUSIONS

The childhood asthma admissions in the hospitals of Athens appear seasonal with a peak in March and a minimum in August. Male children are more vulnerable to asthma than the female ones and the admissions decreased rapidly as the time goes by and they are minimized at the age of fourteen.

The multivariate analysis applied to the meteorological and medical datasets revealed that there is a statistically significant negative relationship between daily mean, maximum and minimum air temperature, diurnal air temperature range, absolute humidity, mean irradiance, mean sunshine, wind speed and CAA. On the other hand, high atmospheric pressure and low relative humidity are meteorological factors for increased CAA. Besides, it was found that the day-to-day changes of the examined meteorological parameters do not affect CAA, except T_{min} changes which influence negatively CAA.

In addition, the weather types (extracted by Factor and Cluster analysis) that are associated with high incidence of CAA appear during the cold period of the year. 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.

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Received: December 15, 2005
Accepted: February 23, 2006

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FEB/ Vol 15/ No 8b/ 2006 – pages 936 - 942