Influence of Meteorological Parameters and Air Pollutants onto the Morbidity due to Respiratory Diseases in Castilla-La Mancha, Spain

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ABSTRACT

This study considers the relationship between the risk of hospital admission due to respiratory diseases, the daily weather, and the air pollution conditions between 2000 and 2006. A synoptic climatological approach is used to investigate the links between weather types and all hospital admissions due to respiratory diseases in Castilla-La Mancha (CLM), Spain. The main circulation weather types (CWTs) were determined for winter and spring, the seasons with the highest percentage of hospital admissions, and the frequency distribution of these types was also analyzed. The study includes a summary of the main characteristics of the hospital admission series and their distribution over the study period of seven years, as well as the frequency distributions of the admissions classified by gender and age, for each season, month and day of the week. In addition, an admission index was used to compare CWTs and hospital admissions due to respiratory diseases. The results show distinctly different responses of daily respiratory disease admission rates (RD) to the eight CWTs identified in winter and in spring. In winter, three CWTs (southwesterly (SW), anticyclonic (A) and hybrid anticyclonic southwesterly (HASW)) present values 1.5 times above the average admission rates. In contrast, there are no significant differences in spring. Finally, the results of Principal Component Analysis applied to the daily series of meteorological parameters, atmospheric pollutants and morbidity data revealed that in winter the decrease in RD is related to increases in temperature and pressure. These results represent an important step in identifying reliable connections between weather-air pollutants and human health.

Keywords: Weather types; Hospital admissions; Aerosol; Epidemiology; Time lag.

INTRODUCTION

Respiratory diseases are one of the main causes of morbidity and mortality in most countries. As a result, an increasing number of studies focus on the role of meteorological parameters and other ambient factors in this type of pathologies (Macfarlane et al., 2000; Fernandez-Raga et al., 2010).

The effect of aerosol and gaseous pollutants on human health is an important topic of research nowadays (Eleftheriadis and Emmanuelou, 2011; Calvo et al., 2013). Air pollution causes the premature death of over 16,000 people per year in Spain. About 35% of the Spanish population, i.e., 16 million people, breathe polluted air, according to the 43rd Conference of the Spanish Society of Pneumology and Thorax Surgery 2010 (www.troposfera.org).

Atmospheric pollution comprises a wide range of substances which, if present in high concentrations, constitute a risk factor in a number of pathologies, particularly respiratory diseases (Katsouyanni, 2003). Pollution includes gases such as CO, NOx, NO₂, SO₂, and O₃, as well as particulate matter.

The seasonal reasons for the increase in the number of cases of asthma have been explained in terms of meteorological parameters and air pollution factors (Hwang et al., 2011). As for the meteorological parameters, many studies have found that the symptoms may be related to temperature (Beer et al., 1991; Yuksel et al., 1996; Crighton et al., 2001; García Pina et al., 2008, Lim et al., 2012), the relative humidity and rain patterns (Magas et al., 2007), fog (Kashiwabara et al., 2002; Villeneuve et al., 2005), wind speed (Hashimoto et al., 2004), or changes in the barometric pressure and storms (Sutherland and Hall, 1994; Newson et al., 1997).

As for air pollutants, hospital admissions due to asthma may increase in periods with low air quality, in particular when there are increases in ozone rates (Gouveia and Fletcher, 2000a, b; Tolbert et al., 2000; Fusco et al., 2001; Tortolero et al., 2002; Jalaludin et al., 2004; Ho et al., 2007; Hanna et al., 2011). Links have been found between...
daily ozone levels and respiratory symptoms (Gent et al., 2003; Rabinovitch et al., 2004; Middleton et al., 2008; Stieb et al., 2009). However, there are also studies that show no clear relationship between ozone levels and morbidity (Hwang and Chan, 2002; Farhat et al., 2005; Luginaah et al., 2005; Hinwood et al., 2006; Cheng et al., 2009). These differences may be due to geographic reasons, although a number of methodological factors may also play a role.

The aim of this paper is to reveal the underlying connections between weather situations and contaminants, on the one hand, and human health, on the other hand, in particular in the case of Castilla-La Mancha, in central Spain. The approach adopted is a synoptic climatological one, with a proved effectiveness when analyzing climate-morbidity relationships (de Pablo et al., 2009). This study, based on Monsalve (2011), will a) examine the seasonal, monthly and weekly variations in the occurrence of respiratory diseases in the period 2000–2006; b) identify the major circulation weather types (CWTs) in winter and spring that affect Castilla-La Mancha (CLM); c) assess the possible links between the CWTs identified and the number of daily respiratory hospital admissions (RD); and d) identify the environmental variables (meteorological parameters as well as air pollutants) affecting respiratory diseases in winter and spring in CLM.

**MATERIALS AND METHODS**

**Study Area**

Castilla-La Mancha (CLM) is a region in central Spain made up of five provinces (Fig. 1(a)). This region is bordered by the Central Mountain Range to the North, by the Iberian Mountain Range to the northeast, and by the Mountains of Toledo to the south. Castilla-La Mancha has a total land area of 79,463 km².

The temperatures are extreme in this region, with very warm summers and very cold winters. The thermal oscillation is 18.5°C, due to its Mediterranean climate. The summer season is dry and the temperature often exceeds 30.0°C. In contrast, in winter the temperatures frequently fall below 0°C (reaching even -20.0°C). Frost occurs in clear nights and there are sporadic snowfalls. Rainfall is not very copious and it shows a pronounced gradient from the central region (around 400 mm per year) to mountainous zones (more than 1,000 mm per year).

With respect to CO, the inmission levels are very similar in the whole of the study zone, with average values between 0.3 and 0.5 μg/m³. In the case of NOx and NO2, the areas of Puertollano and the northern industrial zone – with local emissions of NOx and poor dispersion conditions – make them stand out from the rest of the study zone, with average values of NOx between 9.4 and 16.7 μg/m³, and between 16.0–26.1 μg/m³ for NO2. As for SO2 and O3, Puertollano is the only area with higher values than in the rest of the study zone due to an extraordinary anthropogenic contribution and peculiar dispersion conditions of pollutants; the average values range between 3.9–7.5 μg/m³ for SO2 and between 55.0–68.9 μg/m³ for O3. Finally, in the case of PM10 the values vary greatly between the different areas, mainly because of different local conditions. Two areas present only what may be considered background levels of pollutants: "Montes de Toledo" and "Montes de Guadalajara"; and another two areas present extremely high levels because of considerable anthropogenic contributions to the atmosphere: the northern industrial zone and Puertollano, with average values between 28.7 and 48.0 μg/m³ (Monsalve, 2011).

According to the population census of 2008 by the Spanish National Institute for Statistics (www.ine.es), the region has a total population of 2,043,100 inhabitants distributed over its total land area with an average density of 25.7 inhab./km². The population pyramid of Castilla-La Mancha (Fig. 2) is the typical one for a developed region, with a broad central area and narrower lower and upper areas. The population aged between 16 and 44 accounts for 44.0% of the total; the population between 45 and 64 represents 21.3%, and the group of over 65 amounts to 18% of the total. Finally, children under 16 are 15% of the total population. These data illustrate the progressive ageing of the population in Castilla-La Mancha. Considering gender, 50.25% of the inhabitants are males and 49.75% are females.

**Data**

For this analysis, daily hospital admission data were collected between January 1st 2000 and December 31st 2006 for residents living in CLM. The data were obtained from the hospital databases and kindly provided by Dr. A. Nájera, (Albacete, University of Castilla-La Mancha). The information was classified according to the International Classification of Diseases, Revision 10 (ICD-10). The hospital admission data concerning patients with respiratory diseases (ICD-10 J00-J99) were retained, and the data were also classified by gender and age (0–65 and over 65). The data were obtained from the following hospitals: Complejo Universitario de Albacete (2 hospitals), Complejo Hospitalario de Ciudad Real (2 hospitals), Hospital General Virgen de la Luz (Cuenca), Hospital General y Universitario (Guadalajara), and Complejo Hospitalario de Toledo (2 hospitals).

Daily records of mean temperature (T), pressure (P), relative humidity (RH) and radiation (Rad) are obtained from the Spanish National Agency for Meteorology (AEMET) for Albacete (38°57'N; 1°52'W; 704 m), C. Real (38°59'N; 3°55'W; 627 m), Cuenca (40°04'N; 2°18'W; 956 m), Guadalajara (40°38'N; 3°10'W; 708 m) and Toledo (39°53'N; 4°02'W; 516 m) at www.aemet.es, and the concentrations of PM10, CO, NOx, NO2, SO2, and O3 from the Air Quality Control Network in CLM for Albacete, Azuqueca de Henares (Guadalajara) (40°34'N; 3°16'W; 626 m), Puertollano (C. Real) (38°41'N; 4°40'W; 711 m) and Toledo. Although PM2.5 concentrations are important in respiratory diseases, these data were not available for our study period in particular.

For the aims of this study, spring is considered as the period between the 1st of March and the 31st of May, summer is the period between the 1st of June and the 31st of August, fall is the period between the 1st of September and the 30th of November, and winter is the period between the 1st of December and the 28th/29th of February.
Fig. 1. a) Study area: Region of Castilla-La Mancha (central Spain), with its five provinces. b) Location of the 16 points used to get the sea level pressure to compute the flow and vorticity variables.
Daily CWT Classification

Weather types are pressure patterns formed with a relatively high frequency and with common characteristics, but with varying intensities and directions according to the season of the year. Stark contrasts of the meteors tend to come with these weather types or with their movements. In the case of the Iberian Peninsula, weather types are usually classified into two main groups: anticyclonic and cyclonic circulation. CWTs have long been used to study the links between morbidity and mortality data and data related to atmospheric variations. We may mention here the studies by Kalkstein (1991), Kalkstein and Greene (1997), Pajares et al. (1997), McGregor (2001), González et al. (2001) and García Herrera et al. (2005).

This study follows the weather type classification put forward by Lamb (1972) and later implemented by Jenkinson and Collison (1977) and by Jones et al. (1993). The same classification has been used before to study rainfall patterns and air pollution in the Iberian Peninsula (Trigo and DaCamara, 2000; Calvo et al., 2012; Fernandez-Gonzalez et al., 2012).

This classification is based on indices describing the direction and vorticity of the geostrophic wind. The geostrophic wind is a physical approximation to real wind, the theoretical wind that would result from an exact balance between the Coriolis effect and the pressure gradient force. This is an objective classification, i.e., it does not depend on any particular individual carrying out the classification. Each weather type is determined according to 6 variables computed from the daily values of the atmospheric pressure at sea level recorded at 16 sites located around the Iberian Peninsula (Fig. 1(b)).

The surface pressure was obtained from the IRI (International Research Institute for Climate Prediction) at http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.pressure .html. The grid used is the same as the one employed by Trigo and DaCamara (2000). The synoptic situation of each day is classified into one of the 26 possible types of atmospheric circulation. This classification is later reduced to a smaller number of types.

From these data, a classification of 26 weather types was obtained for the Iberian Peninsula using the above-mentioned methodology: 2 types are based on the vorticity (A and C), 8 types are based on the flow, which we will call pure types (NE, E, SE, S, SW, W, NW, N), 8 hybrid cyclonic types (combination of C with the 8 pure types), and 8 hybrid anticyclonic types (combination of A with the 8 pure types). In order to simplify the classification obtained originally, we decided to define dominant types (Monsalve, 2011) as those whose frequency of occurrence surpasses the average value corresponding to the 2000–2006 period (Table 2). According to this criterion, the most frequent dominant winter weather types were: Anti-cyclonic (A), Cyclonic (C), Northeasterly (NE), Easterly (E), Southeasterly (SE), Southwesterly (SW), Westerly (W), as well as one type including hybrid transitional anti-cyclonic situations HASW (Hybrid anti-cyclonic southwesterly), a group which comprises days that could not be assigned unequivocally to one particular weather type. In spring the dominant CWTs were: A, C, NE, E, SW, W, N and HANW (Hybrid anti-cyclonic northwesterly). For a more in-depth explanation of this methodology, readers are referred to Spellman (2000) and Trigo and DaCamara (2000).

Hospital Admission Indices and Trends

McGregor et al. (1999) developed the hospital admission index due to respiratory diseases (RAI) to compare hospital admissions in different years. This RAI index is obtained using the following formula:

\[
\text{RAI} = \frac{N^o \text{ of daily hospital admissions (respiratory diseases)}}{\text{Annual average of admissions}} \times 100
\]

(1)

This index normalizes the number of admissions with respect to a daily average in one year. Thus, a RAI of 150 is interpreted as admissions being 1.5 times higher than the annual average.
**Statistical Analysis**

To determine the annual trends in hospital admissions due to respiratory diseases we have used linear regression techniques. The differences between the number of admissions per month, season and day of the week have been revealed using variance analysis (ANOVA, Snedecor’s F test with bilateral significance) and a non-parametric procedure, the Mann-Whitney U test, which is the one most widely used technique (Sneyers, 1990). U test is an alternative to the t-test which uses the relative magnitudes of the observations in two data series to determine their ranks within a single distribution. Hence, it does not require normality in the data distribution. The test checks that both data samples belong to the same population (null hypothesis). Very large or small U values imply a separation of the ordered observations and are evidence of a difference between the population distributions represented by samples.

The Chi-square test and a conditional probability test have been applied to determine the differences in the number of hospital admissions according to weather type.

Principal Component Analysis (PCA) is applied to identify the environmental variables (meteorological parameters as well as air pollutants) that affect respiratory diseases. PCA is a multivariate technique in which a number of related variables are turned into a smaller set of uncorrelated variables (principal components). The technique rewriting the original data matrix into a new set of principal components (hereafter Factors) which are linearly independent and ordered by the amount of the variance of the original data they explain. The advantage of using PCA is that this method finds a new set of uncorrelated variables that describe the principal variability or joint behavior of the data set. Geometrically, this new set of variables represents a principal axis rotation of the original coordinate axis of the variables around their mean and the projections of the variables onto each new axis are known as factor scores. It is essentially this process that has enabled us to find correlation patterns between the new axis and the original variables (factor loadings), not promptly identified in the analysis of the correlation matrix (Jolliffe, 1986).

The factor loadings are the standardized regression coefficients in the multiple regression equation with the original variable as the dependent variable, and the factors as the independent variables. If the factors are uncorrelated, the values of the coefficients are independent on each other. They represent the unique contribution of each factor and are the correlations between the factors and the variable. To identify the factors, it is necessary to group the variables with large loadings for the same factors.

To judge how well the n-factor model describes the original variables, we may compute the proportion of the variance of each variable explained by the n-factor model. Since the factors are uncorrelated, the total proportion of variance explained is simply the sum of the variance proportions explained by each factor.

In the present study, PCA has been applied with the purpose of obtaining regional series of atmospheric variables and pollutants (factor scores). The aim is to investigate patterns of variability in hospital admissions due to respiratory diseases in relation with meteorological parameters and air pollution, separating the variables into independent factors. The number of variables is 11 (T, P, RH, Rad, PM10, CO, NOx, NO2, SO2, O3 and RD) and the number of events is the number of days in each study).

**RESULTS**

**Annual Distribution of the Morbidity**

In the study period, a total of 129,910 hospital admissions (82,027 men and 47,883 women) were registered in the hospitals selected for the study with respiratory diseases.

Table 1. Out of these 129,910 hospital admissions, 55,273 (42.55%) corresponded to patients under 65. A classification by province revealed the following data: Albacete (21.4%, of which 42.55% < 65), C. Real (28.0%, of which 48.2% < 65), Cuenca (14.3%, of which 36.2% < 65), Guadalajara (10.1%, of which 41.9% < 65) and Toledo (26.3%, of which 40.1% < 65).

The daily average of hospital admissions was 50.85 (± 20.04), 32.10 (± 11.82) in the case of men (63.14%) and 18.74 (± 8.38) in the case of women (36.86%). The maximum daily incidence, all in all, was 174 admissions and the asymmetry (1.086) and sharpness (2.848) coefficients indicate that the frequency distributions were not strictly normal, 

| Table 1. Distribution of annual hospital admissions due to respiratory diseases over the 7 years studied. |
| --- |
| **year** | **Overall** | **Gender** | **Age** |
|  | **Male** | **Female** | < 65 | > 65 |
| 2000 | 15649 | 9950 | 5699 | 7303 | 8346 |
| 2001 | 16210 | 10411 | 5799 | 7546 | 8664 |
| 2002 | 17021 | 10829 | 6192 | 7165 | 9856 |
| 2003 | 19488 | 12271 | 7217 | 8049 | 11439 |
| 2004 | 19996 | 12583 | 7413 | 8359 | 11637 |
| 2005 | 22117 | 13982 | 8135 | 8571 | 13546 |
| 2006 | 19429 | 12001 | 7428 | 8280 | 11149 |
| **Total** | 129910 | 82027 | 47883 | 55273 | 74637 |
| **Annual Mean** | 18600 | 11700 | 6840 | 7900 | 10700 |
| **Annual Std. Dev.** | 2300 | 1400 | 940 | 560 | 1800 |
| **Daily Mean** | 50.85 | 32.10 | 18.74 | 21.64 | 29.21 |
| **Daily Std. Dev.** | 20.04 | 11.82 | 8.38 | 9.48 | 11.43 |
because asymmetry measurements, together with kurtosis, have been used to determine whether a statistical sample follows the normal or Gaussian distribution.

The total hospital admissions number due to respiratory diseases in the 7-year study period (Table 1) has shown a significant annual increase from the year 2000 to the year 2006 ($p < 0.01$), both according to gender and age. The highest number of admissions was registered in 2005: 1.4 times the value registered the first year.

**Seasonal, Monthly and Weekly Distribution**

Figs. 3 and 4 show the specific incidence of respiratory diseases by month and day of the week, according to gender and age, between 2000 and 2006. In the 84 months of the study period, the number of hospital admissions was higher in winter and decreased gradually until it reached its minimum value in summer. The results of the variance analysis have indicated that there are significant differences between seasons ($F = 428.3; p < 0.01$). In the summer, the number of admissions was lowest. These characteristics are similar to those reported in other developed countries (McGregor et al., 1999).

The monthly admissions due to respiratory diseases were more frequent in January (high significant positive correlations with $P_y$ and negative ones with $O_3$) and gradually decreased until the month of August (minimum value) (high positive correlation with $T$), with a new increasing trend after that month. The monthly differences were statistically significant (ANOVA, $F = 177.7; p < 0.01$). Similar figures were found by gender and age. In the weekly distribution, the highest number of admissions was recorded on Tuesdays, with a gradually decreasing trend until reaching the minimum on Sundays. There was a considerable increase between Sunday and Tuesday in the number of hospital admissions: 67.6%. There were statistical differences between the days of the week ($F = 141.89; p < 0.01$).

![Figure 3](image-url)  
*Fig. 3.* Morbidity (Daily average admissions) of respiratory diseases by month according to a) gender and b) age, between 2000 and 2006.
Fig. 4. Specific incidence of respiratory diseases by day of the week, according to a) gender, b) age and c) admissions index RAI in winter and spring, between 2000 and 2006.
The preliminary analysis revealed high values of the RAI index from Monday to Friday, and minimum values at the weekend. The Mann-Whitney U test showed significant differences between the values of RAI on Saturdays and the ones found between Monday and Friday (p < 0.01) (Fig. 4(c)).

The Frequency of Weather Types in Winter and Spring

The original 26 weather types were reduced to 8 dominant types in winter and spring. These 8 dominant weather types occurred on 70.5% of the winter days and on 73.4% of the spring days.

Table 2 shows the inter-annual variability of the frequencies of the dominant weather types in each season studied. The anti-cyclonic weather type (a high-pressure center over the Iberian Peninsula, and between the Iberian Peninsula, Madeira and the Azores) was dominant in both seasons along the study period. Some of the weather types were found to vary considerably along the study period. For example, in winter type E (an anticyclone between the British Isles and the Iberian Peninsula) varied between 0% and 14.4%, type SE (low-pressure regions extending from Madeira to the Azores Islands and high pressure over northern Europe) between 0% and 15.6%, and type C (a low-pressure center over the western Portuguese coast, sometimes accompanied by a blocking anticyclone located between Iceland and the British Isles) between 0% and 10.0%. The winter 2000-01 was remarkable for the low frequency of type A situations, and for the increase in the number of the types SW (a weakening of the Azores high pressure system and strong low-pressure systems between Iceland and the Azores), W (setting of the Azores high pressure at 30°N and low-pressure centers west of the British Isles) and HASW (a SW-NE oriented Azores anticyclonic curvature over the Iberian Peninsula, associated to a low-pressure system over the northwest of the British Isles). In spring, the most outstanding factor was the variability of type C situations (between 1.1% and 16.3%) and the less frequent type was type HANW (presence of the eastern limit of the Azores anti-cyclonic near the southwestern Iberian Peninsula and low-pressure center over the British Isles) with between 1.1 and 6.5% (Fig. 5).

Weather Variables and Atmospheric Pollutants in the Different Weather Types

In this section, PCA was carried out on the local variables T, RH, P and Rad for the period between January 2000 and December 2004. The aim was to reduce the daily data of the 5 local weather stations to single series of T, RH, P and Rad representing regional variables. It was thus possible to characterize meteorologically the different types of dominant situations in each period. In other words, one single climatic series was required for each variable to represent the whole study zone, instead of 4 different variables from the weather stations in each of the 5 provinces of the region. The same process was carried out with the daily local series of each of the pollutants.

For each meteorological parameter we have built the correlation matrix between the various provinces. The values of these correlations were over 0.80 for relative humidity, 0.95 for pressure, 0.90 for radiation and 0.97 for temperature. The same process was also carried out with the pollutants.

The analysis was applied onto the matrix formed by the daily data from the 5 local weather stations, for each variable and each pollutant. In all the cases, the determinant of the correlation matrix was nearly zero. The Kaiser-Meyer-Olkin test (Salvador and Gargallo, 2006) provided positive results (relative humidity: 0.88; pressure: 0.80; radiation: 0.70; temperature: 0.89). Bartlett’s test of sphericity (Salvador and Gargallo, 2006) provided results equal to zero in all cases.

Table 2. Percentage of occurrence of the eight dominant types in winter and spring: A: Anticyclonic; C: Cyclonic; N: North; NE: Northeast; E: East; SE: Southeast; SW: Southwest; W: West; HANW: Hybrid Anticyclonic Northwest; HASW: Hybrid Anticyclonic Southwest (after Monsalve, 2011).

| Winter | A   | C   | NE  | E   | SE  | SW  | W   | HASW |
|--------|-----|-----|-----|-----|-----|-----|-----|------|
| 1999-2000 | 63.3 | 4.4 | 4.4 | 6.7 | 3.3 | 1.1 | 1.1 | 2.2  |
| 2000-01  | 14.4 | 4.4 | 4.4 | 4.4 | 1.1 | 12.2| 18.9| 11.1 |
| 2001-02  | 41.1 | 0.0 | 2.2 | 7.8 | 15.6| 4.4 | 4.4 | 5.6  |
| 2002-03  | 27.8 | 3.3 | 6.7 | 0.0 | 0.0 | 12.2| 10.0| 10.0 |
| 2003-04  | 44.4 | 10.0| 1.1 | 2.2 | 3.3 | 2.2 | 2.2 | 6.7  |
| 2004-05  | 37.8 | 3.3 | 11.1| 14.4| 4.4 | 2.2 | 0.0 | 3.3  |
| 2005-06  | 20.0 | 5.6 | 3.3 | 6.7 | 6.7 | 2.2 | 5.6 | 0.0  |
| All Winters | 38.5 | 4.3 | 4.8 | 5.9 | 4.8 | 5.7 | 6.0 | 6.0  |

| Spring   | A   | C   | NE  | E   | SE  | SW  | W   | N   | HANW |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|------|
| 2000     | 19.6| 16.3| 9.8 | 6.5 | 2.2 | 4.3 | 4.3 | 3.9  |
| 2001     | 21.7| 1.1 | 13.0| 2.2 | 16.3| 13.0| 7.6 | 6.5  |
| 2002     | 23.9| 9.8 | 7.6 | 4.3 | 5.4 | 6.5 | 6.5 | 4.3  |
| 2003     | 21.7| 6.5 | 9.8 | 7.6 | 10.9| 6.5 | 9.8 | 2.2  |
| 2004     | 25.0| 3.3 | 17.4| 9.8 | 2.2 | 5.4 | 8.7 | 4.3  |
| 2005     | 31.5| 4.3 | 9.8 | 4.3 | 9.8 | 5.4 | 5.4 | 1.1  |
| 2006     | 29.3| 9.8 | 9.8 | 6.5 | 3.3 | 7.6 | 3.3 | 3.3  |
| All Springs | 24.7| 7.3 | 11.0| 5.9 | 7.1 | 7.0 | 6.5 | 3.9  |
Fig. 5. Examples of synoptic maps (1000 hPa, 0000 UTC) of selected weather types. a) Anticyclonic (A); b) flow from southwest (SW); c) hybrid anticyclonic from southwest (HASW) (Source: Met Office).
PCA applied onto the matrix formed by 450 days and 10 variables in winter and onto the matrix formed by 460 days and 10 variables in spring resulted in the variable scores of the new components. For each variable and for each pollutant we obtained a component explaining from 88% of the variance in the case of RH up to 99% in the case of T. In the atmospheric pollutants, they explained from 37% in the case of SO2 up to 86% in the case of O3. From the scores we obtained the average values of the different variables according to the dominant weather types in each season (Table 3).

**Conditional Probability Study**

To determine the difference in admissions according to weather type, the 630 daily values of RAI in winter and the 644 values in spring were divided into 4 groups according to the hospital admission risk (low: RAI < 99; medium: 100 < RAI < 124; high: 125 < RAI < 149 and very high: RAI > 150).

The Chi-square test revealed a significant dependence at the level of 0.05 of the RAI data according to weather type. The conditional probability, interpreted as the likelihood that the speed of admissions exceeds a certain level of occurrence of RAI according to the weather type, revealed the nature of this dependence (Table 4).

In winter, the following were outstanding factors: SW situations (with the highest T, see Table 3), A (maximum CO concentration) and HASW (maximum P and maximum concentrations of PM10, NOx, NO2) in the case of extreme events (RAI > 150); in contrast, in spring there were no differences. Also remarkable in winter are type E events (maximum Rad and maximum SO2 concentration) and SE types (minimum T) because of their high conditional probabilities for a RAI of 125 or more. In short, Table 4 shows that in winter, three CWTs (southwesterly, anticyclonic and hybrid anticyclonic southwesterly types) present values of admission rates 1.5 times above average. There were no significant differences in spring weather types, except in the case of type E events (minimum RH, minimum NOx).

### Days with a High RAI Index: The Study of Lags

To detect the possible time lag between exposure to weather conditions and RAI, the comparisons were carried out considering hospitalizations on the current day of each

| Winter | T | P | RH | Rad | PM$_{10}$ | CO | NO$_2$ | NOx | SO$_2$ | O$_3$
|--------|---|---|----|-----|----------|----|-------|-----|--------|----|
| NE     | -1.141 | 0.393 | 0.471 | -0.737 | -0.115 | 0.466 | 0.617 | 0.211 | 0.660 | -0.952 |
| E      | -1.400 | 0.267 | 0.451 | -0.681 | 0.110 | 0.601 | 0.897 | 0.154 | 1.011 | -0.856 |
| SE     | -1.403 | 0.595 | 0.880 | -1.154 | 0.121 | 0.878 | 1.006 | 0.444 | 0.569 | -1.144 |
| SW     | -0.916 | 0.247 | 1.252 | -1.325 | -0.256 | 0.546 | 0.653 | 0.265 | 0.591 | -1.098 |
| W      | -0.942 | -0.431 | 1.248 | -1.194 | -1.008 | 0.214 | 0.014 | -0.070 | 0.131 | -0.416 |
| C      | -1.159 | -1.514 | 1.448 | -1.365 | -0.786 | -0.004 | -0.120 | 0.001 | 0.089 | -0.524 |
| A      | -1.094 | 1.121 | 0.694 | -0.795 | 0.203 | 1.324 | 1.443 | 0.756 | 0.952 | -1.277 |
| HASW   | -1.014 | 1.192 | 1.143 | -1.109 | 0.303 | 1.112 | 1.477 | 0.810 | 0.749 | -1.418 |

| Spring | T | P | RH | Rad | PM$_{10}$ | CO | NO$_2$ | NOx | SO$_2$ | O$_3$
|--------|---|---|----|-----|----------|----|-------|-----|--------|----|
| NE     | -0.075 | -0.456 | -0.108 | 0.713 | -0.398 | -0.452 | -0.404 | -0.499 | -0.621 | 0.661 |
| E      | -0.386 | 0.175 | -0.519 | 0.299 | -0.178 | -0.346 | -0.457 | -0.334 | -0.575 | 0.605 |
| SW     | -0.095 | -0.491 | 0.163 | 0.210 | -0.357 | 0.036 | -0.296 | -0.229 | -0.292 | 0.051 |
| W      | -0.378 | -0.673 | 0.422 | 0.046 | -0.763 | -0.328 | -0.287 | -0.548 | -0.444 | 0.242 |
| N      | -0.336 | -1.109 | 0.404 | 0.015 | -0.849 | -0.373 | -0.421 | -0.520 | -0.779 | 0.596 |
| C      | -0.449 | -1.085 | 0.630 | -0.507 | -0.596 | -0.391 | -0.399 | -0.513 | -0.400 | 0.125 |
| A      | -0.011 | 0.599 | -0.322 | 0.669 | -0.098 | -0.240 | -0.191 | -0.030 | -0.350 | 0.094 |
| HANW   | -0.166 | -0.449 | 0.262 | -0.016 | -0.471 | -0.126 | -0.337 | -0.644 | -0.371 | 0.095 |

| Winter | Risk level | RAI class | A | C | NE | E | SE | SW | W | HASW |
|--------|------------|-----------|---|---|----|---|----|----|---|------|
| Low    | 0–99       | 52        | 63 | 57 | 46 | 57 | 55 | 61 | 68   |
| Medium | 100–124    | 26        | 33 | 27 | 30 | 23 | 33 | 29 | 16   |
| High   | 125–149    | 11        | 4  | 13 | 22 | 20 | 0  | 11 | 5    |
| Very high | > 150 | 11        | 0  | 3  | 3  | 3  | 0  | 12 | 0    |

| Spring | Risk level | RAI class | A | C | NE | E | SW | W | N | HANW |
|--------|------------|-----------|---|---|----|---|----|---|---|------|
| Low    | 0–99       | 52        | 57 | 58 | 68 | 50 | 60 | 45 | 48   |
| Medium | 100–124    | 28        | 21 | 28 | 21 | 21 | 35 | 20 | 38   |
| High   | 125–149    | 17        | 19 | 13 | 8  | 13 | 18 | 17 | 16   |
| Very high | > 150 | 4         | 2  | 1  | 3  | 2  | 2  | 0  | 0    |
weather type (lag = 0) up to admissions that occurred on the following three days (lag = 1, 2 and 3). No lags of more than 3 days were examined. The descriptive statistics (Table 5) showed that in winter, with situations of types NE, SE (minimum T), W (minimum PM₁₀, maximum O₃ concentration) and C (maximum RH and minimum P, Rad, NOₓ, SO₂), the average RAI values on the same day (lag = 0) and in the following days (lag = 1, 2 y 3) were always under 100. This means that the average of admissions was always lower than the average value for the whole period. In contrast, in situations of type A (maximum CO concentration) the average RAI values were always higher than 100, with a tendency to increase with the lag. Situations of type E (maximum Rad, minimum RH and maximum concentration of SO₂) and HASW provided opposite RAI values according to the lag, observing the maximum RAI in (lag = 0) and (lag = 3), respectively.

In spring, with SW situations (maximum concentrations of CO and SO₂ and minimum O₃) and A situations (maximum T and P, and maximum concentrations of PM₁₀, NOₓ and NO₂), the RAI values were always higher than average (100) the same day (lag = 0) and later; in contrast, in situations of type N (minimum P, PM₁₀ and SO₂) they were always lower. In situations of type E (minimum RH and NO₃) and HANW (minimum NO₂) the RAI values were higher than 100, except if lag = 0.

**Links between Environmental Variables and Morbidity (RD)**

In this section, PCA was applied with the purpose of investigating patterns of variability relating meteorological parameters, air pollution and morbidity, and separating them into different independent factors in winter and spring.

As mentioned above in the section on the statistical analysis, to identify the factors, it was necessary to group the variables with large loadings for the same factors. The factors obtained (after Varimax rotation) for winter and spring with an eigenvalue higher than 1 are shown in Table 6. These coefficients may be interpreted as the correlation of each Factor with each of the original variables. For these coefficients, no threshold value was considered as the criterion to associate a particular variable to one or the other Factor; instead, each variable was assigned to the most closely related Factor, i.e., the one that corresponded to the coefficient with the highest absolute value. In winter, Factor 1 explained 37.4% of the total variance; it revealed that all the air pollutants (loadings between 0.587 at SO₂ and 0.891 at NO₄) and the P variable (0.458) were strongly associated (possibly due to the winter high, which makes the pollution events last longer), and in an opposite way to O₃ (–0.875). In contrast, the respiratory morbidity (RD) presented a very low positive weight (0.075). Factor 2 explained 20.0% of the total variance and it presented a very low negative weight with respect to RD (–0.013), a high negative association with RH (–0.958) and a high positive association with Rad (0.919), P (0.314) and SO₂ (0.389). Factor 3 explained 11.1% of the total variance and illustrated that RD had a high negative weight on this component (–0.702) with a positive association with T (0.817). This third factor implied the opposite relation between respiratory morbidity and T in winter, illustrating the influence of atmospheric conditions on respiratory morbidity in winter.

In spring, there were some remarkable similarities and also differences with winter. For instance, Factor 1, which explained 36.9% of the total variance, showed that all the air pollutants and the meteorological parameter P could be grouped into this factor. On the other hand, Factor 1 was not closely linked to RD, because of the very low positive weight (0.071). Factor 2, which explained 26.1% of the total variance, did not show any significant weight on RD (–0.120), but there was a strong positive association between T (0.842) and Rad (0.926), and a negative association with RH (–0.874). Factor 3, which explained 9.8% of the total variance, was more closely related Factor, i.e., the one that corresponded to the coefficient with the highest absolute value. In spring, Factor 1 explained 37.4% of the total variance; it revealed that all the air pollutants (loadings between 0.587 at SO₂ and 0.891 at NO₄) and the P variable (0.458) were strongly associated (possibly due to the winter high, which makes the pollution events last longer), and in an opposite way to O₃ (–0.875). In contrast, the respiratory morbidity (RD) presented a very low positive weight (0.075). Factor 2 explained 20.0% of the total variance and it presented a very low negative weight with respect to RD (–0.013), a high negative association with RH (–0.958) and a high positive association with Rad (0.919), P (0.314) and SO₂ (0.389). Factor 3 explained 11.1% of the total variance and illustrated that RD had a high negative weight on this component (–0.702) with a positive association with T (0.817). This third factor implied the opposite relation between respiratory morbidity and T in winter, illustrating the influence of atmospheric conditions on respiratory morbidity in winter.

**Table 5.** Descriptive statistics of the mean value of RAI according to the weather type (lag). The 95% confidence interval for the mean value of RAI is shown between brackets (after Monsalve, 2011).

| Lag | Winter | A     | C     | NE    | E     | SE    | SW    | W     | HASW |
|-----|--------|-------|-------|-------|-------|-------|-------|-------|------|
|     |        | (101–112) | (84–100) | (88–106) | (88–127) | (88–110) | (83–119) | (88–103) | (80–111) |
| 0   | 106    | 92    | 97    | 107   | 99    | 101   | 96    | 103   | 95   |
|     | (101–112) | (84–100) | (88–106) | (88–127) | (88–110) | (83–119) | (88–103) | (80–111) |
| 1   | 108    | 93    | 93    | 105   | 96    | 117   | 86    | 100   |      |
|     | (102–113) | (85–102) | (85–102) | (92–119) | (80–111) | (74–160) | (79–94) | (85–114) |
| 2   | 108    | 99    | 99    | 100   | 94    | 83    | 87    | 103   |      |
|     | (103–114) | (89–108) | (89–109) | (79–121) | (81–108) | (43–120) | (78–96) | (90–116) |
| 3   | 109    | 94    | 98    | 97    | 95    | 61    | 87    | 103   |      |
|     | (103–114) | (85–103) | (89–108) | (88–106) | (80–110) | (22–101) | (79–94) | (88–118) |

| Lag | Spring | A     | C     | NE    | E     | SW    | W     | N     | HANW |
|-----|--------|-------|-------|-------|-------|-------|-------|-------|------|
| 0   | 118    | 91    | 100   | 98    | 104   | 108   | 95    | 95    |      |
|     | (106–129) | (83–99) | (94–106) | (89–108) | (95–113) | (100–116) | (86–104) | (86–103) |
| 1   | 116    | 100   | 97    | 106   | 102   | 100   | 97    | 101   |      |
|     | (104–127) | (92–107) | (91–104) | (96–116) | (92–112) | (91–109) | (86–109) | (92–110) |
| 2   | 114    | 103   | 101   | 105   | 102   | 99    | 96    | 101   |      |
|     | (102–126) | (95–110) | (92–111) | (97–114) | (93–111) | (90–108) | (85–107) | (91–111) |
| 3   | 111    | 95    | 101   | 102   | 100   | 106   | 99    | 100   |      |
|     | (99–123) | (88–102) | (92–110) | (93–112) | (91–110) | (98–114) | (88–110) | (92–109) |
Table 6. Principal component analysis for winter and spring (Varimax rotation).

| Variable | Winter          |          |          | Summer          |          |          |
|----------|-----------------|----------|----------|-----------------|----------|----------|
|          | Factor 1 | Factor 2 | Factor 3 | Factor 1 | Factor 2 | Factor 3 |
| T        | -0.023   | 0.068   | 0.817    | -0.133   | 0.842   | -0.073   |
| P        | 0.458    | 0.314   | 0.281    | 0.689    | 0.352   | -0.184   |
| RH       | 0.079    | -0.958  | 0.031    | -0.219   | -0.874  | 0.145    |
| Rad      | 0.065    | 0.919   | 0.159    | -0.003   | 0.926   | 0.044    |
| PM_{10}  | 0.769    | 0.238   | 0.087    | 0.743    | 0.260   | -0.021   |
| CO       | 0.884    | -0.019  | -0.102   | 0.676    | 0.038   | 0.400    |
| NO\textsubscript{x} | 0.891   | 0.041   | -0.041   | 0.786    | -0.183  | 0.294    |
| NO\textsubscript{2} | 0.758   | -0.082  | -0.133   | 0.793    | 0.054   | 0.401    |
| SO\textsubscript{2} | 0.587   | 0.389   | -0.095   | 0.760    | -0.105  | -0.158   |
| O\textsubscript{3} | -0.875  | 0.262   | -0.017   | -0.722   | 0.458   | -0.093   |
| RD       | 0.075    | -0.013  | -0.702   | 0.071    | -0.120  | 0.899    |
| % Var    | 37.4     | 20.0    | 11.1     | 36.9     | 26.1    | 9.8      |

variance, showed a strong positive association with RD (0.899) and smaller coefficients with all the contaminants, mainly CO (0.400) and NO\textsubscript{x} (0.401). Thus, in spring the relationship between RD and the other variables was less clear, and one cause may be the respiratory morbidity. In any case, if the variable RD was assigned to this third factor, it would seem that respiratory morbidity was more closely linked to the concentrations of some pollutants (like CO, NO\textsubscript{x} and NO\textsubscript{2}) than to the meteorological parameters.

Finally, a remarkable fact must be highlighted here: two of the variables (namely RH and O\textsubscript{3}) were linked to their assigned factors through a negative coefficient. The physical meaning was very simple: the behavior of these variables was opposite to the others included in the same factor, i.e. when this variable increased, all the other variables in the same factor would decrease, and vice versa. The negative sign of the Ozone loading was similar to the one found in Sao Paulo (Gonçalves et al., 2007).

**DISCUSSION**

As far as the authors know, there have been no previous studies addressing the influence of weather types on health indicators on the Central Spanish Plateau. This paper has presented the results obtained by analyzing the association between daily weather types and hospital admissions due to respiratory diseases in Castilla-La Mancha along seven years (2000–2006). The objective weather type classification by Lamb (1972) has been used, which has also recently been applied to rainfall patterns in the Iberian Peninsula (Fernandez-Gonzalez et al., 2012). Other authors like Hanna et al. (2011) have found that certain synoptic air masses (dry tropical, transitional and extreme moist tropical) in conjunction with ambient ozone air levels were associated with increased asthma hospitalizations. In our study, it was very useful to reduce the total number of situations to a smaller, more manageable number for each period in order to achieve plausible conclusions.

The time-distribution of daily morbidity relating to age and gender may be considered typical, and this fact has been studied on many other occasions. Low thermoregulation is possibly the main factor explaining the high morbidity among the elderly, as suggested by Graudenz et al. (2006). It would be interesting for the future to assess the influence of some other factors, such as the socio-economic status or previous pathologies (O’Nell et al., 2003; Bateson and Schwartz, 2004; Jerrett et al., 2004; O’Nell et al., 2005).

The gradually decreasing weekly trend of admissions until reaching a minimum on Sundays was due probably to a number of causes, such as an increased difficulty in transport during the weekend; more studies should focus on this aspect.

The present work has shown that hospital admission numbers due to respiratory diseases in CLM were strongly related to specific weather types. We have found a remarkable link between the anticyclonic component situations and high concentrations of contaminants, in conjunction with a high RAI in winter. In fact, several studies have evaluated associations between air pollution and hospital visits for respiratory diseases (Stieb et al. 2009): concentration of CO exhibited a correlation with upper respiratory infection (Peel et al., 2005), concentration of NO\textsubscript{2} with asthma (Erbas et al., 2005), concentration of particulate matter with pneumonia (Peel et al., 2005), concentration of SO\textsubscript{2} with asthma (Wilson et al., 2005) and concentration of O\textsubscript{3} with asthma too (Jaffe et al., 2003).

In relation with the similarities shown by the weather types A, SW and HASW, one could look for a meteorological reason. For example, do A and SW weather types have any features in common? Obviously they are different, but not opposite. In fact, A and SW refer to different synoptic parameters: A is linked to vorticity and SW to flow direction. The HASW type involves some characteristics of both A and SW weather types.

It must be reminded here, that no data were available for our study period on PM\textsubscript{2.5} nor on ultrafine particles, both very important for respiratory health. Taking into account these limitations, we argue that the results obtained are congruent with the conclusions of the study by Hanna et al. (2011). Bucholz et al. (2010) found that the air quality, related with ozone and PM\textsubscript{10} concentrations, was better in cyclonic situations than in anticyclonic ones. We may explain these results with the fact that air movement is easier in cyclonic situations. McGregor et al. (1999) and McGregor (2001) found different differential responses of
respiratory admission rates and ischemic heart disease mortality events for the Birmingham area (UK) in relation with different winter air mass types and large-scale atmospheric circulation variables.

We have observed associations between air pollution concentrations and hospital admissions by respiratory diseases with lags from zero to three days. There are also positive associations between temperature and pressure with emergency admissions in spring for the anticyclonic weather type. These results were congruent with the ones found by Pudpong and Hajat (2011), who demonstrated that the effects of high temperatures could be noted in an increased morbidity by respiratory diseases with lags of up to two weeks. On the other hand, De Pablo et al. (2009) found significant increases in hospital admissions up to 2–3 days after weather type C and up to 4 days after type NE.

It is remarkable that, in some articles, the effects of the O₃ have been found as predominant up to lag 2 for respiratory emergency visits (Gouveia and Fletcher, 2000b; Lin et al., 2008; Stieb et al., 2009). In contrast, in our study, in winter, the maximum value for ozone was related with type W, whose days have an average index of admissions lower than the average for all the lags. A possible reason for this result could be the lower traffic pollution in our study area in comparison with the cities discussed in the articles mentioned above.

We consider the inclusion of the Principal Component Analysis positive because of the difficulties of researchers in designing consistent models to integrate all the contaminants. This technique has already been applied by González et al. (2006), who have investigated variations in concentrations of pollutants in Campo de Gibraltar. In our case, the results are congruent with the investigations by Gonzalves et al. (2005) and Braga et al. (2000). Later, Peng et al. (2009) also found positive relations between particle matter and morbidity by respiratory diseases.

Lin et al. (2008) pointed out two limitations in their study that we have also encountered: first, hospital admission data only register the most severe cases and miss most mild cases; and second, these data cannot distinguish between incident and prevalent disease. An additional difficulty arises at this point: the study of the relation between particulate matter and health is difficult because of the complexity of the chemical composition of PM, as shown in Cardenas et al. (2008).

And lastly, because the weather types affecting a particular location may be forecast routinely (Rantamaki et al., 2005; Otero et al., 2008), the methodology described in this study could assist the health authorities in taking relevant decisions and implementing suitable preventive measures and interventions, targeting lifestyles or types of behaviors known to be risk factors.

The main limitation of the present study is that, although the amount data of hospital admissions for respiratory causes is significant, the results would be improved if a long-term study covering more than seven years could be undertaken. For this reason, it was decided not to consider gender or age groups. These results cannot be extrapolated to a larger territory owing to the limited geographical area under study.

CONCLUSIONS

The main conclusions that may be drawn from the analysis are the following:

- In the study period (2000–06), the mean number of daily hospital admissions was 50.85, the maximum daily incidence was 174. The male/female ratio is 1.7 for men and the age > 65/age < 65 ratio is 1.3.
- The results showed a clear link between morbidity and the values of the meteorological parameters. The asymmetry and sharpness coefficients indicated that the frequency distribution of the respiratory diseases was not strictly normal. The hospital admissions number over the seven years studied showed a significant linear increase from 2000 to 2006 (p < 0.01).
- There were significant differences between the values of the different seasons (p < 0.01), with maximum values in winter and minimum values in summer, as in other Mediterranean countries. There were also significant differences between the values of the different months (p < 0.01), with the maximum in January and the minimum in August.
- The maximum number of admissions was found in the middle of the week (Tuesday–Thursday) and the lowest number of admissions was observed at the weekend, regardless of gender and age. Such results could be due to the fact that patients who feel unwell during the weekend tend to wait until Monday–Tuesday to go to hospital for their own convenience.
- Observing the relationships between the risk of admissions and the daily atmospheric condition recorded in CLM, the results obtained show that:
- In cases of extreme events (RAI > 150), we found the relative importance in winter of situations SW, A and HASW; in contrast, in spring there were no differences.
- The descriptive statistics showed that, in winter, with situations of type A, the average RAI values on the same day (lag = 0) and on the following days (lag = 1, 2 and 3 days) were always higher than 100. This happened in spring with situations of types SW and A, indicating that the effects of the weather conditions continue in these weather types during several days after the event itself. This is consistent with findings of recent studies in the UK. The effect of the weather type has not been studied for lags of more than 3 days.
- When applying a Principal Components Analysis, the Factors obtained in winter (opposite relation between respiratory morbidity and temperature), have indicated the influence of atmospheric conditions on morbidity in this season, something which could be of interest for the health authorities. In contrast, in spring, the respiratory morbidity was more closely linked to the concentrations of some pollutants (like CO, NOₓ and NOₓ) than to the meteorological parameters.

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