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ORIGINAL ARTICLE

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Effects of extremely hot days on people older than 65 years in Seville (Spain) from 1986 to 1997

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Abstract The effects of heat waves on the population have been described by different authors and a consistent relationship between mortality and temperature has been found, especially in elderly subjects. The present paper studies this effect in Seville, a city in the south of Spain, known for its climate of mild winters and hot summers, when the temperature frequently exceeds 40 °C. This study focuses on the summer months (June to September) for the years from 1986 to 1997. The relationships between total daily mortality and different specific causes for persons older than 65 and 75 years, of each gender, were analysed. Maximum daily temperature and relative humidity at 7.00 a.m. were introduced as environmental variables. The possible confounding effect of different atmospheric pollutants, particularly ozone, were considered. The methodology employed was time series analysis using Box-Jenkins models with exogenous variables. On the basis of dispersion diagrams, we defined extremely hot days as those when the maximum daily temperature surpassed 41 °C. The ARIMA model clearly shows the relationship between temperature and mortality. Mortality for all causes increased up to 51% above the average in the group over 75 years for each degree Celsius beyond 41 °C. The effect is more noticeable for cardiovascular than for respiratory diseases, and more in women than in men. Among the atmospheric pollutants, a relation was found between mortality and concentrations of ozone, especially for men older than 75.

Keywords Hot days · Temperature · ARIMA · Mortality · Elderly

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Introduction

Classically, mortality has been considered as an indicator of the population's health and of its conditions of life. Various studies in different countries indicate that the seasonal behaviour of daily mortality as a function of diverse environmental variables, especially temperature (Montero et al. 1997; Alberdi et al. 1998), has a V-shaped functional relationship (Kunst et al. 1993; Sáez et al. 1995). When specific causes of mortality are analysed, it is found that the increase in winter and summer mortality involves respiratory and cardiovascular diseases especially in the elderly (Pan et al. 1995; Alberdi and Díaz 1997).

The importance of the phenomenon is clear, since the so-called heat waves are, for some authors (Kalkstein and Greene 1997), the primary cause of mortality associated with natural catastrophes. According to models that estimate possible climate warming (IPCC 2001), summer mortality would increase substantially (Smith and Tirpak 1989; Semenza et al. 1996, 1999; Ungar 1999), while winter mortality would decrease (Kalkstein and Greene 1997).

The effects on health of the combination of temperature with other environmental factors, such as atmospherics pollutants, have also been investigated (Katsouyanni et al. 1993; Sartor et al. 1995; Samet et al. 1998). In summer, emissions of pollutants associated with fixed sources that use fossil fuels (such as sulfur dioxide and particles in suspension) diminish considerably. On the other hand solar radiation, together with the increased temperatures cause an increase in photochemical pollutants, especially ozone. Its strong oxidizing properties produce inflammatory responses in humans, made evident by cellular and biochemical changes, especially at high concentrations (Koren et al. 1989).

The objective of this work is to investigate the influence of meteorological and air pollution variables on the total daily mortality in persons over 65 years of age, specifically those dying from circulatory and respiratory diseases, in the city of Seville, where summer daily maxima frequently exceed 40 °C.

Materials and methods

The data used were taken from records of daily deaths between 1986 and 1997 among residents in the city of Seville (Fig. 1). From the same record, data on the sex, age group, and specific causes of mortality were taken. The groups of causes selected were as follows: all causes except accidents (ICD-9 codes 1–799), diseases of the circulatory system, (390–459) and diseases of the respiratory system (460–519). The study focused on the population over 65 years of age since this group is responsible for most of the excess summer mortality (Alberdi and Díaz 1997; Whitman et al. 1997; Semenza 1999), for both genders. A separate analysis was performed for persons over 75 years. Therefore, the mortality variables are the following:

- Daily mortality for all causes for those over 65 years (All 65)
- Daily mortality for all causes for men over 65 years (Allm 65)
- Daily mortality for all causes for women over 65 years (Allw 65)
- Daily mortality for respiratory causes for those over 65 years (Resp 65)
- Daily mortality for circulatory causes for those over 65 years (Circ 65)
- Daily mortality for all causes for those over 75 years (All 75).

The environmental variables are daily maximum temperature (*T*max) and relative humidity (*H*r) at 7 a.m.; they were made available by the National Institute of Meteorology. Daily average pollutant values were calculated by averaging hourly values from the local monitoring network in Seville. The pollutants considered are: sulfur dioxide (SO_2), total particulates in suspension, nitrogen dioxide (NO_2) and tropospheric ozone (O_3). The pollutant data were recorded from 1992 to 1997 except for those relating to ozone (from 1994 to 1997). These data were made available by the Regional Ministry of Environment. During the modelling procedure only the summer months (from June to September) were considered, since this is the period when maximum values are reached in Seville.

Sine and cosine variables with a 4-month period (120 days) were created to account for the seasonal confounding. Previous research (Díaz et al. 1998, 1999; González et al. 2001) has shown that the associations between mortality and pollution and between mortality and temperature are non-linear. To identify the type of relationship, dispersion diagrams were plotted using those days with the highest mortality (95th percentile of the mortality series). They were linear for all cases except for tropospheric ozone, which was quadratic, with an inflexion at the daily average of 35 μg/m³ (Fig. 2). See Díaz et al. (1999) for more details. This allows two new variables relating to tropospheric ozone to be defined:

$$O_{3H} = O_3 - 35 \quad \text{if } O_3 > 35\mu g/m^3$$

$$O_{3L} = 35 - O_3 \quad \text{if } O_3 < 35\mu g/m^3$$

A Lowess fitting procedure was used to adjust the curve according to the different temperatures ranges. We defined extremely hot days as those with a maximum temperature higher than the inflexion value in the mortality/temperature curve (Fig. 3).

The lagged effect of pollution on mortality is well known; so, on the basis of results obtained from previous studies in the same region (Díaz et al. 1998, 1999; González et al. 2001), lags of up to 4 days are considered for sulfur dioxide, particulates and nitrogen dioxide, and up to 8 days for ozone.

Univariate ARIMA were used initially (Makridakis et al. 1983). We ensured that their partial autocorrelation function and simple autocorrelation functions were white noise.

Next, the series were prewhitened through Box-Jenkins methodology (Box and Jenkins 1980) to eliminate the existence of analogous periodicities and autocorrelation between the series of mortality and temperature. Once the series were prewhitened, the residual cross correlation functions were computed to identify those lags with significant relationship between the variables. This led to lagged variables being created for all environmental variables.

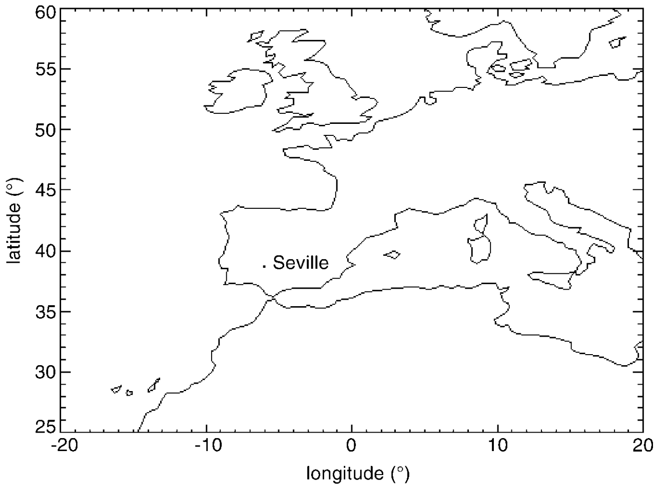

Fig. 1 Map of Europe showing the location of Seville

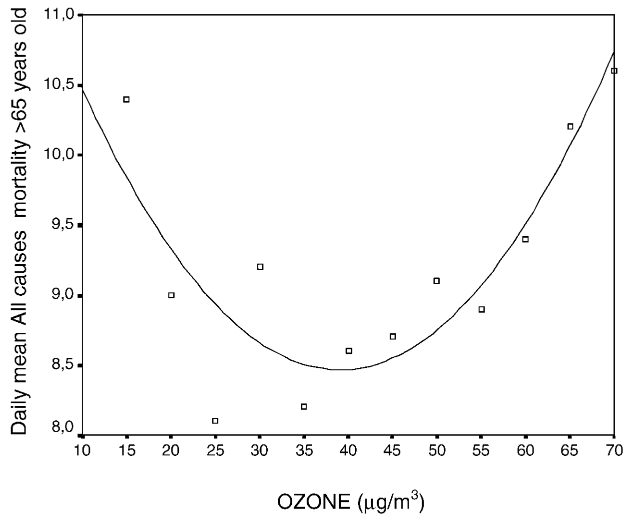

Fig. 2 Scatter-plot diagram for daily "all causes" mortality over the age of 65 years and tropospheric ozone

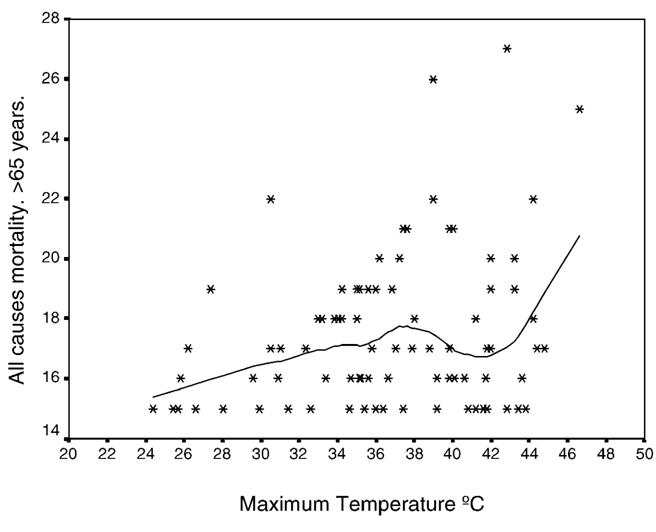

Fig. 3 Scatter-plot diagram for daily "all causes" mortality over the age of 65 years and maximum temperature

Table 1 Descriptive statistics for the mortality and environmental variables. Only the summer months (from June to September) were considered. The variables are defined in Materials and methods

Variable	Maximum	Minimum	Mean	SD
All 65	27	0	8.9	3.5
Allm 65	12	0	4.0	2.1
Allw 65	18	0	4.9	2.6
Resp 65	7	0	1.3	1.2
Circ 65	17	0	4.2	2.3
All 75	21	0	6.1	2.9
SO_2 (μg/m^3)	18	2	7.3	2.6
TSP (μg/m^3)	112	17	45.9	13.2
NO_2 (μg/m^3)	92	11	45.1	13.6
O_3 (μg/m^3)	69	8	38.2	11.1
*T*max (°C)	46.6	20.6	33.7	4.5
*H*r(%)	100	18	72.6	13.3

Finally, multivariate ARIMA models with the environmental variables as exogenous variables were used to describe mortality behaviour. Variables for long-term trends, seasonality, temperature and air pollutants were included in these models. Minimal residual variance was the main criterion used for model selection. For each mortality group, all variables were introduced; only those that were significant at the 95 % level were retained.

Results

Descriptive statistics are shown in Table 1. The maximum concentrations reached by the primary pollutants are lower than the levels set by Spanish law and WHO (World Health Organization 1987).

The temperature/mortality dispersion diagram (Fig. 3) shows that for temperatures above 41 °C the slope of the curve (and consequently the impact of temperature on mortality) rises abruptly. This value was the threshold chosen to define extremely hot days in Seville. Coincidentally, this value is also the 95th percentile of the maximum temperature series.

In Fig. 4 it can be noted that extreme heat tends to persist for fewer than 3 days; only on rare occasions lasting for more than 4; thus, the term "heat wave" should not be used to describe extreme heat events in Seville. When the excess mortality is analysed for extremely hot days, it can be observed that the effect increases with the persistence of high temperatures (Fig. 5). The excess reached 89% of the average daily mortality during the heat wave of 1995, which lasted 11 days.

In order to analyse further the effect of maximum temperature and take into account the dispersion diagram, two new temperature variables were defined:

$$T\text{hwave} = T\max - 41, \quad \text{if } T\max > 41\,^{\circ}\text{C}$$
$$T\text{cwave} = 41 - T\max, \quad \text{if } T\max < 41\,^{\circ}\text{C}$$

Figure 6 shows the results obtained for the prewhitened cross correlation functions between maximum temperature and mortality for all causes for subjects over 65 years old. It can be noted that a significant effect exists and extends from lag 1 to lag 3.

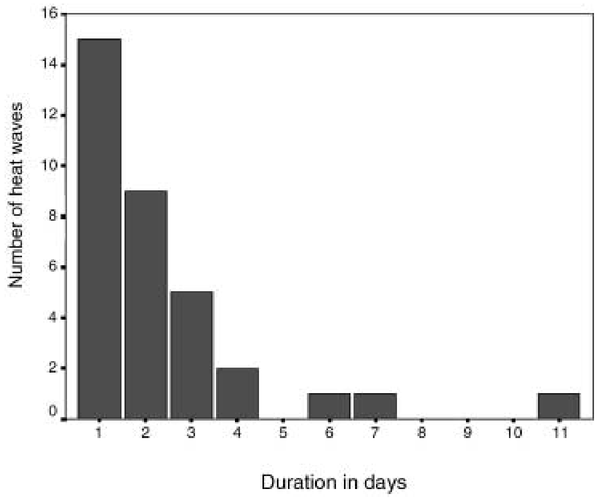

Fig. 4 Bar chart corresponding to the number of heat waves and the duration in days

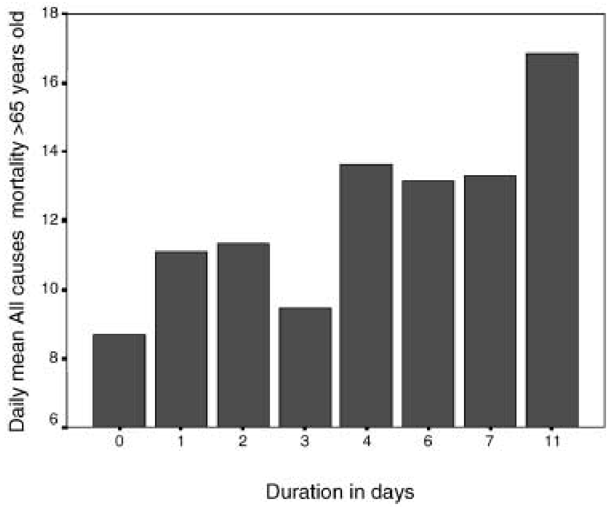

Fig. 5 Bar chart corresponding to the effect of duration in days of heat wave

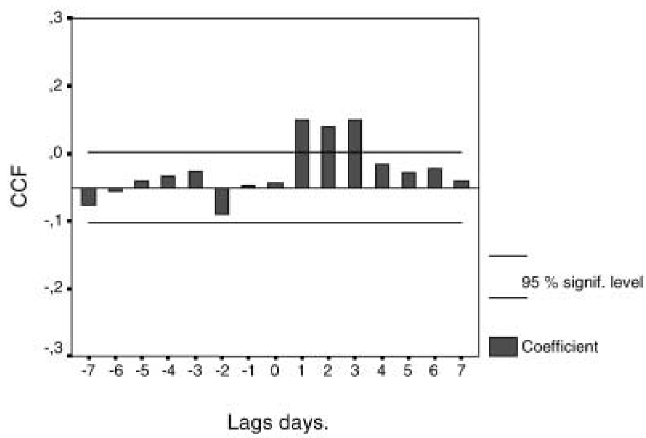

Fig. 6 Cross-correlation function (*CCF*) between "all causes" mortality over the age of 65 years and maximum temperature

Table 2 Complete statistically complete equations for mortality variables. M_t refers to mortality in day t, E_{t-1} include the moving average term, which is related to the previous residuals of the previous day. *T*hwave = T_{max} values higher than 41 °C. O_{3H} = O_3 values higher than 35 μg/m³. $t-1$ indexes refer to the previous *i* days.

Mortality variables	Complete statistically derived equations
All 65	$M_t = 0.97\,M_{t-1} + 0.94\,E_{t-1} + 1.84\,T\text{hwave}_{t-1} + 1.58\,T\text{hwave}_{t-2} + 0.14\,O_{3Ht-1} + 8.65$
Allm 65	$M_t = -0.97\,M_{t-1} - 0.96\,E_{t-1} + 0.61\,T\text{hwave}_{t-2} + 0.55\,T\text{hwave}_{t-4} + 0.07\,O_{3Ht-1} - 0.02\,\text{Hr}_{t-6} + 2.75$
Allw 65	$M_t = 0.95\,M_{t-1} + 0.91\,E_{t-1} + 1.18\,T\text{hwave}_{t-1} + 1.08\,T\text{hwave}_{t-2} - 0.01\,\text{Hr}_{t-2} + 5.73$
Resp 65	$M_t = 0.81\,M_{t-1} + 0.73\,E_{t-1} + 0.39\,T\text{hwave}_{t-1} + 1.32$
Circ 65	$M_t = -0.46\,M_{t-1} - 0.42\,E_{t-1} + 1.40\,T\text{hwave}_{t-1} + 0.72\,T\text{hwave}_{t-3} + 0.10\,O_{3Ht-8} - 0.02\,\text{Hr}_{t-2} + 5.91$
All 75	$M_t = 0.51\,M_{t-1} + 0.56\,E_{t-1} + 1.58\,T\text{hwave}_{t-1} + 0.95\,T\text{hwave}_{t-2} + 0.64\,T\text{hwave}_{t-4} + 0.12\,O_{3Ht-2} + 2.47$

Table 3 The percentage contribution of the *T*hwave (by each °C) effect on daily mean mortality during the study period. How Table 3 was calculated is indicate in the text

Mortality variables	Contribution of *T*hwave (%)
All 65	38
Allm 65	29
Allw 65	46
Resp 65	29
Circ 65	49
All 75	51

Table 2 shows the complete statistically derived equations for the different causes of mortality analyzed. It can be seen that Thwave is the variable most strongly related to mortality, since it shows higher coefficients and it explains a greater percentage of variance than the other variables.

The model for all causes over 65 years is show below as an example. In this case trend and seasonal components were not significant at the 95% level. The model has three prats: autoregresive, moving average and exogenous inputs, which, in this case, include the environmental variables.

$$M_t = 0.97\,M_{t-1} + 0.94\,E_{t-1} + 1.84\,T\text{hwave}_{t-1} + 1.58\,T\text{hwave}_{t-2} + 0.14\,O_{3Ht-1} + 8.65$$

M_t refers to mortality in day t, while $t-1$ indexes refer to the previous i days. E_{t-1} include the moving average term, which is related to the previous day residuals.

Table 3 shows the mortality increase for a 1° increase above 41° for each mortality group. Table 3 was calculated addend the Thwave contribution and calculating the percentage on the daily mean mortality during the study period, as an example the *T*hwave contribution for all causes mortality over 65 is 3.42 (1.84+1.58), which means a 38% increase over the daily mean mortality for this cause (8.9 deaths/day). It can be deduced that this effect is more important in women than in men and that its effect is greater for the older population. When specific causes are considered, the circulatories show the closest association. For pollutants, tropospheric ozone is the only one that shows a significant relationship with mortality (mainly with mortality due to circulatory problems in males). The effect of relative humidity, on the contrary, is significant for women and in the sense that an atmosphere with low humidity favors an increase in mortality.

Discussion

The threshold temperature of 41 °C is much higher than that established for Belgium at 27.5 °C (Sartor et al. 1995), higher than that for other places like Madrid, where the figure is 36.5 °C (Díaz et al. 2001), Japan at 38 °C (Nakai et al. 1999) or Chicago at 37.8 °C (Whitman et al. 1997), and similar to that for St Louis (Smoyer 1998), where the threshold value was set at 40.8 °C. This suggests that, in Seville, the effect of acclimation is important. Humans possess certain physiological characteristics that allow them to adapt to certain ecological niches, such as those in the tropics (Scholander et al. 1950), and the rest are the result of a progressive acclimation to conditions where they reside (Douglas et al. 1991a, b).

On the other hand, just as in Madrid (Díaz et al. 2001), extremely hot days in Seville are not very persistent, only three episodes longer than 4 days being recorded in the period evaluated. The longest was 11 days. This period is much shorter than the 42 days noted in Belgium (Sartor et al. 1995) in 1994 and is similar to periods recorded in Mediterranean Europe, such as Athens in 1987 (Katsouyanni et al. 1993). The reason for this short average duration is the meteorological pattern generating these extreme values (García et al. 2002). They are, in general, very dynamic, associated either with troughs over the Iberian Peninsula, or with flows of African origin. Their nature makes them evolve rapidly, usually in less than 48 h, thus leading to episodes of short duration.

The effects recorded in Fig. 4, showing an increase of mortality with the duration of the heat wave, are coherent with those described in other studies on the effects of heat waves on mortality (Semenza et al. 1999; Whitman et al. 1997; Smoyer 1998), notably that by Greenberg et al. (1983), which suggests that the persistence of high temperatures is the principal cause of excess deaths. In a recent study done in Japan, Nakai reaches similar results (Nakai et al. 1999). Nonetheless, the results obtained in the present study indicate that, even if the threshold is exceeded only during 1 day, the impact is significant.

The fact that the temperature/mortality associations are significant both qualitatively (in the cross correlation functions) and quantitatively (in the ARIMA models) is coherent with the underlying biological mechanisms (Wen-Harn et al. 1995; Whitman et al. 1997) and with results found in other studies (Kunst et al. 1993, Díaz et al. 2001). Similar comments apply to the fact that the effect is higher for circulatory than respiratory causes and for the older population. On the other hand, The greater impact on women could be attributable to the fact that there are more susceptible women (60.6%) than men (39.4%). There is a clear explanation for the fact that ozone is the only significant pollutant affecting summer mortality. Tropospheric ozone needs solar radiation to form, which means that its highest levels occur in summer, when the rest of the pollutants reach their minimum values (Díaz et al. 1999). This same association, especially with cardiovascular diseases, has been found in other studies (Sartor et al. 1995; Díaz et al. 1999, 2001; Wong et al. 1999; Burnett et al. 1997). The fact that small values for relative humidity are associated with an increase in mortality follows the pattern found in other research where low relative humidity reinforces the effect of other pollutants (Katsouyanni et al. 1993), especially ozone (Sartor et al. 1995; Díaz et al. 2001).

The effect of temperature on mortality on an extra hot day is clear from Table 3, which indicates that an increase of 1 °C above 41 °C is associated with an increase of 51% above the average mortality.

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References

Alberdi JC, Díaz J (1997) Modelización de la mortalidad diaria en la Comunidad Autónoma de Madrid (1986–1991). Gac Sanit 11:9–15

Alberdi JC, Díaz J, Montero JC, Mirón IJ (1998) Daily mortality in Madrid community (Spain) 1986–1991: relationship with atmospheric variables. Eur J Epidemiol 14:571–578

Box GE, Jenkins GM (1980) Time series analysis. Forecasting and control. Holder Day, San Francisco

Burnett R, Cakmak S, Brook J (1997) The role of particulate size and chemistry in the association between summertime ambient air pollution and hospitalization for cardio-respiratory diseases. Environ Health Perspect 105:614–620

Díaz J, Alberdi JC, Montero JC, Mirón IJ (1998) Asociación entre la contaminación atmosférica por dióxido de azufre y partículas totales en suspensión y la mortalidad diaria en la Comunidad de Madrid (1986–1992). Gac Sanit 12:203–211

Díaz J, García R, Ribera P, Alberdi JC, Hernández E, Pajares MS (1999) A modelling of air pollution and its relationship with mortality and morbidity in madrid (Spain). Int Arch Occup Environ Health 72:366–376

Díaz J, López C, Alberdi JC, Jordán A, García R, Hernández E, Otero A (2001) Heat waves in Madrid, 1986–1997: effects on the health of the elderly. Int Arch Occup Environ Health 75:163–170

Douglas AS, Allan TM, Rawles JM (1991a) Composition of seasonality of disease. Scottish Med J 36:76–82

Douglas AS, Al-Sayer H, Rawles JM, Allan TM (1991b) Seasonality of disease in Kuwait. Lancet 337:1393–1397

García R, Prieto L, Díaz J, Hernández E, Del Teso MT (2002) Synoptic conditions leading extremely hig temperatures in Madrid (Spain). Ann Geophys 20:237–245

González S, Díaz J, Pajares MS, Alberdi JC, Otero A, López C (2001) Relationship between atmospheric pressure and mortality in the Madrid autonomous region: a time-series study. Int J Biometeorol 45:34–40

Greenberg JH, Bromberg J, Reed CM, Gustafson TL, Beauchamp RA (1983) The epidemiology of heat-related deaths, Texas, 1950, 1970–79, and 1980. Am J Public Health 73:805–807

IPCC (2001) IPCC WGI Third Assessment Report. Shanghai Draft 21-01-2001

Kalkstein LS, Greene JS (1997) An evaluation of climate/mortality relationship in large U.S. cities and the possible impacts of a climate change. Environ Health Perspect 105:84–93

Katsouyanni K, Pantazopoulou A, Touloumi G, Tselepidaki I, Moustris K, Asimakopoulos D, Poulopoulou G, Trichopoulos D (1993) Evidence for interaction between air pollution and high temperature in the causation of excess mortality. Arch Environ Health 48:235–242

Koren HS, Devlin RB, Graham DE, Mann R, Mcgee MP, Horstman DH, Kozumho WJ, Becker S, House DE, Mcdonnell WF, Bromberg PH (1989) Ozone-induced Inflammation in the lower airways of human subjects. Am Rev Respir Dis 139:407–415

Kunst AE, Looman CWN, Mackenbach JP (1993) Outdoor air temperature and mortality in The Netherlands. A time-series analysis. Am J Epidemiol 137:331–341

Makridakis S, Wheelwright SC, McGee VE (1983) Forecasting methods and applications. Wiley, San Francisco

Montero JC, Mirón IJ, Díaz J, Alberdi JC (1997) Influencia de variables atmosféricas sobre la mortalidad por enfermedades respiratorias y cardiovasculares en los mayores de 65 años en la Comunidad de Madrid. Gac Sanit 11:164–170

Nakai S, Itoh T, Morimoto T (1999) Deaths from heat-stroke in Japan: 1968–1994. Int J Biometeorol 43:124–127

Pan WH, Li LA, Tsai MJ (1995) Temperature extremes and mortality from coronary heart disease and cerebral infarction in elderly Chinese. Lancet 345:353–355

Sáez M, Sunyer J, CastellsaguéJ, Murillo C, AntóJM (1995) Relationship between weather temperature and mortality: a time series analysis approach in Barcelona. Int J Epidemiol 24:576–582

Samet J, Zeger S, Kelsall J, Xu J, Kalstein LS (1998) Does weather confound or modify the association of particulate air pollution with mortality? An analysis of the Philadelphia data 1973–1980. Environ Res 77:9–19

Sartor F, Snacken R, Demuth C, Walkiers D (1995) Temperature, ambient ozone levels and mortality during summer 1994 in Belgium. Environ Res 70:105–113

Scholander PF, Waiters V, Hock R (1950) Body insulation of some arctic and tropical mammals and birds. Biol Bull 99:225–236

Semenza JC (1999) Are electronic emergency department data predictive of heat-related mortality? J Med Syst 23:419–424

Semenza JC, Rubin CH, Falter KH (1996) Heat-related deaths during the July 1995 heat wave in Chicago. N Engl J Med 335:84–90

Semenza JC, MCCullough J, Flanders DW, McGeehin MA, Lumpkin JR (1999) Excess hospital admissions during the 1995 heat wave in Chicago. Am J Prev Med 16:269–277

Smith JB, Tirpak DA (1989) The potential effects of global climate change in the United States. Environmental Protection Agency, document 230-05-89-057, Appendix G, Washington DC

Smoyer KE (1998) A comparative analysis of heat-wave associated mortality in St. Louis, Missouri – 1980 and 1995. Int J Biometeorol 42:44–50

Ungar S (1999) Is strange weather in the air? A study of U.S. national network news coverage of extreme weather events. Clim Change 41:133–150

Wen-Harn Pan, Lung-An Li, Ming-Jan Tsai (1995) Temperature extremes and mortality from coronary heart disease and cerebral infarction in elderly Chinese. Lancet 345:353–355

Whitman S, Good G, Donoghue ER, Benbow N, Shou W, Mou S (1997) Mortality in Chicago attributed to the July 1995 heat wave. Am J Public Health 87:1515–1518

Wong TW, Lau TS, Yu TS (1999) Air pollution and hospital admissions for respiratory and cardiovascular diseases in Hong Kong. Occup Environ Med 56:679–683

World Health Organization (1987) Air quality guidelines for Europe. WHO Regional Publications, European Series, 23. Copenhagen