The effect of air temperature and the thermal index PET on mortality in Athens, Greece

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1. INTRODUCTION

The weather variability is a risk factor for mortality and many studies have been carried out in order to reveal the relationship between mortality and environmental variables, especially air temperature. Besides, mortality has been considered as an indicator of the population’s health and of its conditions of life. Curriero et al. (2002) found associations between extremely high or low temperatures and mortality in 11 cities of the eastern USA. McGregor (2005) investigating the possible association between the level of ischaemic heart disease mortality for three English counties and the winter North Atlantic Oscillation (NAO) found that winters with elevated mortality levels, have been shown to be clearly associated with a negative NAO phase and anomalously low air temperatures. On the other hand, Diaz et al. (2002) found that very hot weather is associated with high mortality levels, especially regarding persons over 65 years old. An increase of 1 °C above 41 °C is associated with an increase of 51% above the average mortality. Miron et al. (2008) studying the time trend in the maximum temperature of minimum organic-cause mortality in Castile-La Mancha (Central Spain), in the period 1975 to 2003, ascertained that the fall in comfort temperature is attributable to the increase in the effects of heat on mortality, due, in all likelihood, to the percentage increase in the elderly population.

Various studies in different countries indicate that the daily mortality as a function of air temperature 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). According to the models projections for possible climate warming, summer mortality would increase substantially (Semenza et al. 1999; Ungar 1999), while winter mortality would decrease (Kalkstein and Greene 1997).

This paper investigates whether there is any association between the daily mortality and the air temperature and the thermal index Physiologically Equivalent Temperature (PET), within the wider region of Athens, Greece, for the period 1992-2001.

2. DATA AND METHODS

The daily organic-cause mortality datasets were acquired from the Greek Census, and the daily meteorological datasets, concerning daily maximum and minimum air temperature, from the Helliniko meteorological station, established at the headquarters of the Greek Meteorological Service, for the period 1992-2001. Besides, the daily values of the thermal index Physiological Equivalent Temperature (PET) were evaluated, in order to interpret the grade of the physiological stress.

The first step was the application of Pearson’s χ² test, the most widely used method of independence control of groups in lines and columns in a table of frequencies. In the process, the evaluation of the possible relationship between daily mortality and the meteorological variables was achieved by the application of Generalized Linear Models (GLM) with Poisson distribution described by McGullagh and Nelder (1997). In the models fitting procedure we used as dependent variable the daily mortality while as independent covariates the aforementioned meteorological and biometeorological parameters were included. Models’ goodness-of-fit was evaluated through deviance residuals (McGullagh and Nelder 1997). Additionally, Logistic Regression Analysis was applied in order to estimate odds ratios for the independent variable (air temperature or thermal index PET) in the constructed model. Logistic regression is useful for situations in which you want to be able to predict the presence or absence of a characteristic or outcome based on values of a set of predictor variables. It is similar to a linear regression model but is suited to models where the dependent variable is dichotomous.
3. RESULTS

The analysis was performed by using daily series of maximum, minimum air temperature, thermal index PET and organic cause mortality, for the period 1992-2001. In the first stage of the statistical analysis, the values of each meteorological variable were grouped in three classes. The values of PET were grouped in well defined thermo physiological strain classes of the thermal index PET (Matzarakis and Mayer 1996). Accordingly, the first class contained the lowest 10% (lowest thermal sensation) and the last class the highest 10% (highest thermal sensation) of all values. The results of this step were assembled in a contingency table for every parameter. Table 1 presents the number of days of mortality within the examined percentiles for each class of Tmax. Pearson’s $\chi^2$ test applied to the compiled contingency tables, resulted in that the probability of independence is 0 ($p=0.000$); namely, mortality is in close relation to the air temperature parameters and PET.

Table 1. Cross tabulation of daily mortality and Tmax percentiles

<table>
<thead>
<tr>
<th>Daily mortality percentiles</th>
<th>&lt;10%</th>
<th>10% - 90%</th>
<th>&gt;90%</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tmax percentiles</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;10%</td>
<td>3</td>
<td>285</td>
<td>87</td>
<td>375</td>
</tr>
<tr>
<td>10% - 90%</td>
<td>341</td>
<td>2368</td>
<td>221</td>
<td>2930</td>
</tr>
<tr>
<td>&gt;90%</td>
<td>26</td>
<td>278</td>
<td>44</td>
<td>348</td>
</tr>
<tr>
<td>Total</td>
<td>370</td>
<td>2931</td>
<td>352</td>
<td>3653</td>
</tr>
</tbody>
</table>

The bioclimatic regime of Athens is well illustrated by the bioclimate diagram (Figure 1), which includes ten days frequencies of the daily PET values for the period 1992 to 2001. Figure 1 depicts that 50 % of the days from the middle of April to the beginning of November are within the PET classes of 18 °C (thermal comfort) and above, while from the end of May to the end of October, extreme thermal stress (PET > 35 °C) can also be observed for the study region. Additionally, the mean, the absolute maximum and minimum value of PET and also the frequencies of cold days (days with PET < 10 °C) and heat stress days (days with PET > 35 °C) are presented in Figure 1.

Figure 1. Bioclimate diagram for Athens for the period 1992 – 2001.

In the process, GLM findings showed that statistical significant relationships ($p < 0.01$) between air temperature, PET and mortality exist. More concretely, a 10% decrease in daily maximum air temperature, minimum air temperature, temperature range and PET is related with an increase 7%, 9%, 7% and 5% of the probability having a death, respectively. Notwithstanding the general aspect that cold conditions seem to be favourable factors for daily mortality, the air temperature...
Exceedances over specific thresholds reveal that very hot conditions are risk factors for the daily mortality.

Using Logistic Analysis we found that, daily minimum air temperature greater than 23.4 °C (the upper 90th percentile) seems to 4folds the risk (odds ratio = 3.750, 95% CI 0.927–15.176, significant level = 0.064) of observing the daily mortality in the upper 99th percentile (i.e. > 124 deaths of any case per day) compared to the lower 1st percentile (i.e. < 53 deaths of any case per day). With respect to the daily maximum air temperature similar results were found; namely daily maximum air temperature greater than 33 °C (the upper 90th percentile) seems to 6folds the risk (odds ratio = 5.786, 95% CI 1.157–28.939, significant level = 0.033) of observing the daily mortality in the upper 99th percentile compared to the lower 1st percentile. A very worthy finding is that strong heat stress conditions (PET > 35) seems to 2folds the risk (odds ratio = 2.054, 95% CI 1.194–3.533, significant level = .009) of observing the daily mortality in the upper 90th percentile (i.e. > 99 deaths) compared to the lower 10th percentile (< 64 deaths).

Figures 2 to 4 indicate a non linear V-shaped relationship (quadratic function) between air temperature, PET and mortality. As it can be seen, not only do the daily mortality fall with air temperature increases but, in addition, the right-hand part of the characteristic V-shape, depicts the “hot” component of the relationship. It is remarkable the abrupt increasing trend in daily mortality, which is appeared during strong heat stress (PET > 35 °C), or when the maximum and minimum air temperatures exceed the respective 90th percentiles, as it is illustrated by the linear trends in the cold and hot part of the relationships between daily minimum, maximum temperature, thermal index PET and organic-cause mortality in Athens, respectively. All these trends are statistically significant (p=0.000). The vertical lines in the scatter plots represent the 10th and 90th percentiles of the maximum and minimum air temperature and the thresholds for strong extreme heat (PET > 35°C) and cold (PET < 8 °C) stress, while the horizontal lines represent the 10th and 90th percentiles for the daily mortality. Besides, these boundaries show that the daily mortality frequency of the right-hand part of the V-shaped relationship reaches higher levels. This reveals that extreme heat waves are associated with higher daily frequencies of mortality.
4. DISCUSSION

We have examined the associations of the daily air temperature and the thermal index PET with daily mortality in Athens, Greece, for the period 1992-2001 and we have found that the daily mortality as a function of air temperature or PET has a V-shaped relationship, which is in agreement with other researchers (Kunst et al. 1993; Saez et al. 1995; Miron et al. 2008). The magnitude and shape of this relationship also depend on other factors such as the characteristics of the population and the climate conditions. Towns with lower annual mean temperatures have been observed to register higher heat-related mortality and, conversely, the greater the influence of the summer season, the higher the cold-related mortality (The Eurowinter Group 1997). The application of the GLM with Poisson distribution resulted in that a decrease in the air temperature is related to an increase in daily mortality, indicating that extreme cold conditions favour mortality more than hot conditions, being more intense in the elderly population (Diaz et al. 2002; Conti et al. 2005). Dilaveris et al. (2006) also have found that, for Athens territory, deaths caused by acute myocardial infarction in winter were 31.8% higher than in summer. On the other hand, regarding the hot component of the V-shaped relation, a clear abrupt increase in the daily mortality frequency is appeared, as the air temperature or the thermal index PET exceed the defined extreme hot thresholds. These thresholds depend on the effect of acclimatization to the population. For instance, the daily maximum temperature threshold of 33 °C in Athens is lower than the threshold of 41 °C in Seville (Diaz et al. 2002).

5. CONCLUSION

The performed analysis revealed that there is a clear influence of the air maximum, minimum air temperature and the thermal index PET on the daily mortality, in Athens, Greece. This relationship is V-shaped indicating that both the cold and hot components account for increased daily mortality, but extreme cold conditions affect the daily mortality frequencies more than extreme hot conditions. Nevertheless, when the established air temperature exceeds specific for the region thresholds, mortality increases abruptly.

REFERENCES

The Eurowinter Group, 1997: Cold Exposure and winter from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe. Lancet 349:1341–1346.