Relationships between human mortality and short-term variability of meteorological variables

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Abstract In order to better understand relationships between weather and the human health for a future time horizon, links between meteorological variables and mortality under the present climate conditions need to be examined. In the Czech Republic, impacts of weather on mortality have been analyzed mostly using monthly data and/or relatively short time series, and studies of relationships between daily series of meteorological variables and mortality have been confined to heat-related effects although the range of links of mortality to weather and its short-term variability (considered here on the scale of days to about one month) is wide.

The present study aims at analyzing links between meteorological variables and daily mortality (total mortality and mortality due to cardiovascular diseases, which both display clear sensitivity to weather) in the population of the Czech Republic in all seasons. The analysis is carried out separately for males and females and for individual age groups to identify dependence of the mortality impacts on gender and age. The stressful weather conditions are identified in each season, and the most suitable time series model of the relationship between mortality and meteorological variables (particularly air temperature and biometeorological indices) is determined. The time series models examined include linear and log-linear regression models, with temperatures, deviations of temperature from the mean seasonal course, synthetic temperature variables and biometeorological indices during the previous 30 days as predictors.

Key words: *biometeorology, human mortality, short-term variability, extreme events, the Czech Republic*

1. Introduction – brief survey of the present state and motivation for the study

Links between weather and the human health are extremely complex and have not been understood in many aspects yet, despite the renewed interest since the early 1990s (largely due to potential negative impacts of climate change on health) as well as the long-term knowledge of the existence of these links. It is generally accepted that the climate change, already under way (IPCC, 2007), is likely to have wide-ranging and mostly adverse impacts on human health, with a possible significant loss of life. Direct impacts, due to e.g. the exposure to thermal extremes and altered frequency and/or intensity of other extreme weather events would arise in the longer term, and implications of the recent warming trend and the possible future climate change for the human health are thus subjects of major interest (e.g. Martens and McMichael, 2002; Davis et al., 2004). However, little is known about the potential overall impacts of the climate change on mortality and morbidity in European mid-latitudes. In order to better understand relationships between weather and the human health for a future horizon, we should study the links between meteorological variables and mortality under the present climate conditions.

In mid-latitudes, the most direct effects of weather on mortality are observed during and after hot summer periods that lead to significant increases and intraseasonal shifts ('displacements') in mortality. Heat-related mortality has been investigated in many European regions including United Kingdom (e.g. Rooney et al., 1998; Hajat et al., 2002), western Europe (Huynen et al., 2001; Sartor et al., 1995; Laschewski and Jendritzky, 2002; Grize et al., 2005; Filleul et al., 2006), southern Europe from Portugal to Greece (Dessai, 2002; Díaz et al., 2002a, 2002b; Zauli Sajani et al., 2002; Katsouyanni et al., 1993; Matzarakis and Mayer, 1997) as well as central Europe (Kyselý and Kříž, 2003; Kyselý, 2004; Hutter et al., 2007). After concerns about possible effects of climate change on infection diseases have decreased in recent years, heat-related mortality represents the main source of negative impacts of the likely future global warming on human mortality at least in the mid-latitudes (Keatinge and Donaldson, 2004).

Cold-related mortality is another example of the effects of weather on the human health (Khaw, 1995; Auliciems et al., 1997; Keatinge et al., 2000; Huynen et al., 2001; Curriero et al., 2002; Laschewski and Jendritzky, 2002; Díaz et al., 2005). Lags between cold weather and its impacts on mortality are usually longer (about 3-8 days compared to 0-2 days for heat-related mortality) and the relationship is less direct, geographically variable and to some extent confounded by other factors that strongly influence mortality in winter (e.g. influenza epidemics, outbreaks of acute respiratory infections). Although the mortality impacts tend to be larger and more direct for extreme heat in summer than extreme cold in winter, overall mortality is significantly higher in winter than summer in all mid-latitude countries (the increase is referred to as 'excess winter mortality'), partly because of the enhanced spread of infectious diseases in winter.

Impacts on mortality and morbidity are less frequently linked to meteorological variables other than air temperature (or an index comprising air temperature). Such applications focus mostly on circulation types/indices and air masses (Kalkstein and Greene, 1997; McGregor, 2001, 2005; Kassomenos et al., 2001) and consist in identifying oppressive weather conditions, which lead to negative human health effects.

Relatively little is known about impacts of other climatic extremes than heat and cold waves on mortality (e.g. impacts of rapid day-to-day temperature and air pressure changes, passages of strong cold fronts, etc.). Also, there is a limited understanding of the seasonality of the weather-mortality link (e.g. Davis et al., 2004).

The difficulty in quantifying weather-related impacts on the human health arises among others from the dependence of the extent of possible disorders on numerous interacting factors that characterize the vulnerability of the population, including other environmental circumstances (e.g. air pollution, water quality) and access to health care services. Air pollution effects on the human health and mortality are a topical issue mainly for urban populations (e.g. Jelínková and Braniš, 2001; Gryparis et al., 2004).

In the Czech Republic, relationships between weather and human mortality have been analyzed mostly using monthly data and relatively short time series (e.g. Kazmarová et al., 2002). Studies of relationships between daily series of meteorological variables and mortality have been confined to heat-related mortality (Kyselý and Kříž, 2003; Kyselý, 2004; Kyselý and Huth, 2004a, 2004b) although the range of links of mortality to weather and its variability is wide.

The present study deals with impacts of short-term variability of weather (considered here on the scale of days to about one month) on total mortality and mortality due to cardiovascular diseases (CVD) in the population of the Czech Republic, over time period 1986-2005.

2. Data and methods

2.1 Population under study

Mortality impacts in the population of the country as a whole are evaluated instead of urban populations (on which majority of recent studies on weather-human health links have focused, including several European projects). Although it is usually supposed that some weather impacts, particularly those of heat stress, are exacerbated in cities (due to both urban heat island and air quality), a recent study by Sheridan and Dolney (2003) has demonstrated that there are no significant differences in the heat vulnerability over urban, suburban and rural environments in the US, and that the relative increases are even more pronounced in rural and suburban than urban populations. The analysis of heat-related mortality in the Czech Republic has also shown that the increases are of a similar magnitude in the city of Prague and over the whole area of the Czech Republic (Kyselý and Kříž, 2003).

Reasons for studying mortality in the entire population are twofold: First, the sample (population of the Czech Republic corresponds to about 10 million inhabitants) is much larger than samples for the city of Prague and other big cities, and thus enables more robust conclusions to be derived. Secondly, effects of the air pollution on mortality are likely to be relatively small compared to weather impacts because the majority of the population (67% in 2003) lives in cities with less than 50 000 inhabitants or in a rural environment where the air pollution effects are usually not observed, while only a small portion (21%) in large cities with more than 100 000 inhabitants (Czech Statistical Office, 2007). Another reason for excluding air quality effects from this step of the research is that results of air pollution studies (that have addressed also weather variables) are inconsistent and depend among others on the population under study, season, and variables and methods used. It also appears that under specific meteorological conditions the impact of air pollution may be less important than health risks associated with offensive weather (e.g. Smoyer et al., 2000).

2.2 Mortality data

Daily mortality data in the population of the Czech Republic are available over 1986-2005; they consist of daily total numbers of deaths and numbers of deaths due to cardiovascular diseases (CVD), both stratified by gender and age groups. Database of the incidence of acute respiratory infections and estimates of mortality due to influenza/acute respiratory infections are also available; these confounding effects need to be taken into account when evaluating weather-mortality links.

2.3 Standardization of mortality data

To account for a long-term decline in mortality (due to demographic, medical-technological as well as life-style changes) and the seasonal and weekly cycles, the daily death counts must be standardized. Excess daily mortality is established, separately for total mortality and mortality due to CVD and for each age group and gender, by calculating deviations of the observed number of deaths from the expected number of deaths for each day of the examined period. The expected number of deaths takes into account effects of the long-term trend in mortality (observed mainly due to changes that have followed the 1989 'Velvet Revolution'; Figure 1), the annual cycle (Figure 2) and the weekly cycle (cf. Kyselý, 2004). A similar standardization procedure is commonly applied; see e.g. Guest et al. (1999), Smoyer et al. (2000) and Whitman et al. (1997). Influenza epidemics (Kynčl et al., 2005) and other confounders are identified and their effects on mortality are eliminated in the excess daily mortality data.

2.4 Meteorological data

Daily series of meteorological variables are available at about 10 stations covering the area of the Czech Republic (over the same period as mortality data). They consist of air temperature, relative humidity/dew-point temperature, wind speed and direction, total cloud amount and air

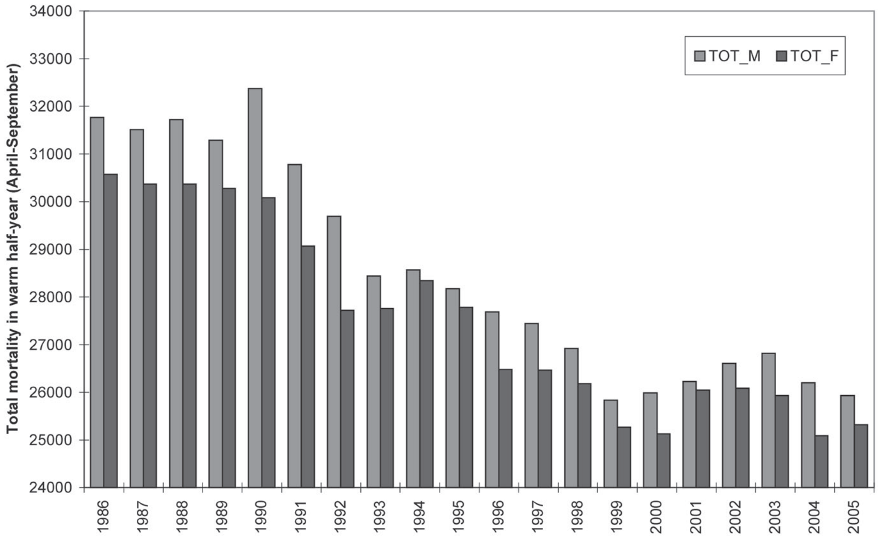

Fig. 1 Long-term changes in total mortality in the period April-September; M – males, F – females

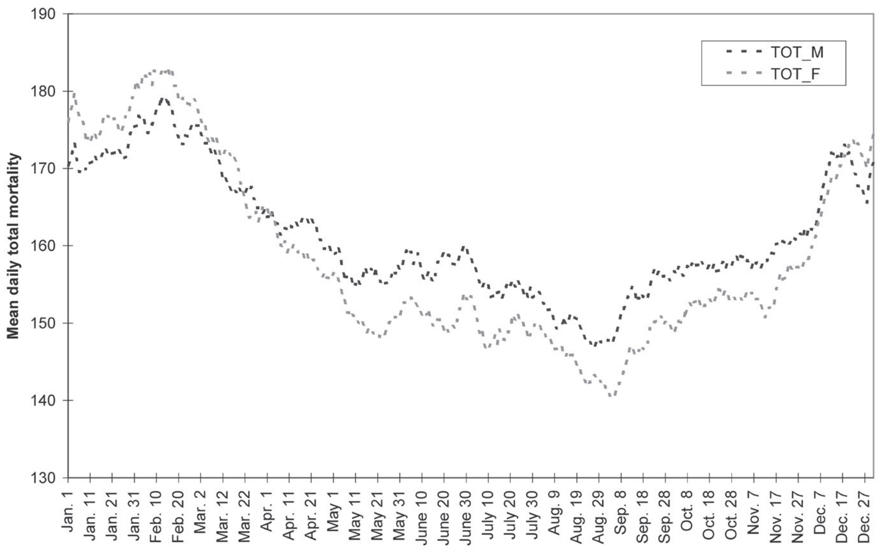

Fig. 2 Annual cycle in total mortality (7-day running means); M – males, F – females

pressure, measured 3 times daily (7, 14, 21 LT). Daily series of maximum and minimum temperature are available as well.

2.5 Biometeorological indices

Since physiological impacts of weather depend on a suite of weather elements, many indices have been developed to account for the joint effects of meteorological variables and to incorporate the entire stress due to weather. The best known of them and still frequently applied are heat index (apparent temperature, Steadman, 1979; utilized e.g. in Davis et al., 2002; Sheridan and Dolney, 2003) and wind chill index (e.g. Bluestein and Zecher, 1999). Although complex biophysiological comfort indices and models (Höppe, 1999; Laschewski and Jendritzky, 2002) are likely to yield better results in evaluating impacts of weather on the human health, their wide-spread use is obstructed by the need for more extensive input data. Temperature is employed as the basic and most frequently used variable in studies of weather-related mortality because of its simple interpretation, comparability and universality throughout year; however, the indices that involve a combination of temperature, humidity, wind speed and potentially other meteorological variables are utilized as well.

2.6 Time series modelling

Time series models used to study effects of weather and/or air pollution on mortality include linear and log-linear regression models, ARIMA models (Box et al., 1994) and Generalized Additive Models (GAMs; Hastie and Tibshirani, 1990; Schwartz, 1994). ARIMA models take into account the history of the modelled series through autoregressive (AR) and moving average (MA) terms, and additional variables can be introduced at varying lags. GAMs are likely the most frequently used tools in epidemiological modelling currently and are very flexible for non-normally distributed variables; the linear predictor is replaced by a non-parametric function, estimated using a scatterplot smoother. They were proved to present the best model fit in terms of the absence of autocorrelation and reduction of overdispersion (Tobías et al., 2003) in modelling short-term effects of air pollution on health. However, simpler linear and log-linear regression models, with temperature, synthetic temperature variables (e.g. Huynen et al., 2001) and biometeorological indices as predictors and lags up to about 30 days are examined as well, as they have been found useful for estimating expected excess mortality in previous studies.

3. Analysis of effects of short-term variability of weather on mortality

The study focuses on the analysis of links between meteorological variables and mortality in individual seasons, with lags of mortality after weather up to 30 days. Both relative (deviations from the mean annual cycle) and absolute threshold exceedances of daily air temperature and biometeorological indices (e.g. apparent temperature / heat index in summer and wind chill index in winter; Steadman, 1979; Bluestein and Zecher, 1999) are examined as to whether they are associated with excess mortality. The most stressful weather conditions are identified in each season. The effects of sudden temperature and air pressure changes, and differences between the timings of temperature peaks (or peaks of other meteorological variables) and mortality peaks are evaluated as well.

The most suitable time series model of the relationship between excess mortality and meteorological variables is determined. The time series models examined include linear and log-linear regression models, with temperatures, deviations of temperature from the mean annual cycle, synthetic temperature variables (like HEAT and COLD utilized by Huynen et al., 2001), and biometeorological indices during the previous 30 days as predictors.

When the relatively simple indicators, representing joint effects of temperature, humidity and wind speed, are found insufficient to reveal relationships and explain a significant part of the mortality variance, more complex biophysiological comfort indices and models are considered.

The analysis is carried out separately for males and females and for individual age groups in order to identify dependence of the mortality impacts on gender (e.g., females have been found to be more sensitive to heat stress than males in most European countries; results for cold-related mortality have been less conclusive) and age (more pronounced effects usually appear in the elderly).

4. Results

At the time of writing this paper, the analysis was still under way, and its results will be presented at the conference.

A preliminary evaluation shows that heat and cold waves as well as rapid temperature changes are among the most stressful weather conditions; however, there are other events leading to mortality increases, and considerable seasonal differences appear, particularly as to the magnitude of the mortality impacts and their lags after the stressful weather (varied lags are identified e.g. for heat waves in summer and cold waves in winter).

Differences in within-season acclimatization between winter and summer also appear; note that some studies indicate a reversed pattern in the two seasons (increasing impacts of cold spells on mortality during winter but decreasing effects of heat waves during summer; Díaz et al., 2005). Rather generally, mortality in other seasons than summer is only partly linked to daily weather.

5. Conclusions

The present study contributes to better understanding of the complex relationships between weather and mortality, particularly in other seasons than summer when mortality impacts are much less known and when no simple cause-effect relationship exists. The results may have also direct applications in health care system, decisions on measures to mitigate future negative impacts of weather on mortality, including climate change – health impact studies, and in predictability of health outcomes and increased mortality due to weather, including biometeorological forecast.

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