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## The Time Trend Temperature–Mortality as a Factor of Uncertainty Analysis of Impacts of Future Heat Waves

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Recently, the paper by Wu et al. (2014), “Estimation and Uncertainty Analysis of Impacts of Future Heat Waves on Mortality in the Eastern United States,” concluded that “the major sources of uncertainty were the relative risk estimates for mortality on heat wave versus non-heat wave days, the RCP scenarios, and the heat wave definitions.” One conclusion to be drawn from reading this manuscript might be that a good definition of “heat wave” based on epidemiological studies and accurate determination of the risks associated with such temperatures would greatly reduce these uncertainties. Although the authors allude to the possible geographic variability of these risks, there is nevertheless no mention of the possible evolution over time that can take place both in heat-wave definition temperatures and in the modifications of these possible impacts, beyond those stemming from the use of air-conditioning equipment and the implementation of heat-wave prevention plans.

Along these lines, recent studies have found that demographic and socioeconomic factors may be behind the trend in minimum mortality temperatures (Mirón et al. 2008). Hence, in Castile-La Mancha (Spain) the minimum mortality temperature went from 32°C in the decade 1975–1985 to 28°C in 1995–2003 as a consequence of population aging. This fact influences the heat-wave definition temperatures, which are very closely linked to the age group > 65 years (Montero et al. 2012).

Added to this uncertainty are the shifts over time observed in the impact of heat waves. Studies conducted in different parts of the world show that, far from remaining constant, these impacts are changing over time, with a trend toward minimizing such effects (Schifano et al. 2012): Although the effect is most pronounced in cardiovascular mortality (Ha and Kim 2013), it has remained practically constant in the case of respiratory mortality (Mirón et al. in press). These results, obtained from a time series covering > 30 years, show that the increase in risk of heat-related mortality for each degree centigrade that the threshold temperature is exceeded went from 13.7% in 1975–1985 to 7.4% in 1997–2008, and specifically that this decline was attributable to circulatory causes, going from 18.2% in 1975–1985 to 5.8%

in 1997–2008. In the case of respiratory causes, however, no such decline was in evidence, with the respective figures remaining practically constant: 11.8% in 1975–1985 versus 13.5% in 1997–2008. This pattern would seem to be linked to improvements in health care services (particularly in the case of patients with cardiovascular diseases), socioeconomic improvements, and the provision of infrastructures for better living conditions. It therefore follows that any changes in the trend of these parameters could reverse the situation and increase the effects of temperature extremes on mortality. This decline in heat wave–related mortality does not appear to be connected with the implementation of prevention plans, in Spain at least (Culqui et al. 2013).

Because the factors that appear to influence the shifts in the relationship between temperature and mortality are not local and are thus extrapolatable to a large proportion of developed countries, their relevance is self-evident.

These uncertainties add to those already cited in the paper by Wu et al. and highlight the need for more in-depth knowledge, not only of temperature forecasts at the different time horizons, but also of the behavior pattern over time of the temperature–mortality relationship. Far from being constant, this relationship displays a time trend that is seldom taken into account in the models used to predict the impact of climate change on human health.

*The authors declare they have no actual or potential competing financial interests.*

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## The Time Trend Temperature–Mortality as a Factor of Uncertainty Analysis of Impacts of Future Heat Waves: Wu et al. Respond

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We thank Linares et al. for their interest in our article and for broadening the discussion on the uncertainties in predicting the health impact of future heat waves. Linares et al. pointed out that the possible evolution over time can take place both in minimum mortality temperatures related to heat waves and in the modifications of these possible impacts due to socioeconomic improvements. Although such considerations were beyond the scope of our published analysis (Wu et al. 2014), we agree that socioeconomic and demographic factors can have profound impacts on the estimated excess mortality in a changing climate.

A heat wave is defined as a period of consecutive days with temperatures exceeding a certain threshold based on physiologic effects (Robinson 2001). The threshold temperature is usually calculated based on local historical data, which can vary in both time and space. Linares et al. suggested that heat wave definition temperatures might be reduced to a consequence of population aging in time. Given these changes in the threshold temperature over time, the heat wave definition would indeed add an additional layer of uncertainty to the predicted health impact of future heat waves on top of what we have characterized in the paper. Such uncertainty, however, is difficult to quantify without detailed data on the structure of future populations, especially age. So far, the U.S. Census Bureau (2012) has issued only national-level, age-specific population projections.

The health impacts of heat waves can be modified by many factors, such as race, age, sex, socioeconomic status, and geographic location (Hajat and Kosatky 2010). The changing impacts of heat waves on cardiovascular/circulatory and respiratory mortality (Ha and Kim, 2013; Mirón et al. 2008) seem to be related to the improvements in health care services and living conditions over time. These trends may be generalizable in space if we are willing to assume that the U.S. health care system has improved its service to cardiovascular patients over the years in a fashion similar to that of Spain, Italy, or other developed countries. However, it may not be justifiable to extrapolate them in time because the impact of these improvements is likely to taper off unless significant technological advancement takes place in the future.

In addition, early warning systems and adaptation strategies can strongly influence the impact of heat waves on a society (Lowe et al. 2011). However, the relative risk of heat waves must be estimated using existing health data records, making it very difficult to take any adaptation measures into consideration

because we lack such examples in the past. In our study, we set future baseline mortality rate and relative health risk of heat waves as constant because robust estimates of these parameters for the 2050s are unavailable. Further research is needed to address these issues in order to provide a more comprehensive and realistic evaluation of the impact of future heat waves.

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