Long-term acclimatization scenarios of temperature-related mortality in Europe

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ABSTRACT

Aim: We show the link between temperature, humidity and daily numbers of deaths in nearly 200 European regions, which are used to infer transient projections of mortality under state-of-the-art high-resolution climate change simulations.

Results: The rise in heat-related mortality will start to completely compensate the reduction of deaths from cold during the second half of the century. Nevertheless, projections suggest that human lifespan might indeed increase if a substantial degree of adaptation to warm temperatures takes place.

1. THE 2003 HEAT WAVE VS. FUTURE SUMMERS

The record-breaking 2003 heat wave in western Europe has been described as an extremely unlikely event given the observed warming, and to share similar characteristics with future summers simulated by state-of-the-art climate models for the end of the 21st century (Figures 1a-c).

This event caused up to 70000 excess deaths, of which 11000 occurred in June, 10000 in July, 15000 during the first week of August and 24000 during the second week. The spatial distribution of the incidence was not however homogeneous, with mortality excesses of 13.7%, 11.8% and 11.6% during the summer of 2003 in Spain, France and Italy, respectively (Figure 1d).

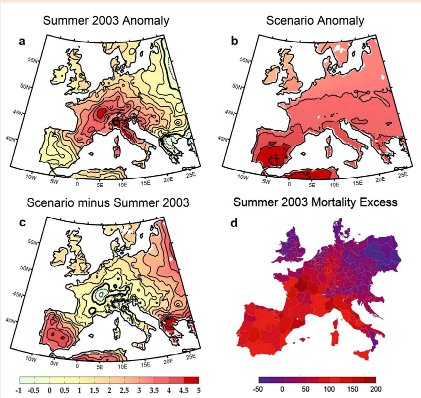

Figure 1. Comparison between summer 2003 anomalies and scenario changes in summer conditions. *a) Temperature anomalies in summer 2003. b) Temperature changes between 1998-2008 and 2090-2100. c) Panel b minus a. d) Mortality excess in summer 2003.*

2. TEMPERATURE/MORTALITY RELATIONSHIP

In the search of an optimal predictor of daily mortality, Figure 2 shows the relationship between daily apparent temperature and mortality in Europe. The amount of variance linearly explained by this relationship at daily resolution is relatively large, i.e. r^2 = 50% and 35-40% in the cold and warm tails, respectively. This fraction is however larger after applying a simple non-linear transformation of daily temperatures. For example, variable $T' = a_0 + a_1 \cdot T + a_2 \cdot T^2 + a_3 \cdot T^3$ explains r^2 = 55% of daily mortality variance in the warm tail.

The transfer functions display an asymmetric U-, V- or J-shape around the comfort temperature. The cold tail covers a larger range of temperatures, but the increase in mortality per unit of temperature is always much steeper in the warm tail. In addition, the T/M dependency is usually non-linear in the warm tail, while it is mostly linear in the cold tail.

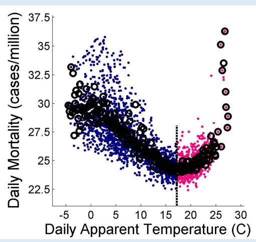

Figure 2. Observed relationship between daily apparent temperatures (°C) and numbers of deaths (cases/million) in Europe (dots). *Circles show the averages of data belonging to equally-spaced intervals of temperature.*

3. CHANGE IN THE SEASONALITY OF MORTALITY

The seasonality of mortality radically changed in 2003, when differences between winter and summer monthly maxima became relatively small (cf. red and blue lines in Figure 3a).

Mortality projections inferred from scenario simulations suggest that this shift in the structure of the seasonality could indeed represent a conservative glimpse of future conditions in summer (Figure 4b). The abnormal summer 2003 only exhibited slightly warmer temperatures in the core of the hot spot (i.e. some local areas in France, Switzerland and northern Italy), compared to future climatologically normal summers simulated for the end of the century (thick contours in Figure 1c).

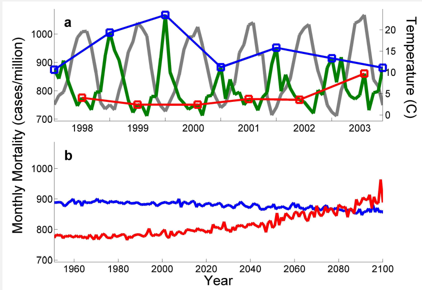

Figure 3. Observations (a) and projections (b) of monthly temperature and mortality in Europe. The grey and green lines depict the monthly observed time series of apparent temperature (°C) and total mortality (cases/million), respectively. The red and blue lines show the evolution of monthly mortality maxima for the set of summer (JJA) and winter (DJF) months, respectively.

4. SCENARIOS OF ADAPTATION

Assuming unchanged transfer functions and profile demographics, the rise in heat-related mortality will nearly (completely) compensate the decrease in cold-related deaths during the first two thirds (the last third) of the century, with a final net increase in overall mortality of up to +15,000 annual deaths in 2070-2100 (solid curves in Figures 4a-c).

The society might (spontaneously or not) adapt to some extent to the new environmental conditions in summer. This conceptual model is here studied by shifting the warm transfer function by a fraction 0 < R ≤ 1 of the mean warming (Figure 4d). Projections indicate that there is room for a substantial reduction in total mortality in a scenario with large adaptation to warm days, with a net reduction in overall mortality of up to -78,000 annual deaths in 2070-2100 (light dashed lines in Figure 4c).

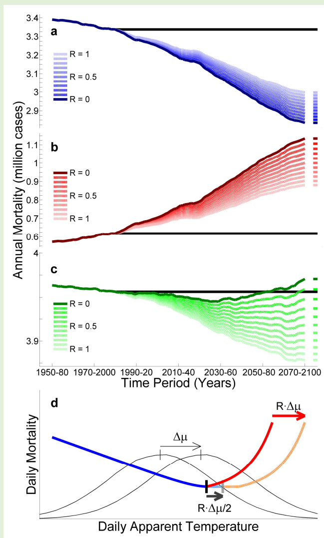

Figure 4. Mortality projections according to scenarios of adaptation to warm temperatures. Mortality projections (million cases) at the continental level for days within the cold tail (a), the warm tail (b) and the whole range of temperatures (c), given a scenario with decreased vulnerability to warm temperatures (d). Solid lines in the projections correspond to a scenario with no adaptation (i.e. R = 0), and dashed curves indicate that the warm transfer functions are shifted by R·Δμ degrees in the temperature space (0 < R ≤ 1), where Δμ represents the time-varying increase in annual mean apparent temperatures.