Anomalous temperature and seasonality of injury mortality in the USA

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Abstract

Background: Temperatures which deviate from long-term norms will be more frequent as the global climate changes, and may be associated with adverse health consequences. There is limited data on how such deviations affect deaths from different injuries, especially by type of injury, month of year, age and sex.

Methods: We used data on mortality and temperature over a 37-year period (1980-2016) in the entire contiguous USA and formulated a Bayesian spatio-temporal model to estimate how anomalous temperatures, defined as deviations from the long-term norm of monthly temperature, affect deaths from different intentional (transport, falls and drownings) and unintentional (assault and suicide) injuries by age group and sex.

Results: We found that a 1°C anomalously warm year would be associated with an estimated 941 (95% credible interval 831-1,053) additional injury deaths in the contiguous USA. 87% of deaths would occur in males, concentrated mostly in adolescent to middle ages. These excess deaths would comprise of increases in deaths from drownings, transport, assault and suicide, offset partly by an overall decline in deaths from falls in older ages.

Conclusions: The findings demonstrate the need for targeted public health interventions against injuries during periods of anomalously high temperatures, especially as these episodes increase with global climate change.

Introduction

The potential health impacts of anthropogenic climate change are one of the key drivers for efforts to mitigate greenhouse gas emissions and for pursuing adaptation measures.[1–3] Current assessments of the health effects of climate change largely focus on parasitic and infectious diseases, and cardiorespiratory and other chronic diseases.[1–6] Less research has been conducted on injuries,[7–9] especially in a consistent way across injury types and demographic subgroups of the population, even though death rates from injuries vary seasonally,[10,11] which means that temperature may play a role in their pathogenesis. Our aim was to evaluate how deaths from various injuries in the USA may be affected by changes in temperature that could arise as a result of global climate change.

Methods

Data sources

We used data on deaths by sex, age, underlying cause of death and state of residence in the contiguous USA from 1980 to 2016 through the National Center for Health Statistics (NCHS) (https://www.cdc.gov/nchs/nvss/dvs_data_release.htm) and on population from the NCHS bridged-race dataset for 1990 to 2016 (https://www.cdc.gov/nchs/nvss/bridged_race.htm) and from the US Census Bureau prior to 1990 (https://www.census.gov/data/tables/time-series/demo/popest/1980s-county.html). We calculated monthly population counts through linear interpolation, assigning each yearly count to July.

The underlying cause of death was coded according to the international classification of diseases (ICD) system (9th revision from 1980 to 1998 and 10th revision thereafter). The 5.7 million injury deaths fell into six categories: transport, falls, drownings, assault, suicide and an aggregate set of other unintentional injuries. We report the results of all of these categories

except other unintentional injuries (1,329,200 deaths or 23% of total injury deaths during 1980-2016), because the composition of this aggregate group varies by sex, age group, state and time.

We obtained data on temperature from ERA-Interim, which combines predictions from a physical model with in-situ and satellite measurements.[12] We used gridded four-times-daily estimates at a resolution of 80 km to generate monthly population-weighted temperature by state throughout the analysis period.

Anomalous temperature metric

With few exceptions,[7,13] current climate change risk assessments typically extrapolate from changes in mortality in relation to daily temperature.[5,6,14–16] Climate change, however, will fundamentally modify weather, including seasonal weather patterns, compared to long-term norms, and hence can disrupt long-term adaptation. To mimic the conditions that may arise with global climate change, we developed methodology to examine how deviations from long-term norm temperature may impact injury death rates. We first defined a measure of anomalous temperature for each state and month relative to long-term norm temperature of the state in that month (Figure 1). To calculate the magnitude of temperature anomaly by state and month, we first calculated 30-year (long-term) norm temperatures (from 1980-2009) for each month in each state. We calculated for 30 years because it is the duration used in climate assessments.[17] We subtracted these long-term norm temperatures from respective monthly temperature values to generate a temperature anomaly time series for each month and year in each state (Figure 1). The temperature anomaly metric measures the extent that temperature experienced in a specific month, year and state is warmer or cooler than the long-term norm to which the population of each state has acclimatized. These values can be different for different months in the same state, and different states in the same month. Further, a state with higher,

but more stable, temperature in a specific month has smaller anomalies than one with lower but more inter-annually variable temperature.

Statistical methods

We analyzed the association of monthly injury death rates with anomalous temperature using a Bayesian spatio-temporal model, described in the Supplementary Appendix. Analyses were done separately by injury type, sex and age group (0-4 years, 10-year age groups from 5 to 84 years, and 85+ years) because injury death rates vary by age group and sex,[10,11,18] as might their associations with temperature. We used the resultant risk estimates and the age-sex-specific death rates from each injury in 2016, to calculate additional deaths if each month in each state were +1°C above its long-term norm, realistic in our lifetimes under current projections of global climate change,[19] as well as within the range of anomaly size experienced by some states (Figure 2). For this calculation, we multiplied the actual death counts for each month, sex, state and age group in 2016 by the corresponding excess relative risk, which was calculated as the exponential of the coefficient of the temperature anomaly term from the above analysis.

Results

From 1980 to 2016, 4,006,454 boys and men and 1,757,862 girls and women died from an injury in the contiguous USA (i.e., excluding Alaska and Hawaii), accounting for 9.2% and 4.2% of all male and female deaths respectively. 95.6% of male injury deaths and 93.9% of female injury deaths were in those aged 15 years and older, and over half (52.6%) of male injury deaths were in those aged 15-44 years (Figure 3). In contrast with males, there was less of an age gradient in females after 15 years of age.

Injuries from transport, falls, drownings, assault, and suicide accounted for 79.0% of injury deaths in males and 72.1% in females. The remainder were from a heterogeneous group

of "other unintentional injuries" (Figure 3), within which the type of injury that led to death varied by sex and age group. Transport was the leading injury cause of death in women younger than 75 years and men younger than 35 years. Between 35 and 74 years of age, more men died of suicide than any other injury. Above 75 years of age, falls were the largest cause of death in both men and women.

There was a decline in age-standardized death rates of three out of five major injuries (transport, drownings and assault) from 1980 to 2016, although assault deaths have shown a recent increase since 2014 (Figure 4). In contrast, age-standardized death rates from falls increased over time while those from suicide initially decreased followed by an increase to surpass 1980 levels. The largest overall decline over time was for transport deaths in both sexes and for deaths from drownings in men, which declined by over 50% from 1980 to 2016. Age-standardized death rates for transport injuries and drownings peaked in summer months but deaths from other major injuries did not have clear seasonal patterns.

Average size of anomaly over the study period (1980-2016), a measure of how variable temperatures are around their central state-month long-term norm, ranged from 0.4°C for Florida in September, to 3.4°C for North Dakota in February (Figure 2). The average size of anomaly had a median value of 1.2°C across all states and months, with 27% less than 1°C and 90% less than 2°C (Figure 2). Temperature anomalies were largest in January and December and smallest in August and September. They were larger in northern and central states than in southern and coastal ones.

We estimated that there would be an estimated 941 (95% credible interval 831, 1,053) excess injury deaths, equivalent to 0.47% of all injury deaths in 2016, in each year in which each month in each state were +1°C above its long-term norm (Figure 5). Deaths from drowning, transport, assault and suicide would be predicted to increase, partly offset by a decline in deaths from falls in middle and older ages and in winter months (Figure 5). Most

excess deaths would be from transport injuries (448) followed by suicide (315). 87% of the excess deaths would occur in males and 13% in females. 80% of all male excess deaths would occur in those aged 15-64 years, who have higher rates of deaths from transport injuries. In those aged 85 years and older, there would be an estimated decline in injury deaths, because deaths from falls are expected to decline in a warmer year.

Proportionally, deaths from drownings are predicted to increase more than those of other injury types, by as much 8.3% (7.3, 9.3) in men aged 15-24 years (Figure S1); the smallest proportional increase was that of assault and suicide (less than 2% in all age and sex groups). There was a larger percent increase in transport deaths for males than for females, especially in young and middle-ages (e.g., 1.25% (0.90, 1.60) for 25-34 year old men versus 0.23% (-0.28, 0.76) for women of the same age) (Figure S1).

Discussion

While there are no previous studies of how deviations of monthly temperature from long-term norm are associated with injury mortality, our results are broadly in agreement with those that have analyzed associations with absolute temperature and for specific injury types. A study of suicide in US counties over 37 years (1968-2004) estimated that 1°C higher monthly temperature would lead to a 0.7% rise in suicides,[7] compared to our findings of 0.44-1% in males and 0.39-1.47% in females in different ages. In a study of six French heatwaves during 1971-2003, mortality from unintentional injuries rose by up to 4% during a heatwave period compared to a non-heatwave baseline.[8] A study of daily mortality from all injuries from Estonia found a 1.24% increase in mortality when daily maximum temperature went from the 75th to 99th percentile of long-term distribution.[9]

That anomalously warm temperature influences deaths from drowning, although not previously quantified, is highly plausible because swimming is likely to be more common when

monthly temperature is higher. The higher relative and absolute impacts on men compared with women may reflect differences in behavior. For example, over half of swimming deaths for males occur in natural water, compared to about quarter for females,[20] which may lead to a larger rise in the former in warmer weather. Similarly, the decline in deaths from falls, which are mostly in older ages, may be because falls in older people are more likely to be due to slipping on ice than in younger ages.[21–23]

The pathways from anomalous temperature to transport injury are more varied. Firstly, driving performance deteriorates at higher temperatures.[24–27] Further, alcohol consumption increases during warm temperature anomalies,[28] potentially also explaining why teenagers, who are more likely than other age groups to crash while intoxicated,[29] experience a larger proportional rise in deaths from transport than older ages when temperatures are anomalously warm. Lastly, warmer temperatures generally increase road traffic in North America;[30–33] With more people generally outdoors in warmer weather,[34] this could lead to more fatal collisions.

Pathways linking anomalously high temperatures and deaths from assault and suicide are less established. One hypothesis is that, similar to transport, more time spent outdoors in anomalously warmer temperatures leads to an increased number of face-to-face interactions, and hence arguments, confrontations, and ultimately assaults.[35,36] These effects could be compounded by the greater anger levels linked to higher temperatures.[37,38] Regarding suicide, higher temperature has been hypothesized as associated with higher levels of distress in younger people.[39] Nonetheless, links between temperature and mental health requires further investigation,[40] including whether the relationship varies by age and sex, as indicated by our results.

The major strength of our study is that we have comprehensively modelled the association of temperature anomaly with injury by type of injury, month, age group and sex. Our measure of temperature anomaly internalizes long-term historical experience of each state,

and is closer to what climate change may bring about than solely examining daily episodes, or average temperature to which people have adapted. To utilize this metric, we integrated two large disparate national datasets on mortality (US vital statistics) and meteorology (ERA-Interim), and developed a bespoke Bayesian spatio-temporal model. A limitation of our study is that, like all observation studies, we cannot rule out confounding of results due to other factors, although it is unlikely that such factors will have the same anomalies as temperature, even if their average space and time patterns are the same.

Our work highlights how deaths from injuries are currently susceptible to temperature anomalies and could also be modified by rising temperatures resulting from climate change, unless countered by social and health system interventions that mitigate these impacts. Though absolute impacts on mortality are modest, some groups, especially men in young to middle-ages, will experience larger impacts. Therefore, a combination of public health interventions that broadly target injuries in these groups – for example targeted messaging for younger males on the risks of transport injury and drowning – and those that trigger in relation to forecasted high temperature periods – for example more targeted blood alcohol level checks – should be a public health priority.

Contributions

All authors contributed to study concept, analytical approach, and interpretation of results. RP, GD and ME collated and organized mortality files. RP performed the analysis, with input from other authors. RP and ME wrote the first draft of the paper; other authors contributed to revising and finalizing the paper.

Conflict of interest

Figure 1. Graphic representation of temperature anomaly measure used in the analysis. The graph shows how monthly temperatures in July two example states (Florida in red and Minnesota in blue) (left panel) for 1980-2016 are used to calculate temperature anomalies. As seen, a warmer state like Florida (top right) can have a smaller inter-annual variation in a particular month (here, July) compared with a cooler state like Minnesota (bottom right).
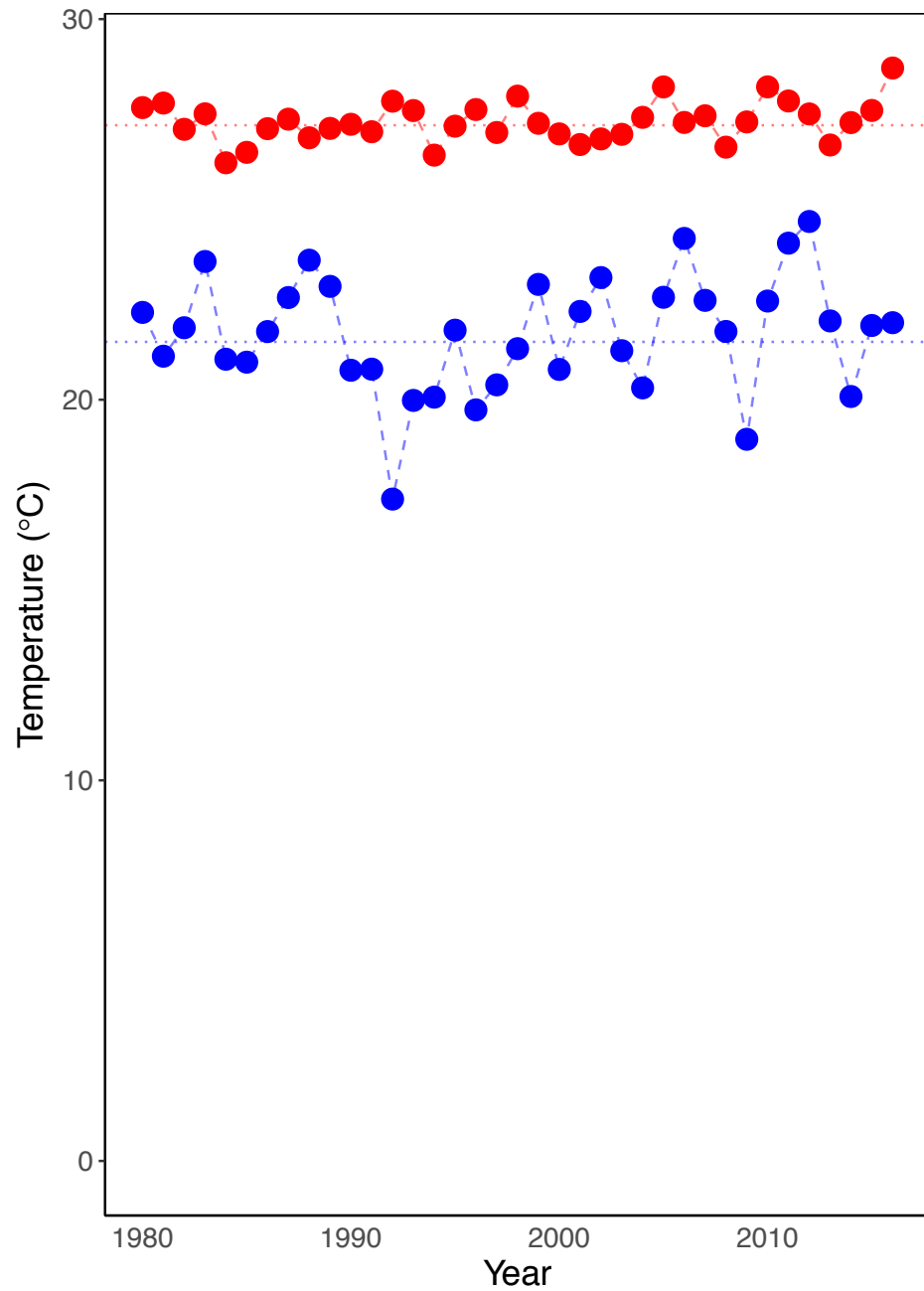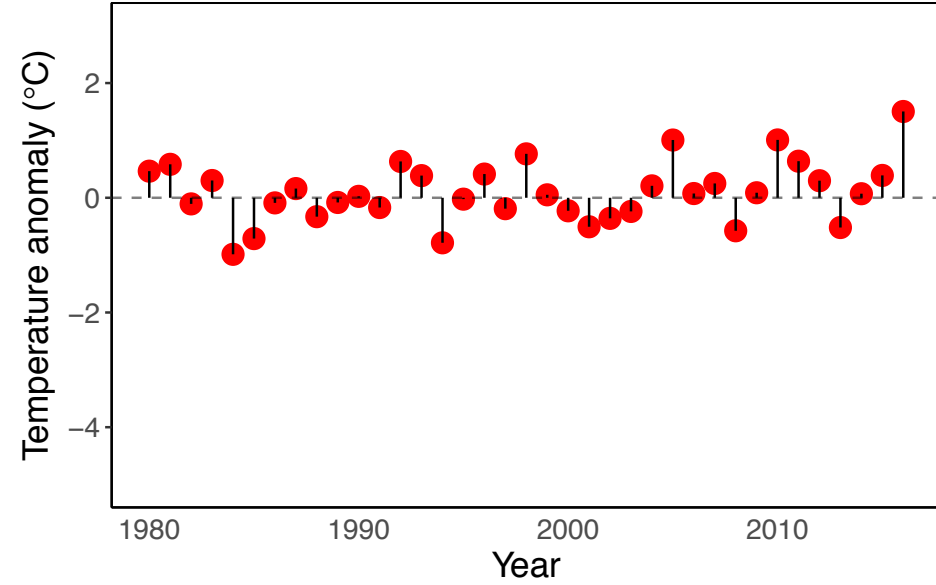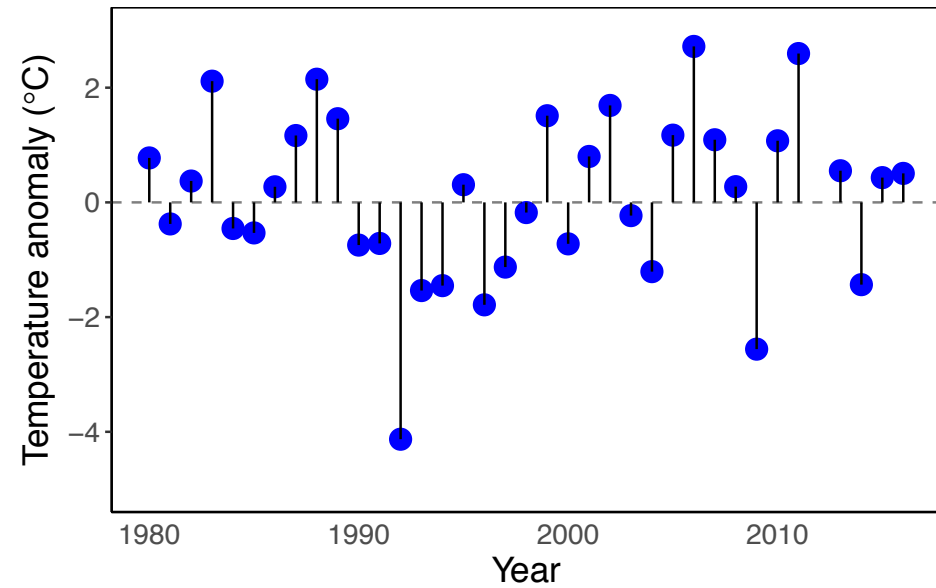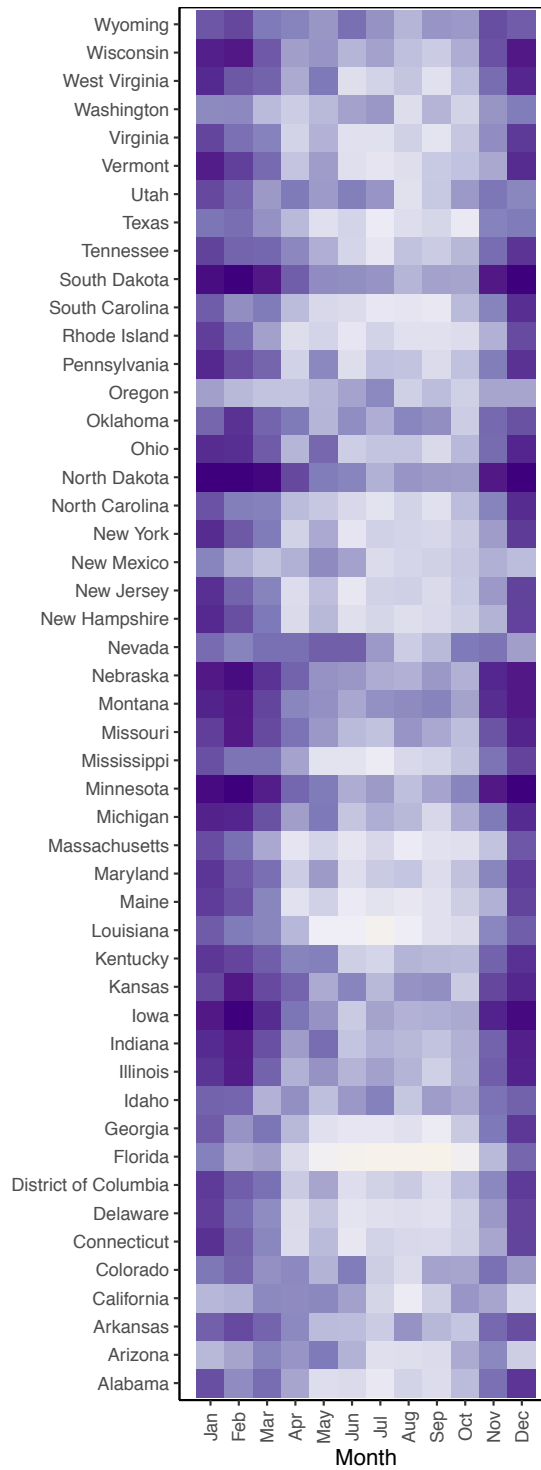
Figure 2. Average size of temperature anomaly (°C) from 1980 to 2016, by state and month. The value for each state and month is the mean of the absolute size of anomaly, be it cold or warm, and hence gives an indication of the scale of anomalies around the norm local temperatures.
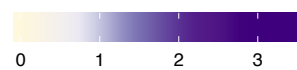
Average size of anomaly (°C)

Figure 3. Number of injury deaths, by type of unintentional (transport, falls, drownings, and other) and intentional (assault and suicide) injury, by sex and age group in the contiguous USA for 1980-2016.
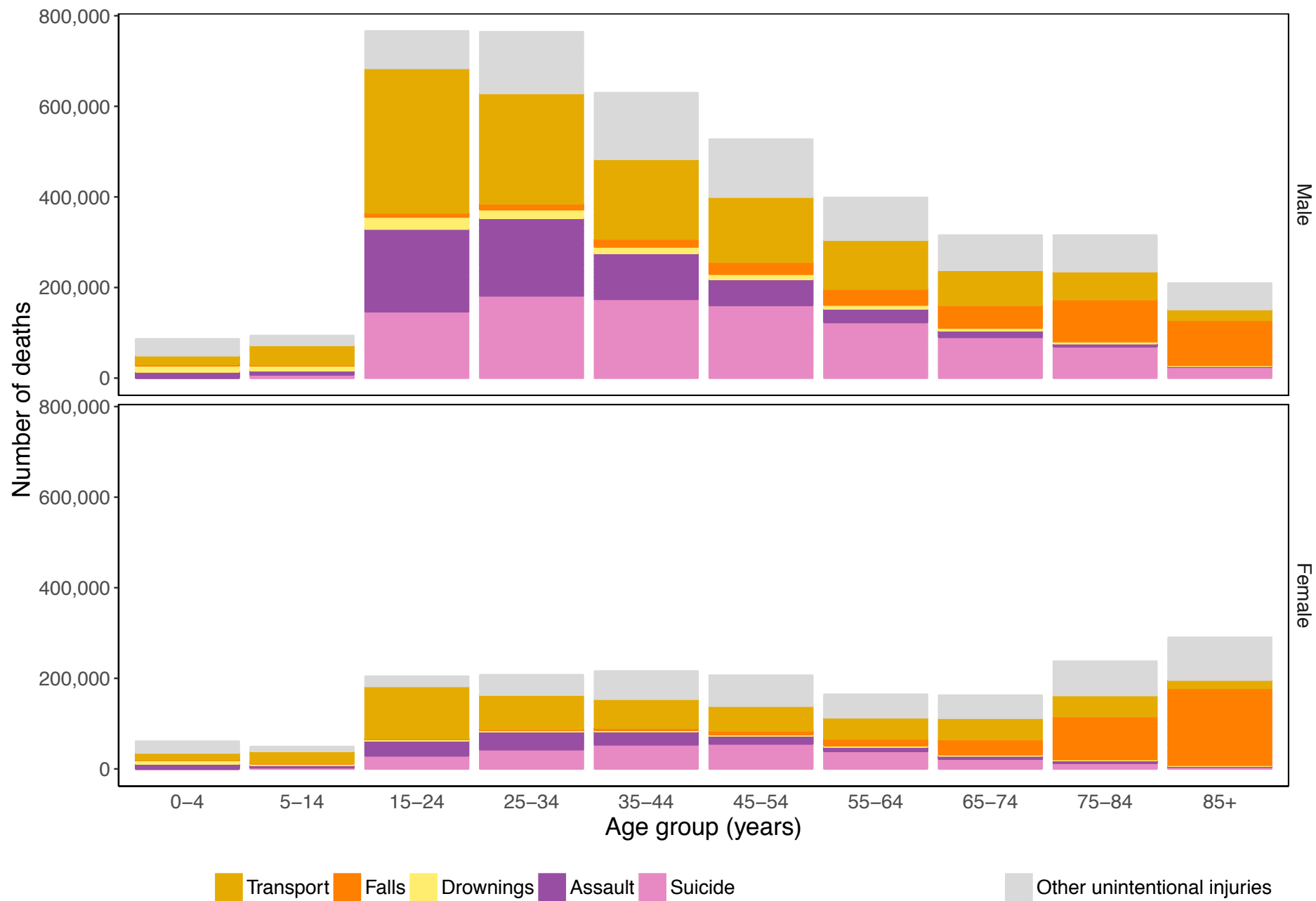
Figure 4. National age-standardized death rates from 1980 to 2016, by type of injury, sex and month.
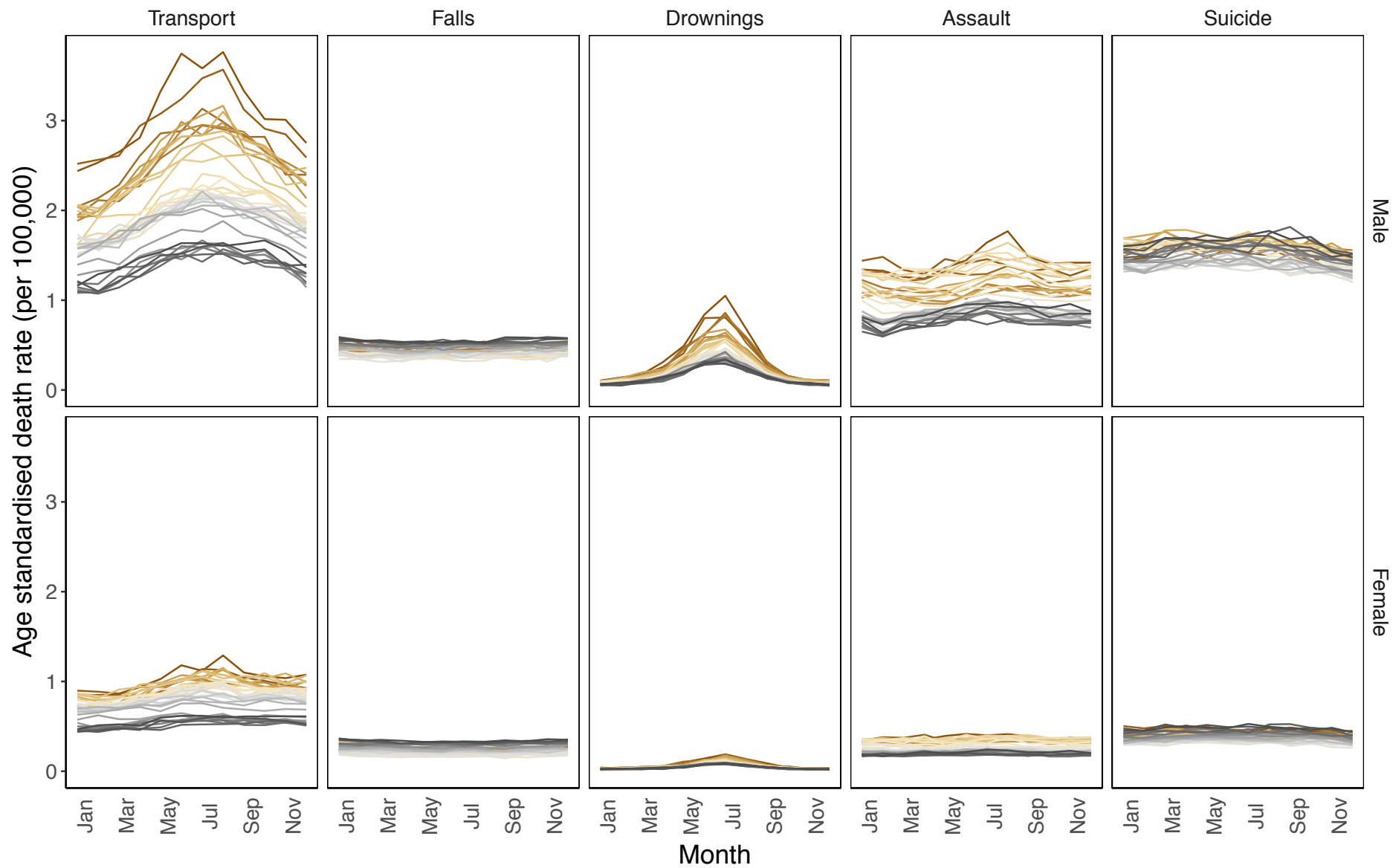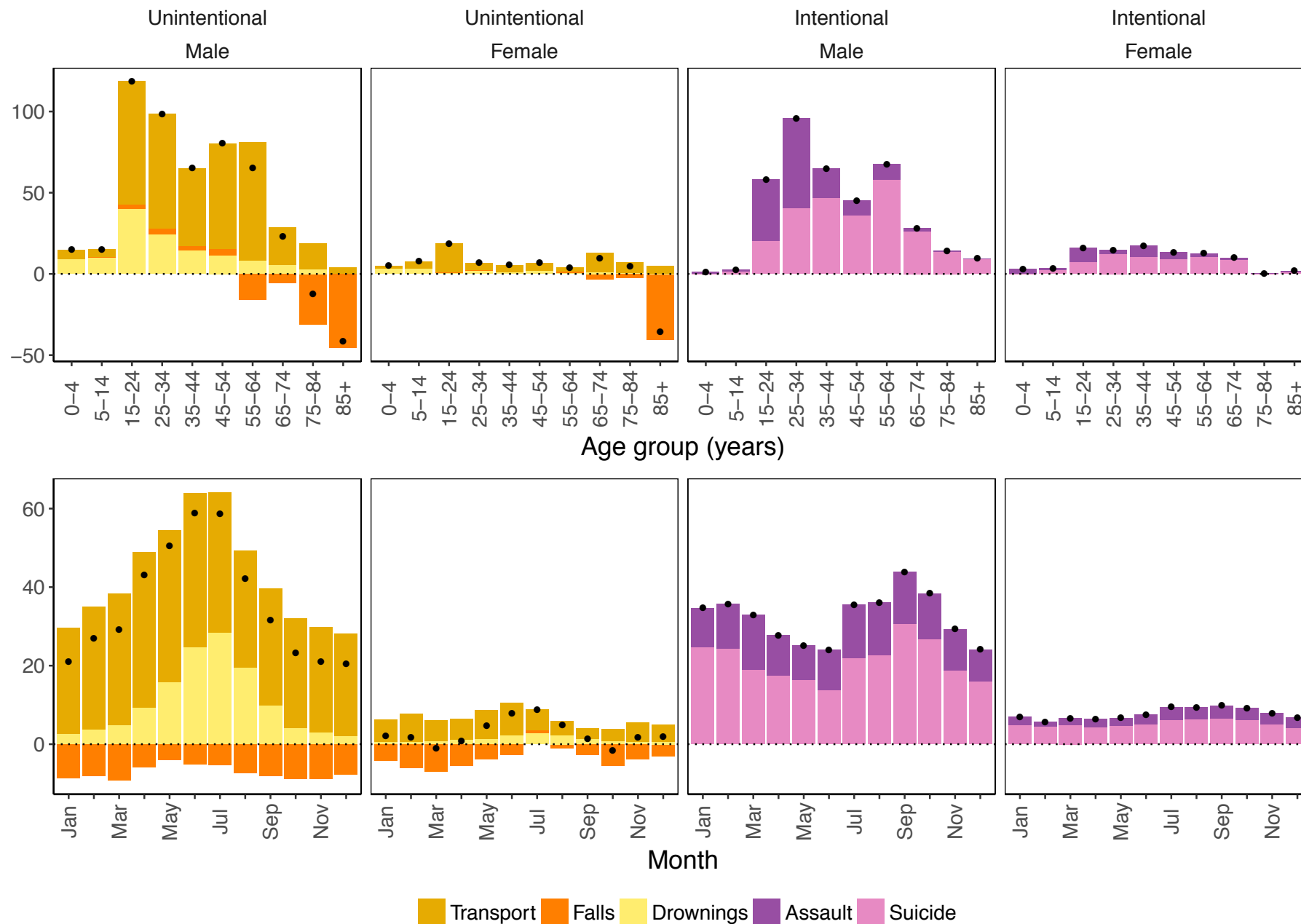
Figure 5. Additional annual injury deaths for the 2016 US population in year in which each month was +1°C warmer compared with 1980-2009 norm temperatures. The top row shows breakdown by type of injury, sex and age group. The bottom row shows the break down by type of injury, sex and month. Black dots represent net changes in deaths for each set of bars.

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