

The Climate Lifespan Link: Investigating the Influence of Temperature Change on Human Mortality

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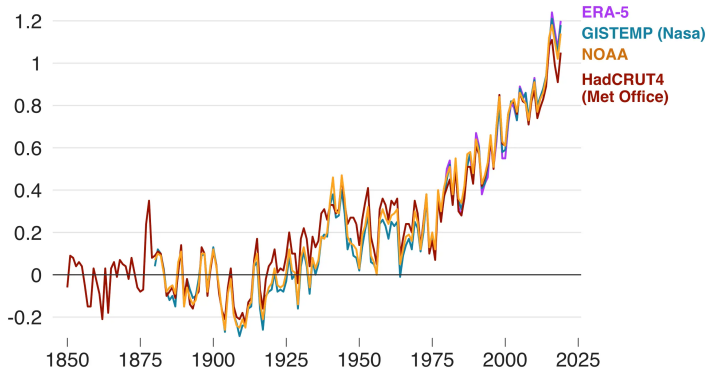
Background and Motivation

- **Climate changes:** global warming and increase in the frequency/severity of extreme temperature
- **Health impacts:** Non-optimal temperatures adversely affect human health
- **Vulnerable populations:** elderly are particularly vulnerable to temperature extremes
- **Research necessity:** essential to develop data-driven models to quantify temperature-mortality relationship

Temperature Trend (Source: Met Office)

Temperature rise since 1850

Global mean temperature change from pre-industrial levels, °C

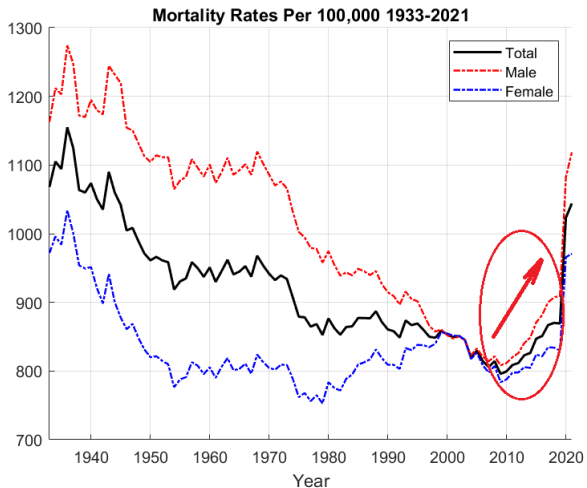


Source: Met Office

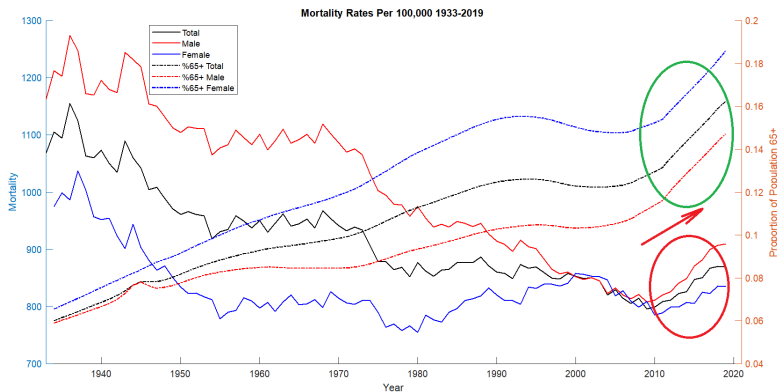
BBC



Mortality Trend (HMD Data)



Mortality Trend (HMD Data)



Major Findings

We propose the Temperature Lee-Carter (TLC) model to incorporate climate risk factors into a mortality model.

What we found:

- Elderly population is particularly vulnerable to the impacts of climate change
- The TLC model projects that by 2099, the global warming will:
 - increase the mortality rate of 65+ by 34.09%, under the “business as usual” scenario (SSP3-7.0), where no action is taken to reduce global CO₂ emissions.
 - increase the mortality rate of 65+ by around 50%, under the extreme weather scenarios (SSP5-8.5).

Literature Review

The impact of climate change on mortality has been relatively underexplored in academic research until recent years.

Research Gap

- Research without age bands
- Research with age bands

We discovered a statistically significant relationship between mortality rates and cold/heat extreme temperatures in the US.

Our Contribution

- Temperature Lee-Carter (TLC) Model
- Temperature measures

Research Without Age Bands

- Isaksen et al. 2016: time-series and relative risk analysis (extreme heat)
- Guo et al. 2017, Guo et al. 2018: time-series analysis (heat waves)
- Armstrong, L.Bell, and Sousa Zanotti Stagliorio Coelho, et al. 2017: (cold & heat)
- Zhao, Guo, and Ye, et al. 2021: (cold effect > heat effect)
- Chen, Schrijver, and Sivaraj, et al. 2024: (heat & population aging)
- Guo, Barnett, and Tong 2012, Petkova, Gasparrini, and Kinney 2014, Sheridan and Dixon 2017, Kalkstein et al. 2018, among others (no age bands)

Research With Age Bands (actuarial studies)

- Naqvi and Hall 2018: generalized additive model (monthly temperature, ages 75-90)
- Miljkovic, Miljkovic, and Maurer 2018: Dumitrescu–Hurlin panel data causality test (middle- and older- population)
- Li and Tang 2022: bivariate peaks over threshold (POT) approach (cold & age 55+)
- Dong et al. 2024: static sensitivity analysis
- Seklecka, Pantelous, and O'Hare 2017, Carannante, D'Amato, and Haberman 2023: Lee-Carter based model (no consideration of optimal temperature)

Our Contribution

- Introduces an age-specific factor to capture the unique sensitivity of temperatures to mortality at **each single age**.
- Captures the **excess mortality** rates caused by temperatures that deviate from the optimal temperature associated with the lowest mortality (*i.e.*, MMT).
- Utilizes **annual mortality** data along with **daily weather** data.

Temperature Lee-Carter Model

We define the following log link function for the Temperature Lee-Carter (TLC) model:

$$\begin{aligned} \ln(m_{x,t}) &= \alpha_x + \beta_x \kappa_t + \delta_x f(Z_t) + \epsilon_{x,t} \\ &= \eta_{x,t}, \end{aligned} \tag{1}$$

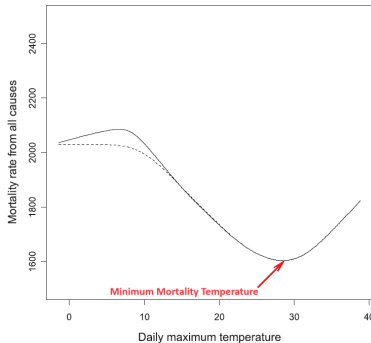
where δ_x is a $1 \times N$ row vector, $f(Z_t)$ is a mortality-centric temperature function of Z_t , and $Z_t = [Z_{1t}, Z_{2t}, \dots, Z_{Mt}]^T$ is the vector of climate covariates. Following the classical Lee and Carter 1992 model, we enforce the following constraints:

$$\begin{aligned} \sum_x \beta_x &= 1, \\ \sum_t \kappa_t &= 0. \end{aligned} \tag{2}$$

Minimum Mortality Temperature (MMT)

- The relationship between temperature and mortality often follows a **V-shaped** curve.
- The temperature associated with the optimal mortality is the minimum mortality temperature (MMT).

Source: [Honda et al. 2007](#) based on Japan Data 1972-1995.



Mortality-centric Temperature Measures

We define a set of mortality-centric temperature measures to capture the excess mortality rates caused by temperatures that deviate from the MMT.

- Cold/Heat Degrees
- Cold/Heat Extremes & Mid Deviation

Cold Degree and Heat Degree

Cold/heat degrees consider all deviations below/above the MMT:

$$\begin{aligned} \text{cold-degree} &= \sum_{t=1}^{365} \max[\text{MMT} - T_t, 0]/365 \\ \text{heat-degree} &= \sum_{t=1}^{365} \max[T_t - \text{MMT}, 0]/365, \end{aligned} \tag{3}$$

where T_t is the daily mean temperature in day t .

Cold Extreme, Mid Deviation, and Heat Extreme

Cold/heat extremes and mid deviation partition the spectrum of temperature into three parts:

$$\text{cold-extreme} = \sum_{t=1}^{365} \max[C_{\text{threshold}} - T_t, 0]/365$$

$$\text{mid-deviation} = \sum_{t=1}^{365} |\{T_t - \text{MMT} | C_{\text{threshold}} \leq T_t \leq H_{\text{threshold}}\}|/365 \quad (4)$$

$$\text{heat-extreme} = \sum_{t=1}^{365} \max[T_t - H_{\text{threshold}}, 0]/365,$$

where $C_{\text{threshold}}$ and $H_{\text{threshold}}$ are cold and heat thresholds for the cold and heat extreme measures.

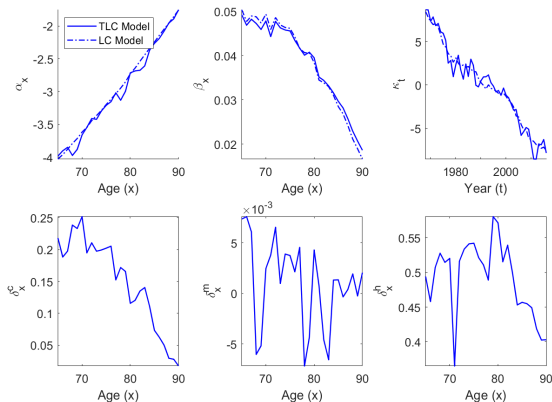
Data Description

Combining annual mortality data with daily weather data helps to fully capture the mortality impacts of temperature shocks:

- Climate Data: daily mean temperature from the nClimGrid-Daily product provided by the National Centers for Environmental Information (NCEI).
- Mortality Data: annual mortality from Human Mortality Database (HMD) for each single age.

TLC Model Parameter Estimates

Parameter estimates of the TLC model (solid line) and the Lee-Carter model (dashed line) using the U.S. total population data with ages from 65 to 90, and years from 1968 to 2019.



Model Fitting Performance

Temperature Measures	Log-Likelihood	# Eff Params	AIC	BIC
Baseline				
Lee-Carter model	-2.6888×10^4	102	5.3981×10^4	5.4512×10^4
One mortality-centric temperature measure				
cold-extreme only	-2.5738×10^4	130	5.1732×10^4	5.2399×10^4
mid-deviation only	-2.6435×10^4	130	5.3127×10^4	5.3794×10^4
heat-extreme only	-2.5620×10^4	130	5.1495×10^4	5.2162×10^4
Two mortality-centric temperature measures				
cold-extreme + heat-extreme	-2.4777×10^4	156	4.9862×10^4	5.0664×10^4
cold-extreme + mid-deviation	-2.5476×10^4	156	5.1260×10^4	5.2063×10^4
mid-deviation + heat-extreme	-2.5188×10^4	156	5.0685×10^4	5.1487×10^4
Three mortality-centric temperature measures				
cold-extreme + mid-deviation + heat-extreme	-2.4547×10^4	182	4.9454×10^4	5.0391×10^4

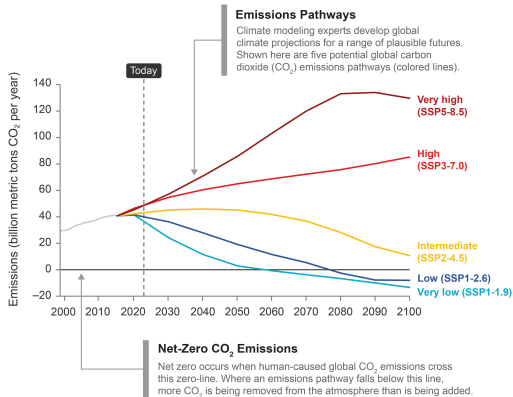
TLC Model Prediction

The prediction is based on various SSP-RCP (Shared Socioeconomic Pathway - Representative Concentration Pathway) scenarios under the 6th phase of Coupled Model Intercomparison Project (CMIP6) overseen by the World Climate Research Programme (WCRP).

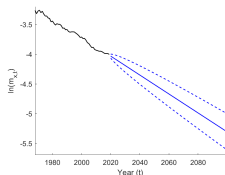
- SSP1-2.6
- SSP2-4.5
- SSP3-7.0
- SSP5-8.5

Carbon Dioxide Emissions Pathways

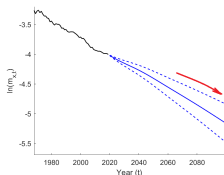
Future Global Carbon Dioxide Emissions Pathways



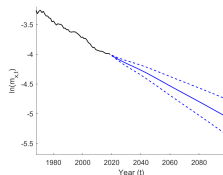
TLC Projection for Age 70 Under Various Scenarios



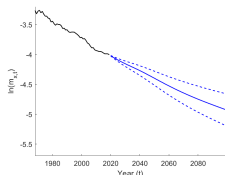
(a) Lee-Carter Model



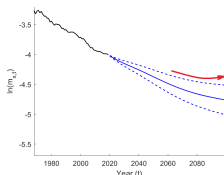
(b) The TLC Model, SSP1-2.6



(c) The TLC Model, SSP2-4.5



(d) The TLC Model, SSP3-7.0



(e) The TLC Model, SSP5-8.5

Impact of Global Warming

We define the following the types of excess relative risk (ERR) on mortality:

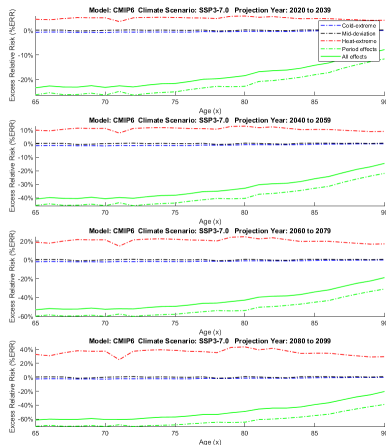
$$\begin{aligned} \text{ERR}_{\text{Climate}}\% &= 100 \frac{\Delta m_{x,t}}{m_{x,t}} \\ &= 100 \left\{ \frac{\exp(\alpha_x + \beta_x \kappa_t + \delta_x f(Z + \Delta Z))}{\exp(\alpha_x + \beta_x \kappa_t + \delta_x f(Z))} - 1 \right\} \\ &= 100 \{ \exp(\delta_x (f(Z + \Delta Z) - f(Z))) - 1 \}. \end{aligned}$$

$$\text{ERR}_{\text{PeriodMortImp}}\% = 100 \{ \exp(\beta_x E[D(\kappa_t)]) - 1 \}.$$

$$\text{ERR}_{\text{Overall}}\% = 100 \{ \exp(\beta_x E[D(\kappa_t)] + \delta_x (f(Z + \Delta Z) - f(Z))) - 1 \}. \quad (5)$$

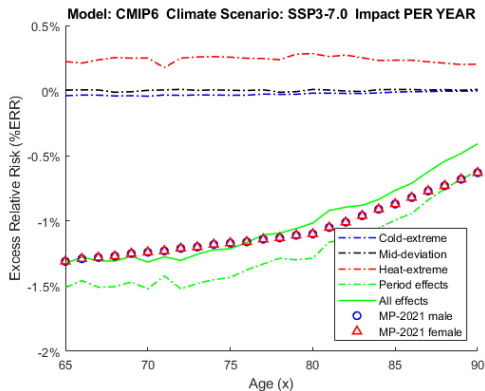
Cumulative ERR%

Cumulative ERR% under CHIP6 climate scenario: SSP3-7.0 for periods 2020-2039, 2040-2059, 2060-2079, and 2080-2099:



Annual ERR%

Annual ERR% under CHIP6 climate scenario: SSP3-7.0 for periods 2020-2099:



TLC vs. MP-2021 Prediction

- Annual ERR% by TLC model:
 - Excluding climate effects: 0.62% to 1.52% per annum
 - Including climate effects SSP3-7.0: 0.41% to 1.33% per annum
- MP-2021 projection via a piece-wise linear function without considering climate factors
 - U.S. males: 0.63% to 1.35% per annum
 - U.S. females: 0.63% to 1.31% per annum

Conclusions

- We propose the Temperature Lee-Carter (TLC) model to capture the temperature sensitivity on mortality at each individual age.
- We quantify excess mortality using mortality-centric temperature measures.
- Climate effects could potentially diminish or even offset long-term improvements in human mortality.
- Under the SSP3-7.0 scenario, the TLC model forecasts a 34.09% rise in mortality rate of 65+ by 2099 due to climate change.

Thank you
for your attention



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