Final Report

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SCOR FOUNDATION FOR SCIENCE

Funded Research Project: "Who, When, and Where? Assessing Mortality Risk of Climate Change"

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Project Objectives

This project is related to results dissemination, knowledge exchange, and presentations to a larger audience of the ongoing research on "*Who, When, and Where? Assessing Mortality Risk of Climate Change*". The Agreement was signed on 21 December 2022. The primary objective of this project is to obtain a richer understanding of how mortality risk is affected by climate change. This presents an important research topic for life insurers in relation to actuarial pricing and product design. Previous analyses suffer from limitations in how they investigate this question since they only consider data over broad geographical regions. In contrast, our analysis aims to fill this gap and is designed to study the impact of climate change on mortality while controlling for other factors that may also drive the mortality experience. A cutting-edge Bayesian modelling approach is proposed to estimate the non-linear relationship between mortality and temperature which allow us to investigate the following important research questions

a) Who are the excess deaths? – Find the age groups that are particularly sensitive to climate change;
b) When do excess deaths occur? – Determine if more excess deaths occur in winter or summer months; and
c) Where are the excess deaths? – Identify regions that are most vulnerable to climate change.

Schedule

The project was initially planned to end in December 2023. The duration of the project has now been extended until 31 December 2024 to facilitate further dissemination, communication, and knowledge exchange of project results. Accordingly, the researchers will inform the SCOR Foundation about the forthcoming dissemination events. The related presentations and the new research articles will be communicated with the SCOR Foundation and posted on the SCOR Foundation website.

Researchers

The project was carried out by the principal investigator (PI) Associate Professor Han Li from the Department of Economics at the University of Melbourne, and the co-investigators (co-I) Associate Professor Anastasios Panagiotelis from the Discipline of Business Analysis at the University of Sydney, and Professor Rob J Hyndman from the Department of Econometrics and Business Analytics at Monash University. The PI is the lead on all papers and presentations produced throughout the project. Bohan Zhang (Beihang University in China) provided excellent research assistance for this project. The project oversight group includes Philippe Trainar (Director), Zeying Peuillet (General Secretary) from the SCOR Foundation, and Adam Shao from the SCOR Biometric Risk Modelling Team.

Summary of Project Objectives Completion

The following steps are completed in line with objectives (a), (b), and (c):

- We built up and improved data linkages between temperature and mortality. Our study focuses on the US experience during 1969–2019. We collected and complied data from the National Center for Health Statistics (NCHS), the Centers for Disease Control and Prevention (CDC), and the National Oceanic and Atmospheric Administration (NOAA).
- We conducted a thorough literature review on the impact of temperature on mortality including previous research in the fields of actuarial science, demography, environmental science, and health and epidemiology [3, 4, 5, 6, 7, and 8].
- We introduced new modeling frameworks to address the following challenges in quantifying mortality risk due to extreme temperatures: 1) The relationship is non-linear; 2) This non-linear relationship may also vary by geography and cause-of-death; 3) There is a need to control for spatial factors which can confound the relationship between temperature and mortality.
- A copula-based model has been developed for monthly cause-specific death counts, where we consider major causes including diabetes, respiratory, neoplasms, vascular, and external. Based on the fitted models, we generate several temperature scenarios and assess cause-specific excess deaths and overall excess deaths due to extreme cold temperatures.
- A non-parametric regression model with random effects has been developed for monthly log mortality, where we incorporate Monthly effects, Year-Age effects, Spatial effects, and Temperature effects. We consider two types of temperature effects, namely the average temperature (captures the level) and temperature range (captures the range).
- This non-parametric model is estimated using computationally intensive Bayesian techniques. We have considered several exact inferential techniques including Markov chain Monte Carlo (MCMC) and Hamiltonian Monte Carlo (HMC), with the latter easily implemented using the STAN software [2].
- We visualized the model results and highlighted the spatial effects, as well as the impact of extreme and persistent temperatures on mortality risk.
- Main findings were obtained for six major US continental areas, defined as in the Actuaries Climate Index [1]. These continental areas are further broken down into NOAA defined climate divisions for the purposes of our analysis.
- For illustrative purposes, the Southwest Pacific (referred to as “SWP”, which includes California, Nevada, Utah, Arizona, Colorado, and New Mexico) is chosen for further discussion in this report.

Dissemination Events

The key findings of the project are disseminated via the following events:

- A promotional video has been recorded by the PI (HL) in April 2023, introducing and explaining the key objectives of the project. The video is made available at the SCOR Foundation for Science website via the link: https://foundation.scor.com/news/mortality-risk-climate-change
- An in-person workshop was organized by SCOR Foundation for Science in Paris to engage with the Biometric Risk Modelling Team in July 2023. The PI (HL) made in-person presentations on the topic of climate change and mortality risk. The recording is made available at the SCOR Foundation for Science website via the link: https://foundation.scor.com/news/scor-foundation-workshop-understanding-and-assessing-climate-driven-mortality-risk
- A webinar was organized by the SCOR Foundation for Science on 22 March 2024. Both the PI (HL) and the Co-I (AP) made an online presentation to an international audience. The presentation slides and recording are made available at the SCOR Foundation for Science website via the link: https://foundation.scor.com/news/scor-foundation-webinar-assessing-mortality-risk-climate-change
- PI (HL) and Co-I (AP) visited the SCOR Foundation for Science in Paris in July 2024, provided updates on the project to Philippe Trainar and General Zeying Peuillet.
- The first research paper “Modeling cold-related excess deaths via stationary vine copulas” has been completed and under review at a renowned actuarial journal. The paper is made available at the SCOR Foundation for Science website via the link: https://tinyurl.com/45m988uj
- The second research paper is currently in the final stages of completion, which will be submitted to the SCOR Foundation for Science once finished.
- A final webinar will be organized by the SCOR Foundation for Science in early 2025 to conclude this project and engage in discussion with the audience.

Summary of Main Findings

The main findings of the second research paper are summarized as follows:

1. We developed a Bayesian modeling framework for quantifying the mortality risk associated with climate change for insurance risk management. Our approach can also be used to assess the impact of climate change on morbidity based on prevalence and/or incidence rate. More importantly, the modeling framework will be applicable to mortality and morbidity experience of an insured population, to better understand the impact of climate on the insurance portfolio.

2. We investigated the differences in mortality experience in the US and found substantial geographical variations across the states. For example, Southern states generally have higher mortality compared to the East Coast and the West

Coast. In Figure 1, we plotted a snapshot of monthly log mortality rate across 344 climate divisions in the US, for ages 75–84 in January 2018.

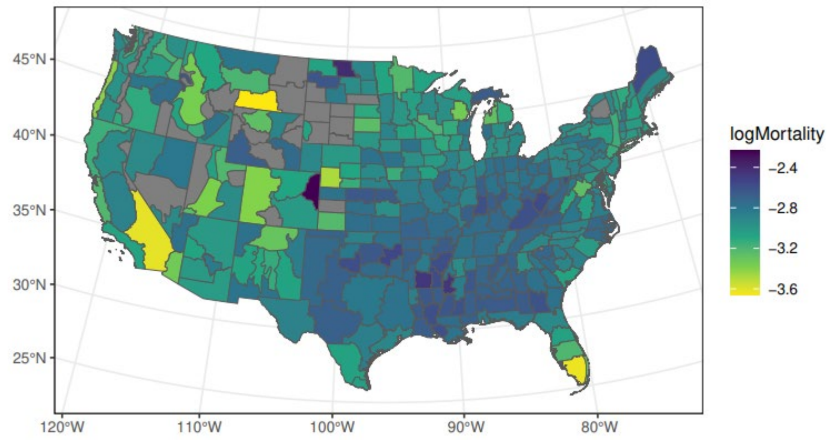

Figure 1: log mortality rate, ages 75–84, January 2018.

3. **<u>Spatial effects</u>**: As mentioned before, we choose the SWP region to demonstrate the main results of this research. In Figure 2, we observe spatial differences within and across different states. Moreover, there seem to be some clustering effects where neighboring areas share similar spatial characteristics.

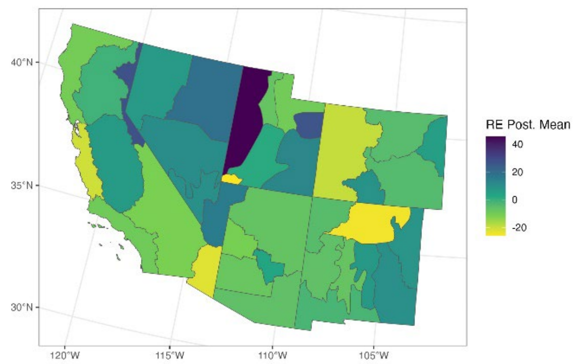

Figure 2: Spatial effects within the SWP.

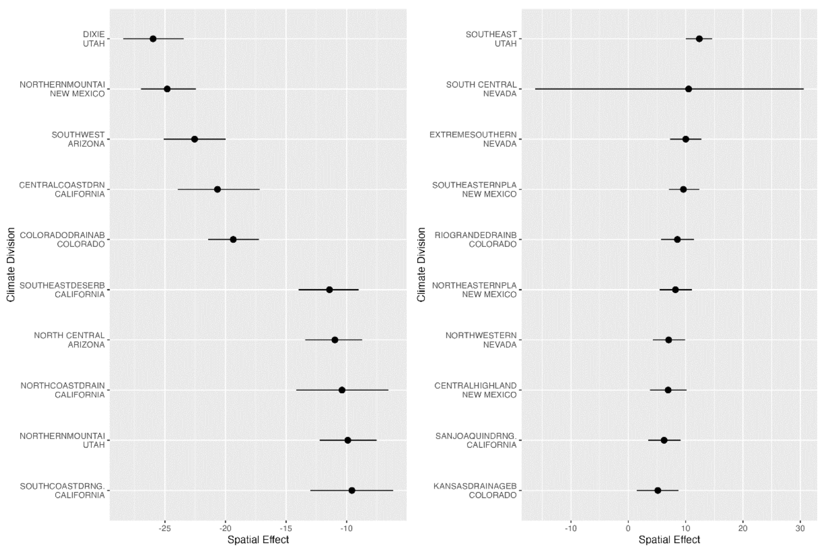

Figure 3: Top 10 and bottom 10 regions in spatial effects within the SWP.

With these estimated spatial effects, we provided a ranking of the "top 10" (representing regions with the best mortality experience) and the "bottom 10" (representing regions with the worst mortality experience) in the SWP area. Confidence intervals of the estimated values are also plotted in the figure. For regions with low populations such as South-Central Nevada these are wide due to more uncertainty. These spatial effects can be considered as random effects which capture socio-economic, demographic, and behavior/lifestyle factors.

4. **Age-Year effects**: It is widely recognized that the overall mortality rates have declined over recent decades. However, this trend does not apply uniformly across all age groups. For example, as shown in Figure 4, individuals aged 55-64 experienced a period of improved mortality in the early 2000s, largely driven by technological advancements in healthcare, and an improved standard of living. However, in more recent years, this trend has reversed, with mortality rates beginning to rise again. There are many potential explanations for this phenomenon, including "deaths of despair", a term used to describe deaths resulting from drug overdoses, alcohol-related diseases, and suicide. Another potential attributing factor is the growing obesity epidemic among the US population, which leads to higher mortality due to heart disease, diabetes, and stroke. It is important to take these different trends into account while assessing the impact of climate change on mortality.

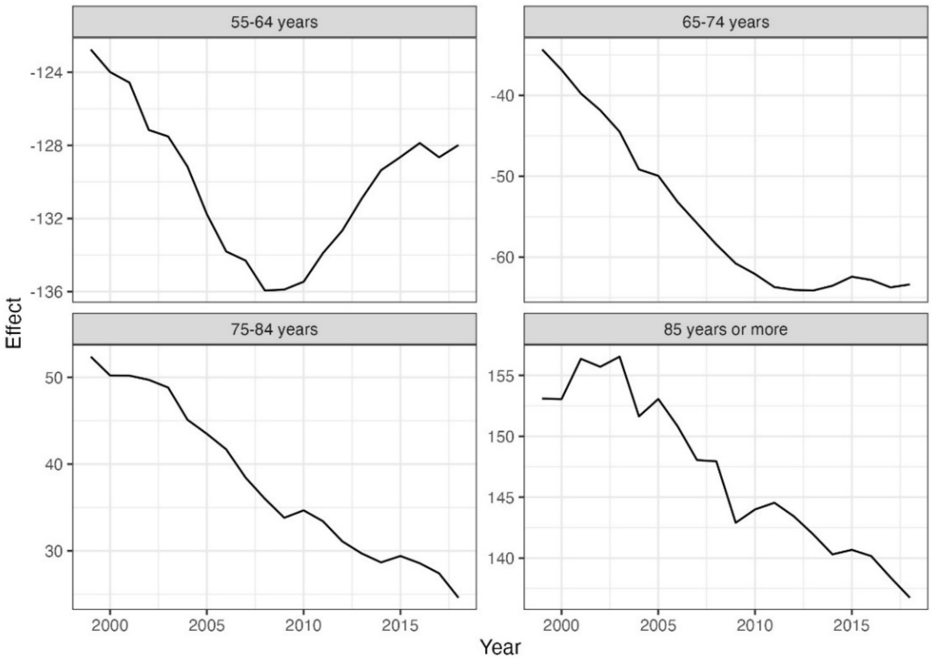

Figure 4: Age-Year effects for 55-64, 65-74, 75-84, and 85+ in SWP.

5. **Monthly effects**: We illustrate the monthly effects on mortality for SWP in Figure 5. The plot shows an elevated level of mortality in winter months, and a lower level of mortality in summer months, which is consistent with findings in the relevant literature.

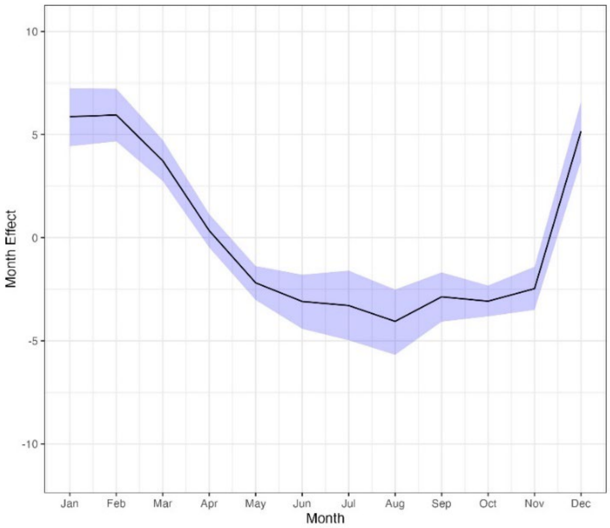

Figure 5: Monthly effects for 55-64, 65-74, 75-84, and 85+ in SWP.

6. **Temperature effects**: Finally, we illustrate the effect of temperature on mortality in Figure 6. Both the monthly maximum and monthly minimum temperature are considered in our research. Since the two variables are highly correlated, they are transformed into the mean of monthly maximum and minimum temperature (average) and difference between monthly maximum and monthly minimum temperature (range). These temperature effects are modeled in a non-linear fashion and are allowed to vary across climate divisions. It should be noted that the monthly effect already captures a large amount of the seasonal variation in mortality. Therefore, the plots in Figure 6 should be interpreted as local variations due to temperatures, on top of the overall monthly effect.

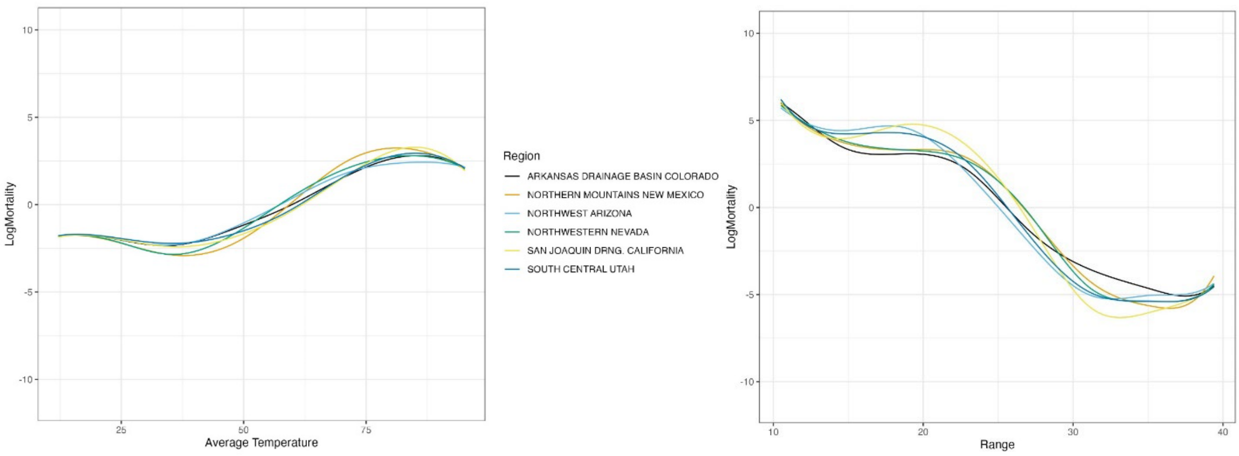

Figure 6: Temperature effects in SWP. Left panel shows the impact of average temperatures and right panel shows the impact of the temperate range.

The left panel of Figure 6 shows that after controlling for an overall monthly effect, extreme hot temperatures are associated with higher levels of mortality. This effect is more pronounced for the Northern Mountains of New Mexico, and less pronounced for Northwest Arizona. These differences suggest a greater adaptation to hot weather, possibly through the increased proliferation of air conditioning, in the generally warmer desert climate of Arizona.

Turning our attention to the right panel of Figure 6, we investigate the impact of monthly temperature range on mortality. In general, lower temperature ranges have a greater effect on mortality than higher ranges. This could indicate that excess mortality due to extreme hot temperatures is more likely to occur when the heat is sustained (*i.e.* during heatwaves). Similarly, excess mortality due to extreme cold temperatures is more likely to occur in sustained cold weather (*i.e.* during cold spells). In both scenarios, the maximum and minimum temperatures are consistently high or low, leading to a low temperature range. Within the SWP, this effect at low ranges is more pronounced for warmer regions such as Northwest Arizona, and less pronounced for mountainous regions in states such as Colorado.

Acknowledgement

We would like to express our sincere gratitude to the SCOR Foundation for Science for funding our research project, “Who, When, and Where? Assessing Mortality Risk of Climate Change.” Especially, we would like to convey our deep thanks to Philippe Trainar and Zeying Peuillet of the Foundation for their precious guidance and support. We also extend our thanks to the SCOR Biometric Risk Modelling Team, as well as to the online webinar audience, for their insightful comments and valuable discussions.

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