Discussion on “Global Warming and Mortality”

Michael Greenstone (University of Chicago)

The Determinants of Mortality

The National Bureau of Economic Research (NBER)

January 10, 2025

Summary of Discussion

1. Global Warming and Health is Hot!

2. Key Findings from Carleton et al. (2022)
   (a) Welfare Impacts of Climate Change are Evident in Mortality **and** Expenditures on Adaptation
   (b) Temperature Impacts Vary Based on Local Climate and Income
   (c) Temperature Impacts are Global and Heterogeneous
   (d) Adaptation is Costly
   (e) Future Impacts of Climate Change are Heterogeneous and Uncertain

3. Future Directions for Research

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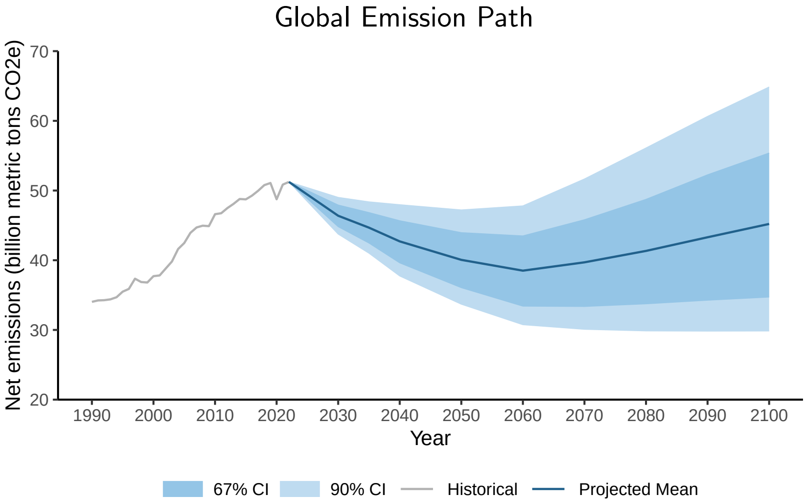
Historical and Projected Greenhouse Gas Emissions and Predicted Temperature Change



Larsen et al. (2024)

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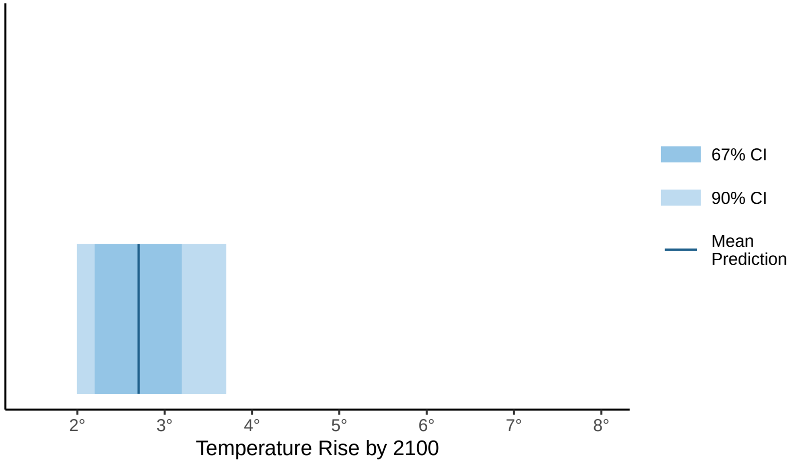

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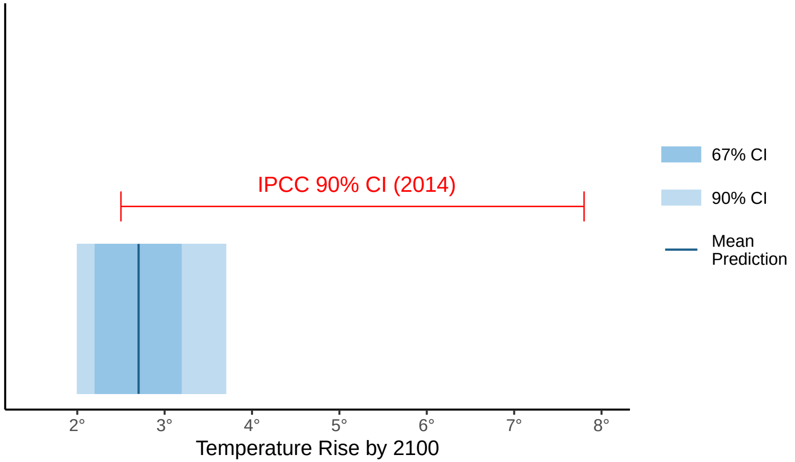

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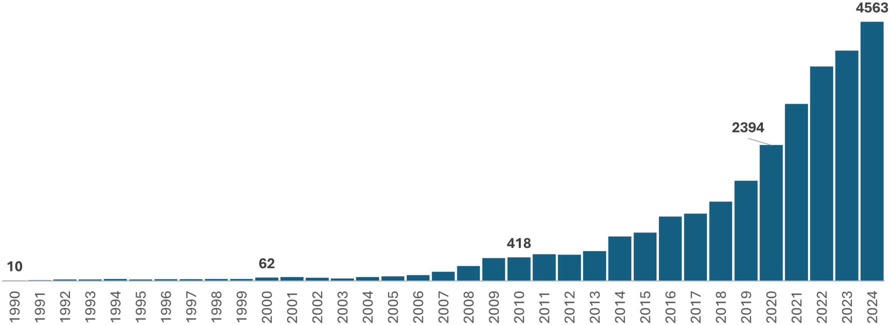
Global Warming and Health is Hot

The number of PubMed articles with the phrases "climate change" and "health" increased sharply



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More Details in Carleton et al. (2022)

Valuing the Global Mortality Consequences of Climate Change Accounting for Adaptation Costs and Benefits* FREE

Tamma Carleton, Amir Jina, Michael Delgado, Michael Greenstone, Trevor Houser, Solomon Hsiang, Andrew Hultgren, Robert E Kopp, Kelly E McCusker, Ishan Nath, James Rising, Ashwin Rode, Hee Kwon Seo, Arvid Viaene, Jiacan Yuan, Alice Tianbo Zhang

The Quarterly Journal of Economics, Volume 137, Issue 4, November 2022, Pages 2037–2105, https://doi.org/10.1093/qje/qjac020

Published: 21 April 2022

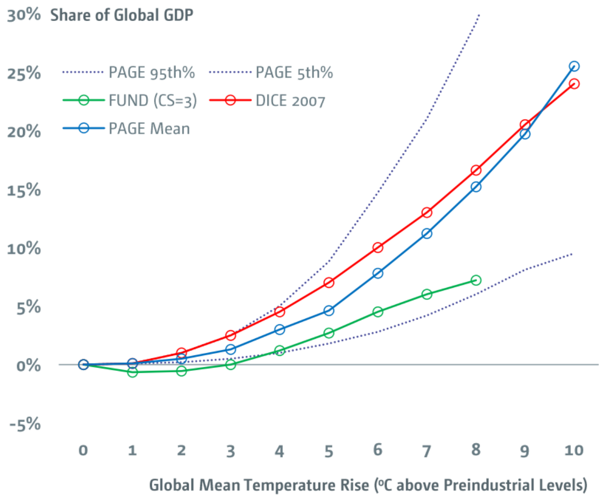
Abstract

Using 40 countries' subnational data, we estimate age-specific mortality-temperature relationships and extrapolate them to countries without data today and into a future with climate change. We uncover a U-shaped relationship where extre6me cold and hot temperatures increase mortality rates, especially for the elderly. Critically, this relationship is flattened by higher incomes and adaptation to local climate. Using a revealed-preference approach to recover unobserved adaptation costs, we estimate that the mean global increase in mortality risk due to climate change, accounting for adaptation benefits and costs, is valued at roughly 3.2% of global GDP in 2100 under a high-emissions scenario. Notably, today's cold locations are projected to benefit, while today's poor and hot locations have large projected damages. Finally, our central estimates indicate that the release of an additional ton of CO_2 today will cause mortality-related damages of $36.6 under a high-emissions scenario, with an interquartile range accounting for both econometric and climate uncertainty of [-$7.8, $73.0]. These empirically grounded estimates exceed the previous literature's estimates by an order of magnitude.

JEL: H23 - Externalities; Redistributive Effects; Environmental Taxes and Subsidies, H41 - Public Goods, I14 - Health and Inequality, Q51 - Valuation of Environmental Effects, Q54 - Climate; Natural Disasters; Global Warming

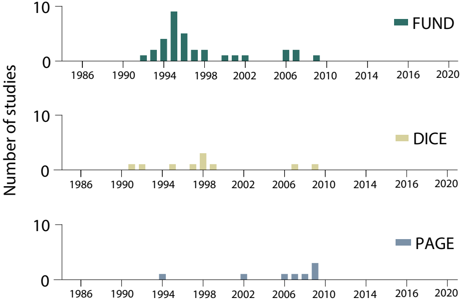
Issue Section: Article

Original Policy Models for Climate Damage



Source: Interagency Working Group on SCC, 2010

Empirical Publications Informing These Models



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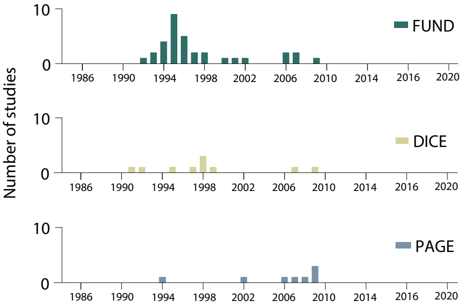

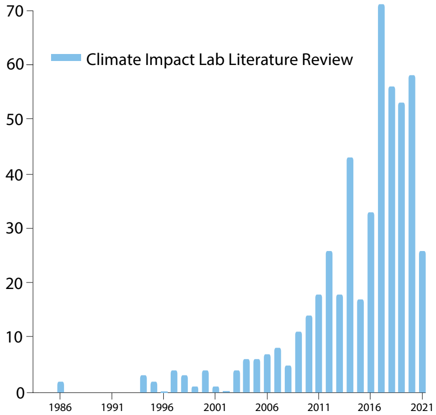

Three Principles for Estimating Climate Damages

1. **Best Available Evidence:** Damage functions should be informed by best available empirical estimates
2. **Reflect Damage from Around the World:** Should use data representing the global population (not just rich countries)
3. **Reflect Adaptation and its Costs:** Should reflect that agents adapt given income & climate, include these costs

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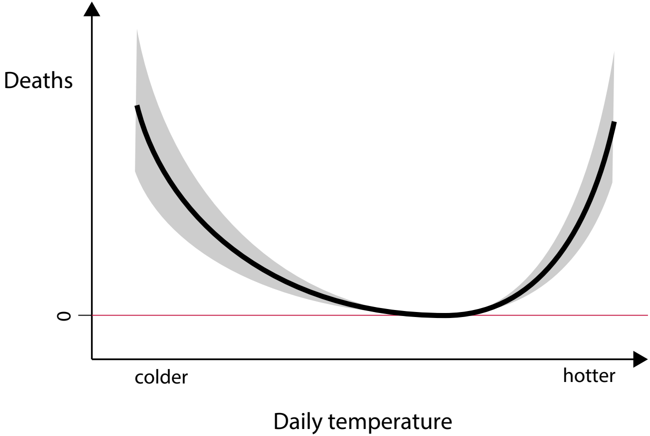
Adapting to Climate Change

A typical temperature mortality relationship shows responses to both cold and hot temperatures.



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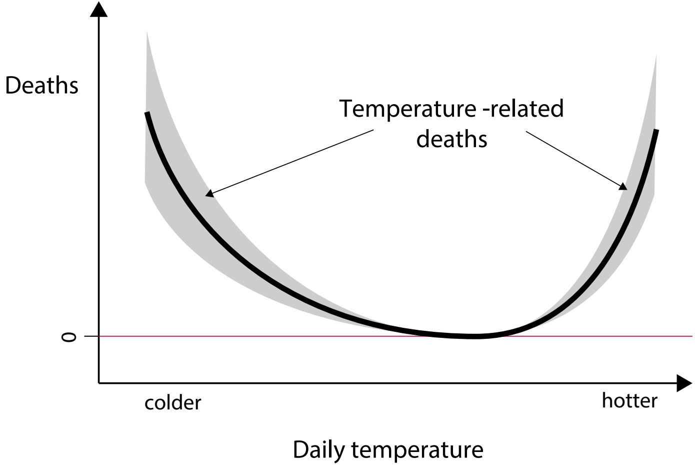

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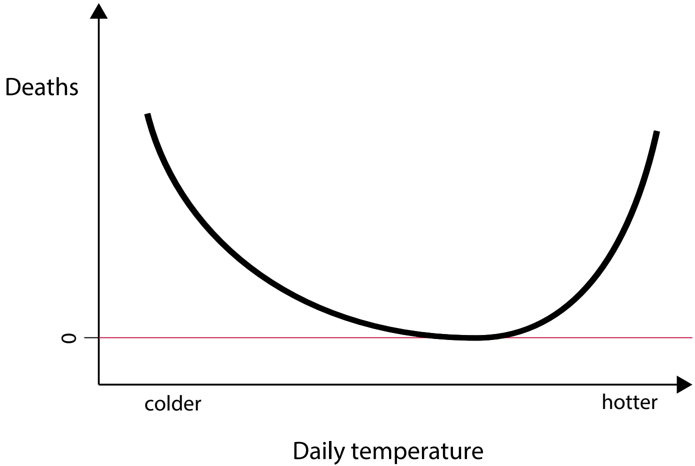
As agents become more adapted to their climate, we expect temperature extremes to cause fewer deaths...



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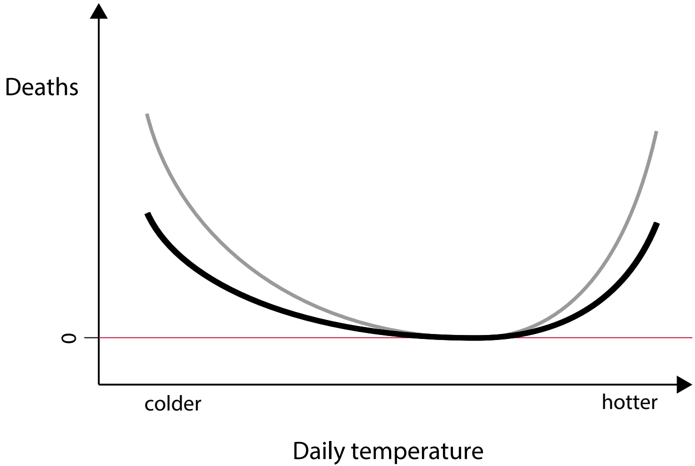

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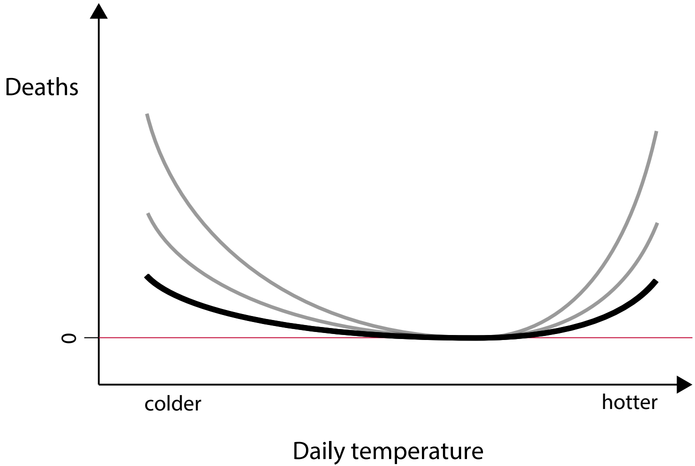

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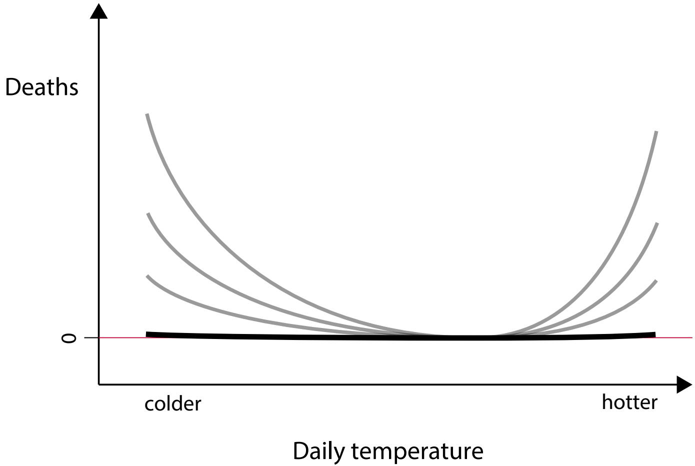
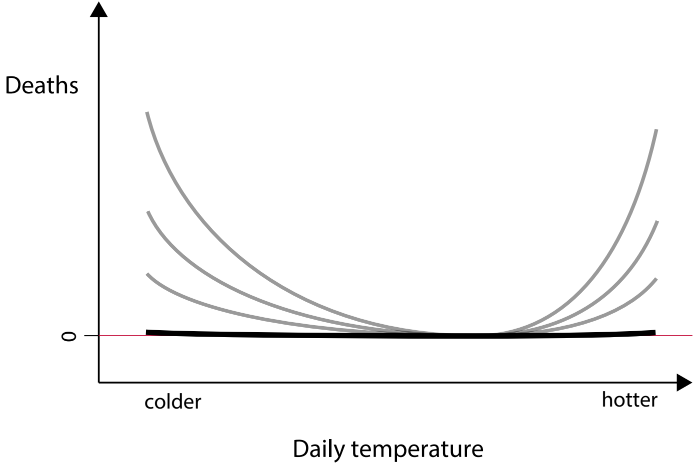


Adapting to Climate Change

...but this only captures the **benefits** of those adaptive changes, it does not capture the **costs**.



The "Full" Mortality Costs of Climate Change

Response function: $Mortality_t = \beta_t Temp_t$

Climate change: $Temp_1 \rightarrow Temp_2$

No adaptation (e.g., Hsiang, Kopp, et al 2017):

$$mortality\ effects\ without\ adaptation = \beta_1 Temp_2 - \beta_1 Temp_1$$

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$Temp_1,\ Temp_2\ \rightarrow$ current & future temperature (global climate models)

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Step 1: Estimate **causal relationship** between climate and mortality, model adaptation response as a function of **income and climate**

Step 2: Predict response functions spatially

Step 3: Develop a **revealed preference approach** to estimate costs of adaptation

Step 4: Project impacts into the **future** using high resolution climate projections

[Step 5: Estimate **empirical damage function** accounting for uncertainty, then calculate a partial mortality-only **Social Cost of Carbon]**

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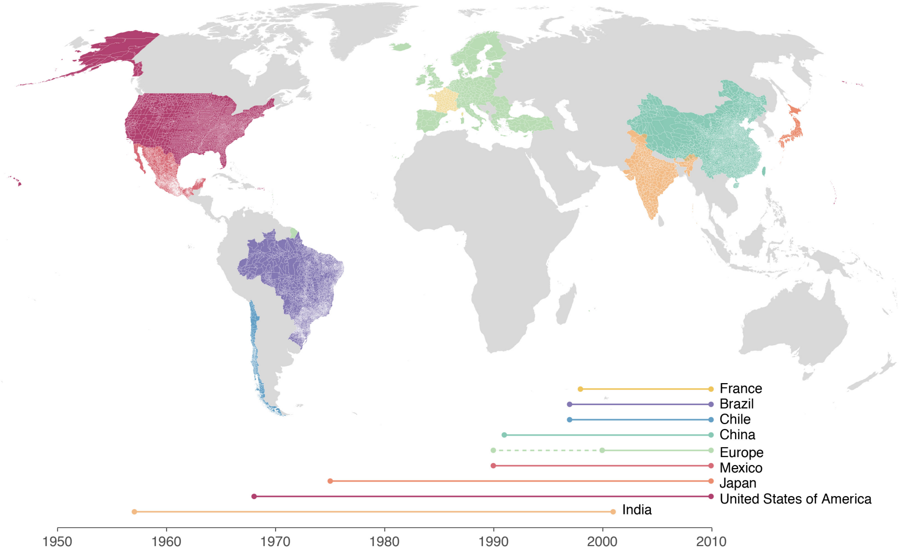
Historical Mortality Data



Estimating a Mortality-Temperature Relationship

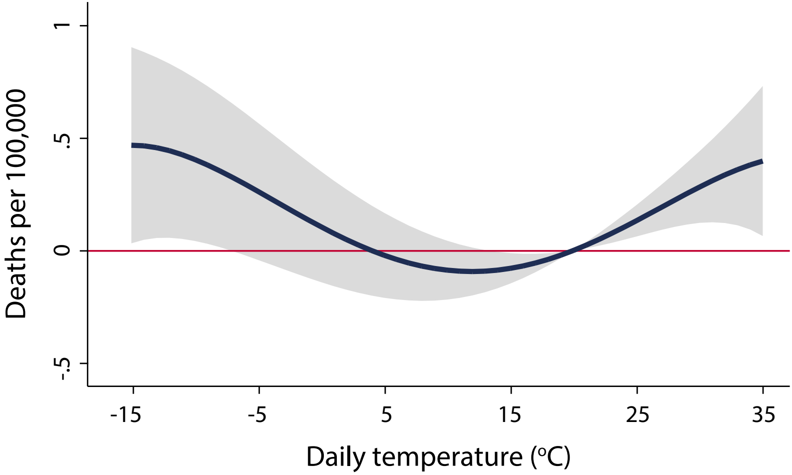
$$Mortality\_rate_{ait} = \sum_p \beta^p Temp_{it}^p + \left[\theta_1^c Precip_{it} + \theta_2^c Precip_{it}^2\right]$$

$$+ age\_by\_county\_fixed\_effects_{ai}$$

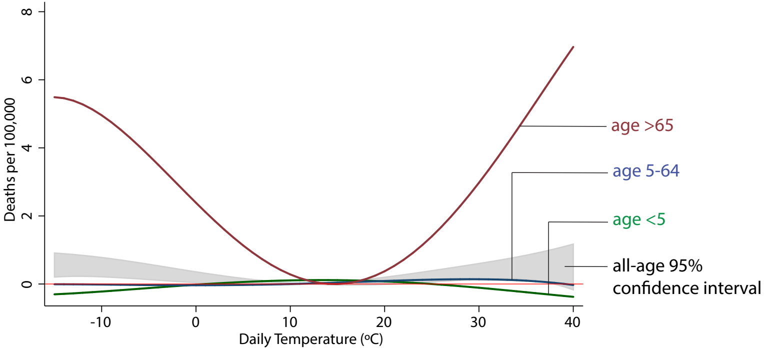
$$+ age\_by\_country\_by\_year\_fixed\_effects_{act} + \varepsilon_{iat}$$

a = age group
i = county ("adm 2")
c = country
t = year

Global Mortality-Temperature Response



Age Group Heterogeneity



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Heterogeneity in temperature-mortality response

Concept

Allow the shape of the function describing the temperature-mortality relationship at a location be a function of conditions at that location.

$$Mortality\_rate_{it} = \sum_p \beta^p \, Temp_{it}^p \, ... \, controls$$

$$\uparrow$$

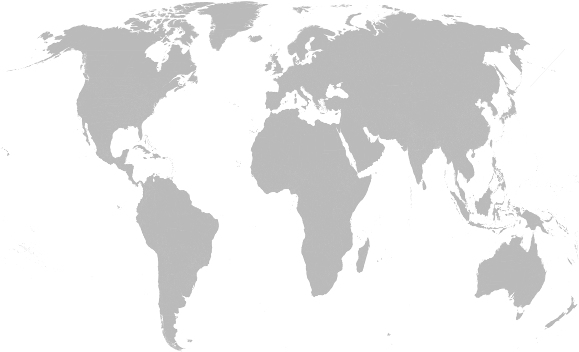
$$\beta^p(s) = \gamma_0^p + \gamma_1^p \, TMEAN_s + \gamma_2^p \, \log(GDPpc)_s$$

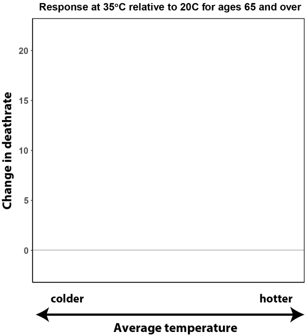
Cross sectional covariates at "state" s (adm1)

→ $TMEAN_s$ = long-run avg. temperature

→ $\log(GDPpc)_s$ = average log income per capita

Adaptation to Climate





Effect day at 35°C relative to 20°C for ages 65 and over.
Coefficient calculated for deciles of *TMEAN* (red shaded area).

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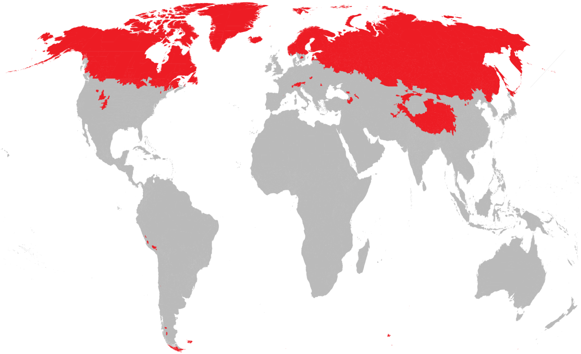

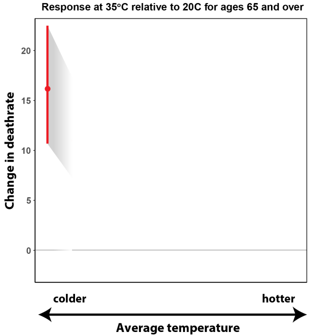

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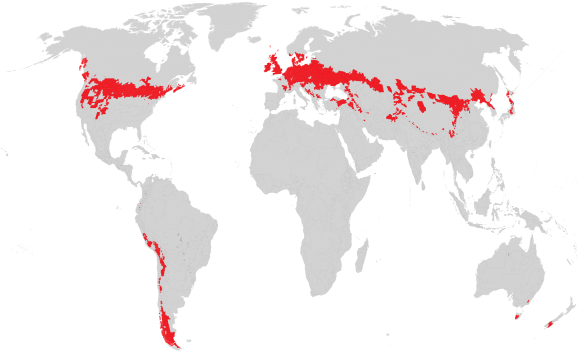

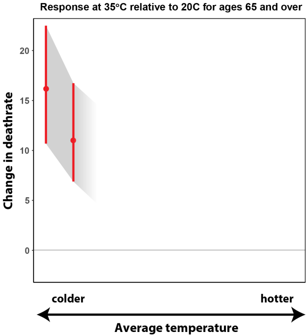

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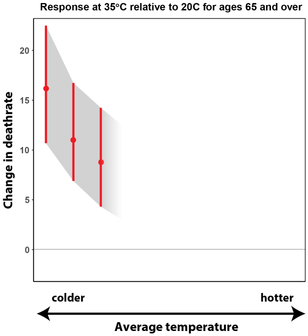

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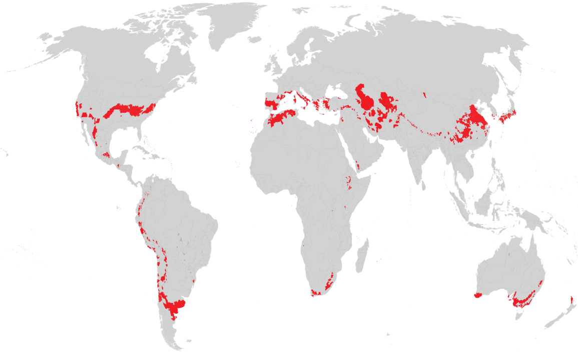

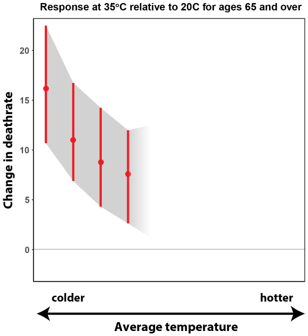

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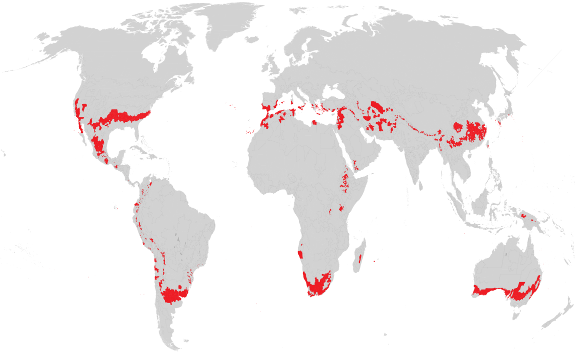

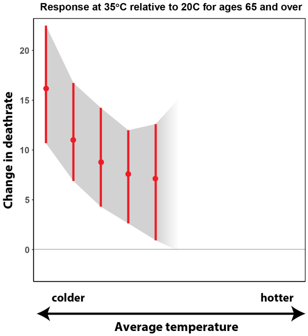

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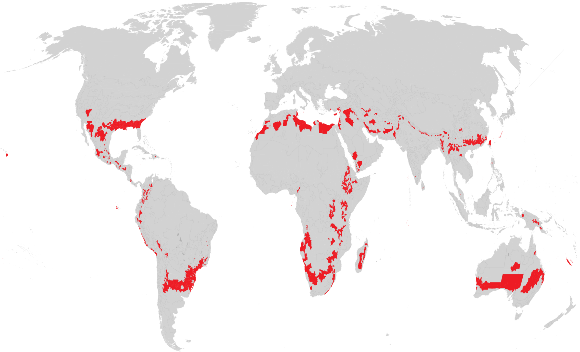

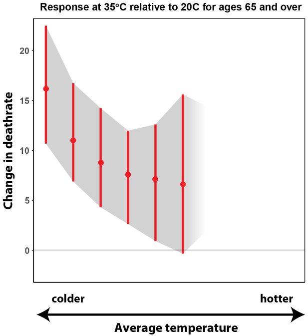

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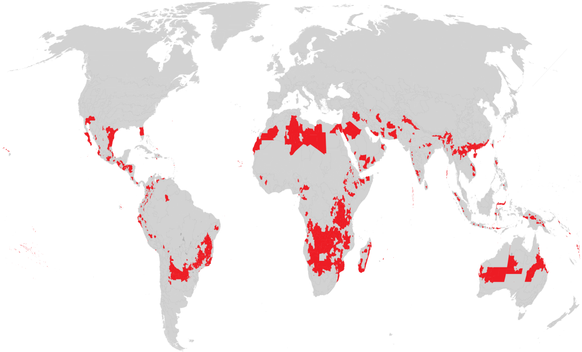

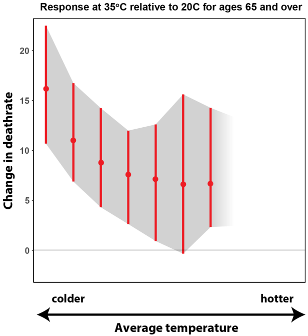

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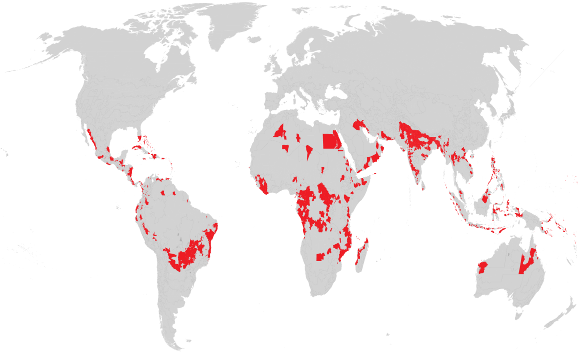

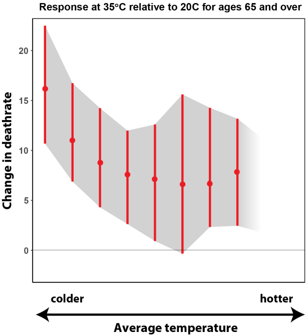

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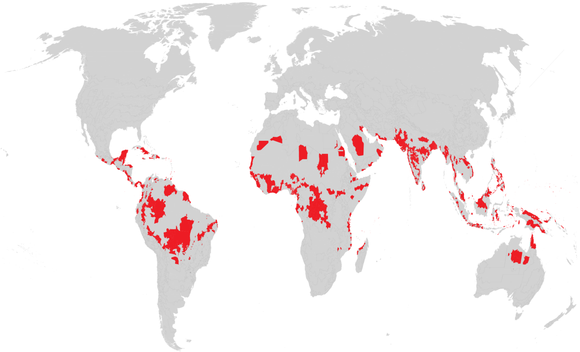
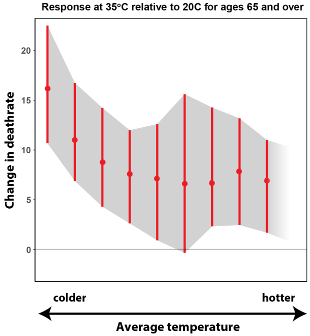
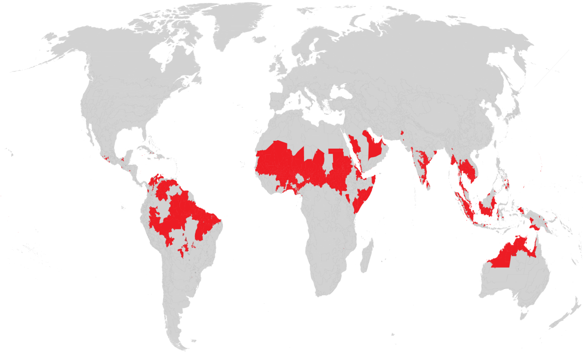
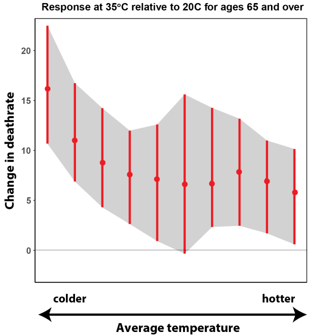




Effect day at 35°C relative to 20°C for ages 65 and over.
Coefficient calculated for deciles of *TMEAN* (red shaded area).

Adaptation to Climate





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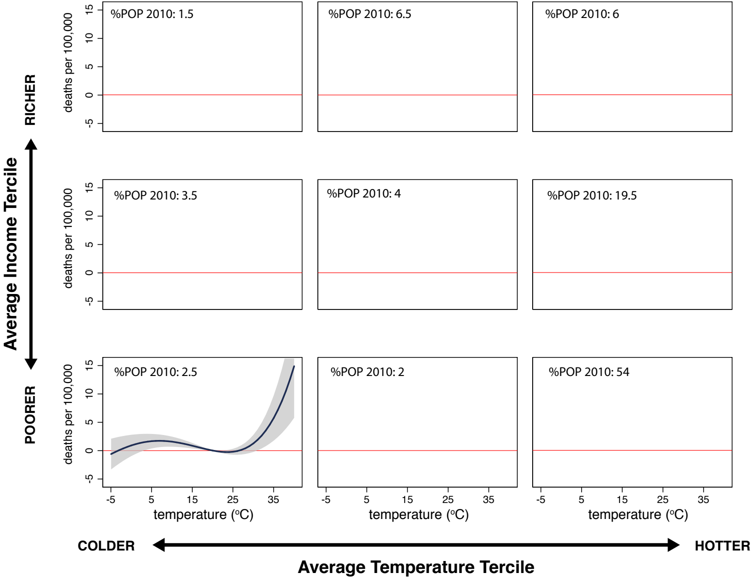

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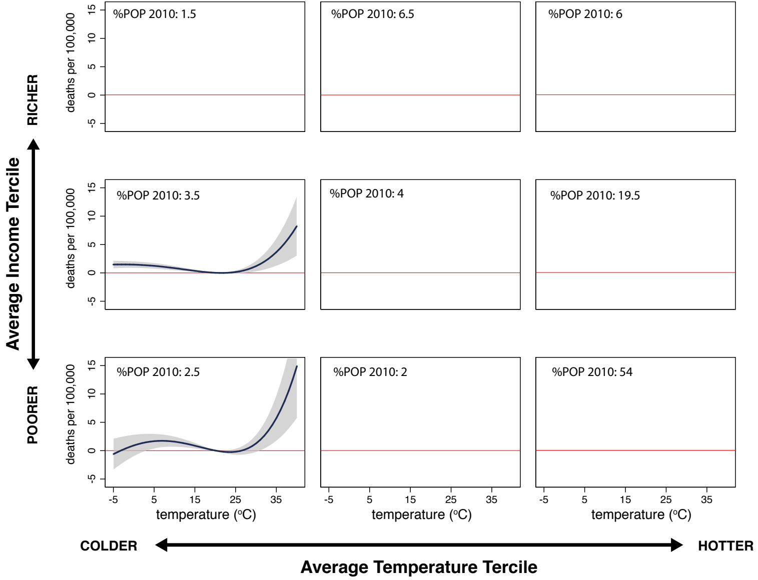

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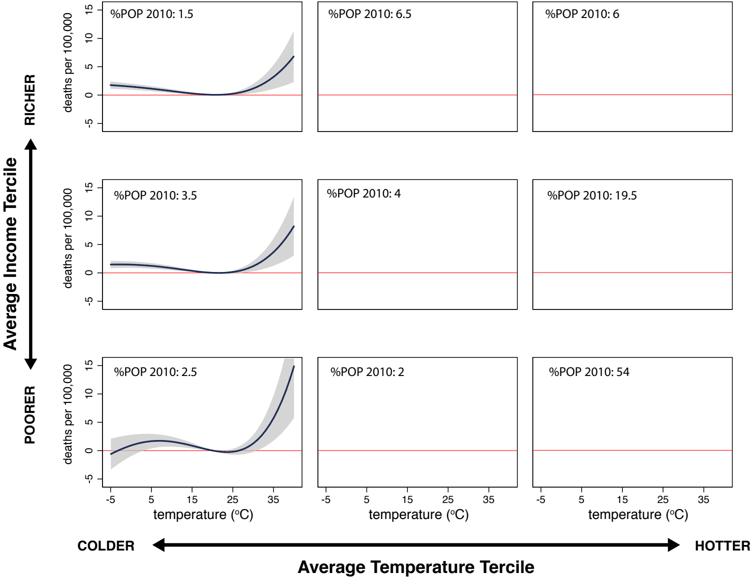

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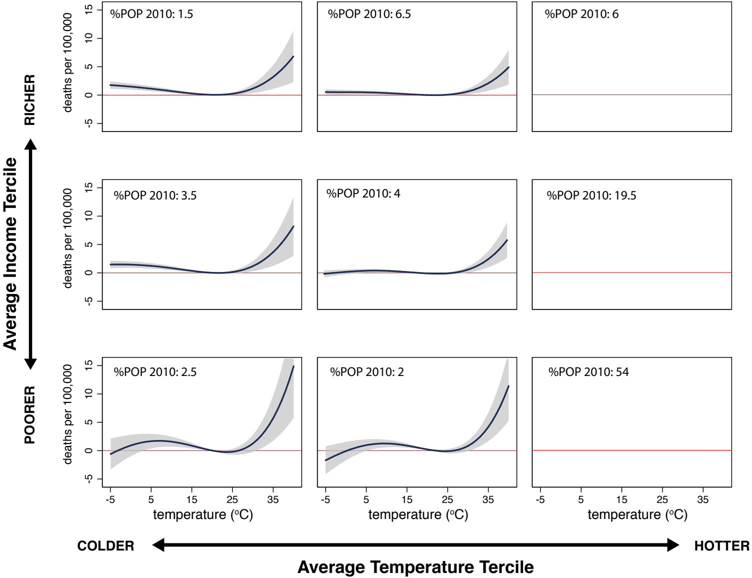

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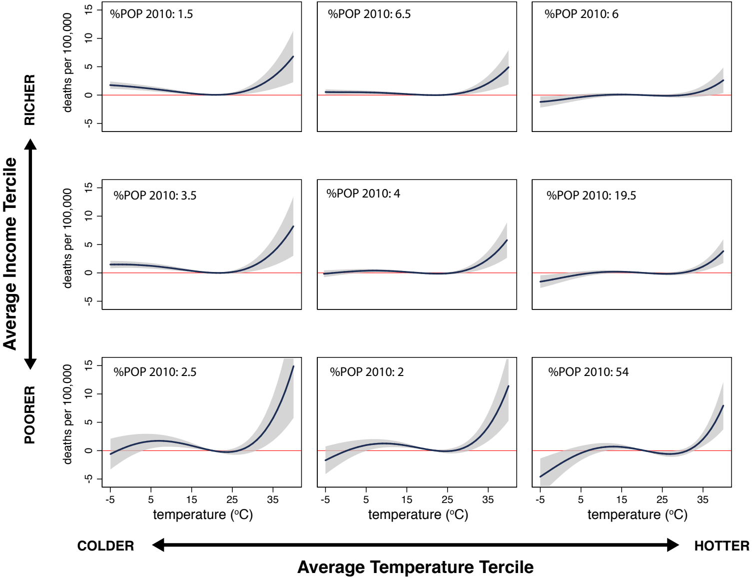

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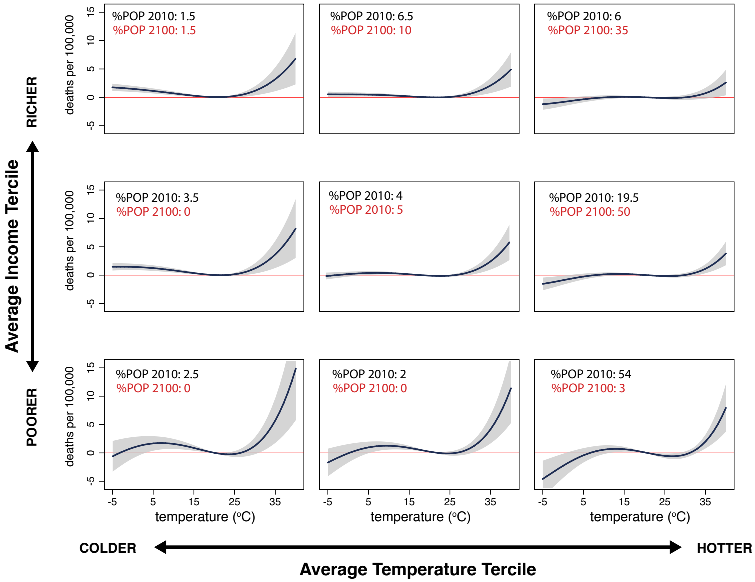

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2. Key Findings from Carleton et al. (2022)
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Spatial Resolution of Early IAMs

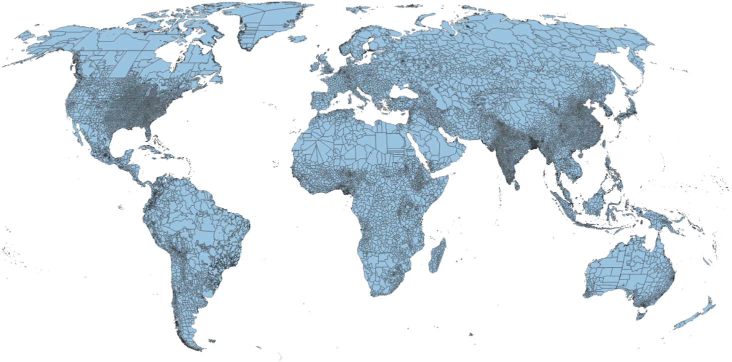
DICE (1992)

1 region

FUND (1996)

16 regions

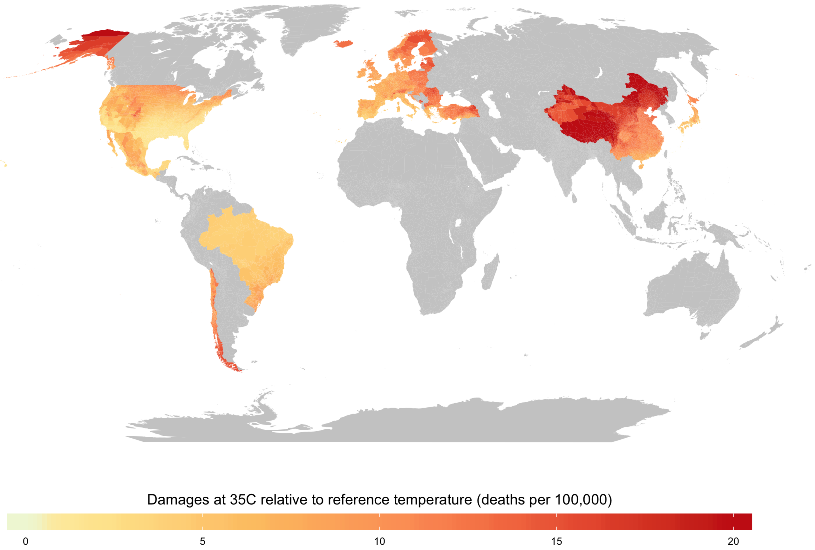
Re-imagining Possibilities with Distributed Computing



Climate Impact Lab (2019)

24,000 regions

Example from Our Sample: Sensitivity to 35(65+)



How to Fairly Represent the Global Population?

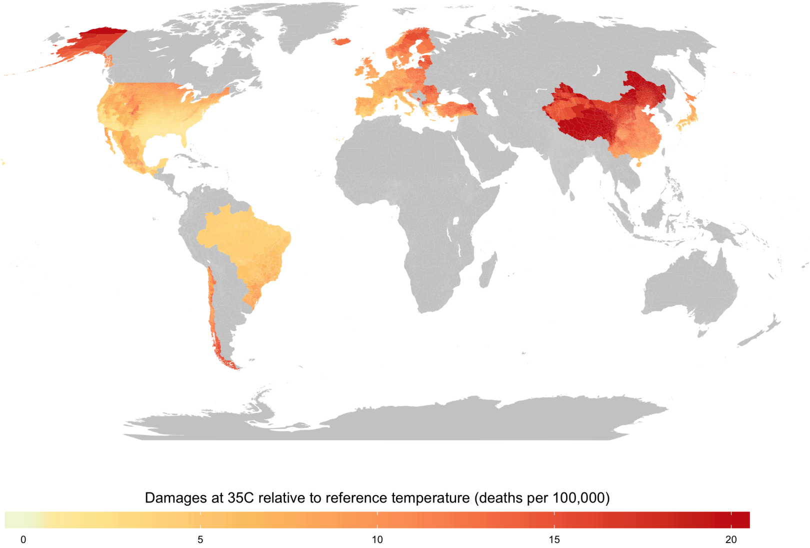
We use our estimated response surface to predict response functions for all impact regions globally.

$$\hat{\beta}^p(s) = \hat{\gamma}_0^p + \hat{\gamma}_1^p \underbrace{TMEAN_s}_{observable} + \hat{\gamma}_2^p \underbrace{\log(GDPpc)_s}_{observable}$$

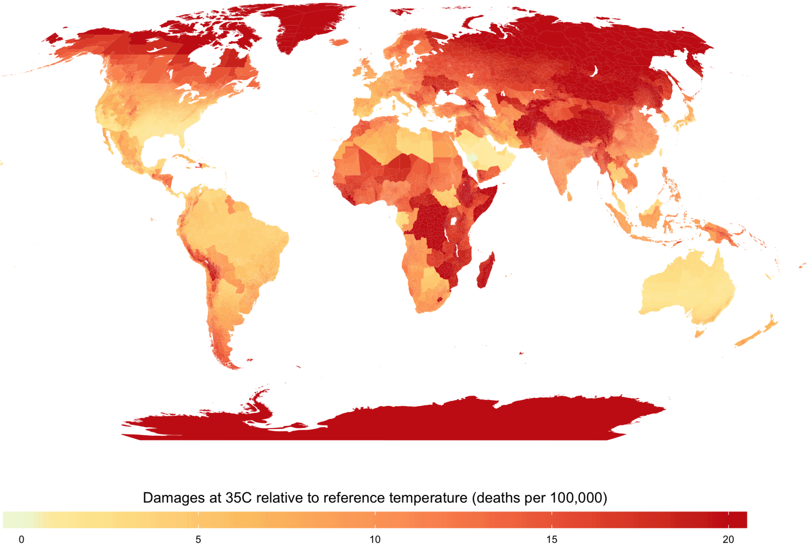
Requires we assemble data for present (and future) in each region

- **Income & populaton:**
  - OECD $\times$ nightlights $\rightarrow$ downscale income to subnational level
  - IIASA Shared Socioeconomic Pathways (SSP) incomes to 2100
- **Weather & climate:**
  - 33 GCMs downscaled to impact region level
  - Average climate calculated as 15 year average of temperature

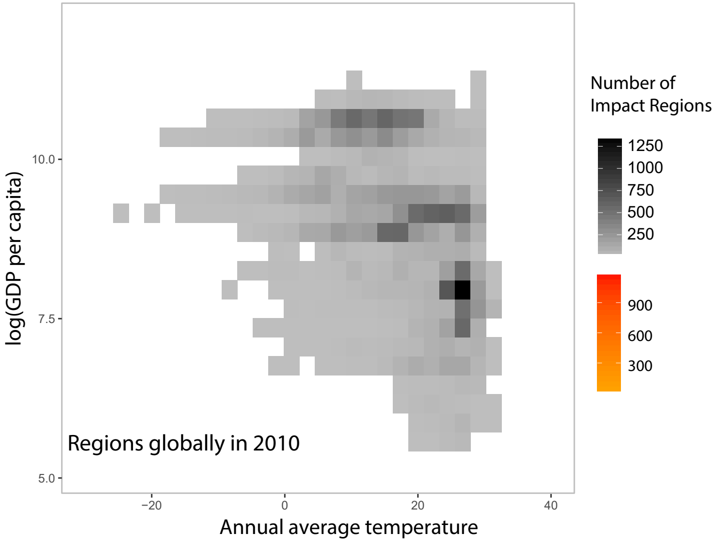
Sensitivity to Hot Days: Our Sample, 65+



Sensitivity to Hot Days: Global, 65+



Evaluating Covariate Overlap: Current Comparability



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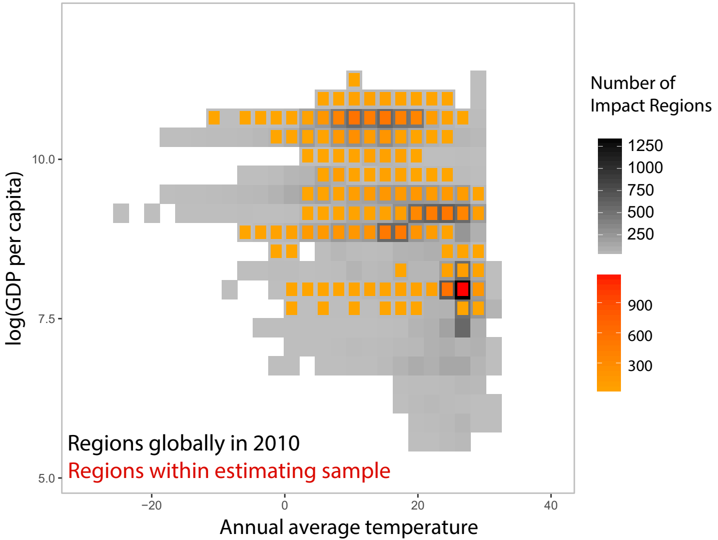
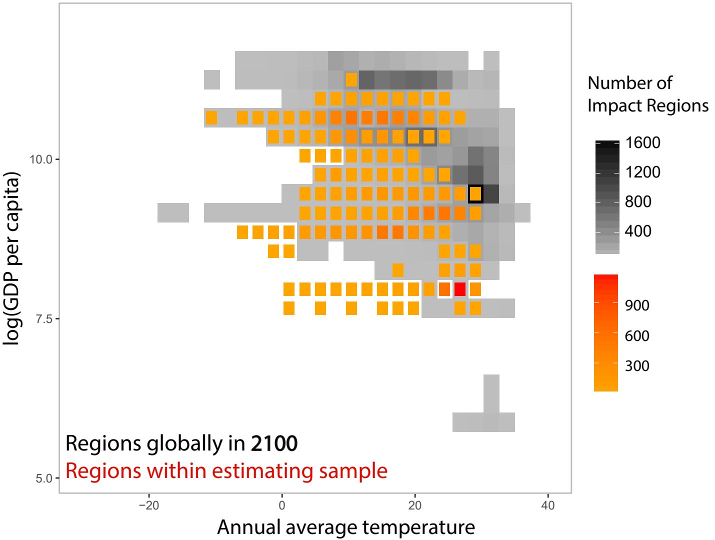


Evaluating Covariate Overlap: Future Comparability



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The “Full” Mortality Costs of Climate Change

No adaptation (e.g., Hsiang, Kopp, et al 2017):

$$\textit{mortality effects without adaptation} = \beta_1 Temp_2 - \beta_1 Temp_1$$

Including adaptation benefits (e.g., Heutel et al 2017):

$$\textit{mortality effects with adaptation} = \beta_2 Temp_2 - \beta_1 Temp_1$$

Accounting for adaptation benefits & costs (this study):

$$\textit{full value of mortality risk} = \underbrace{(\beta_2 Temp_2 - \beta_1 Temp_1)}_{\text{direct mortality effect}} + \underbrace{A(\beta_2) - A(\beta_1)}_{\text{adaptation costs}}$$

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Recovering Adaptation Costs via Revealed Preference

We assume people invest in adaptive behaviors and technologies **until the costs of doing so just equal the protective benefits**

$$\beta^* = \arg\max u(x)[1 - Mort(\beta, Temp)]$$

subject to a budget constraint:

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- **We observe the protective benefits** — changes in sensitivity of mortality to temperature as the climate gradually warms

$$-VSL\frac{\partial Mort(\beta^*, Temp)}{\partial \beta}\frac{\partial \beta^*}{\partial Temp} \approx -VSL\frac{\partial \mathrm{E}[Mort]}{\partial TMEAN}(TMEAN_t - TMEAN_{t-1})$$

- We use measures of these benefits to **back out the costs**

$$A(\beta^*, Temp_1) - A(\beta^*, Temp_0) \approx -\sum_{t=0}^{t=1} VSL_t \frac{\partial \mathrm{E}[Mort]}{\partial TMEAN}(TMEAN_t - TMEAN_{t-1})$$

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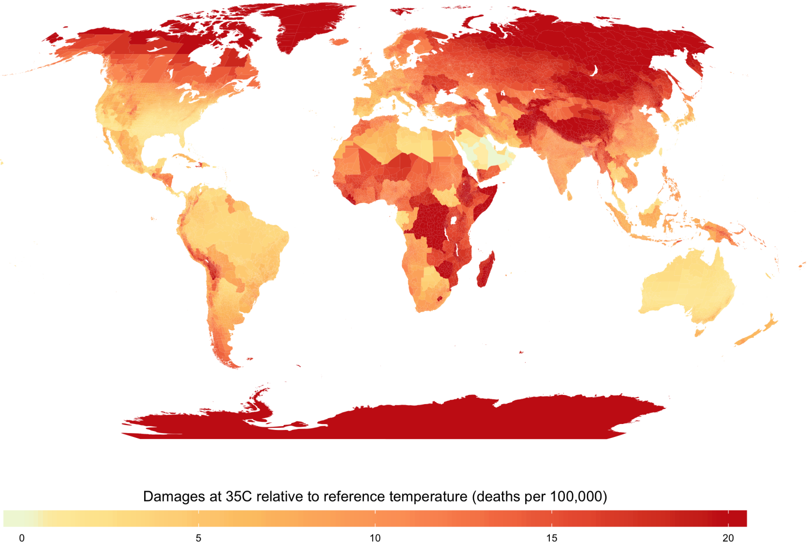
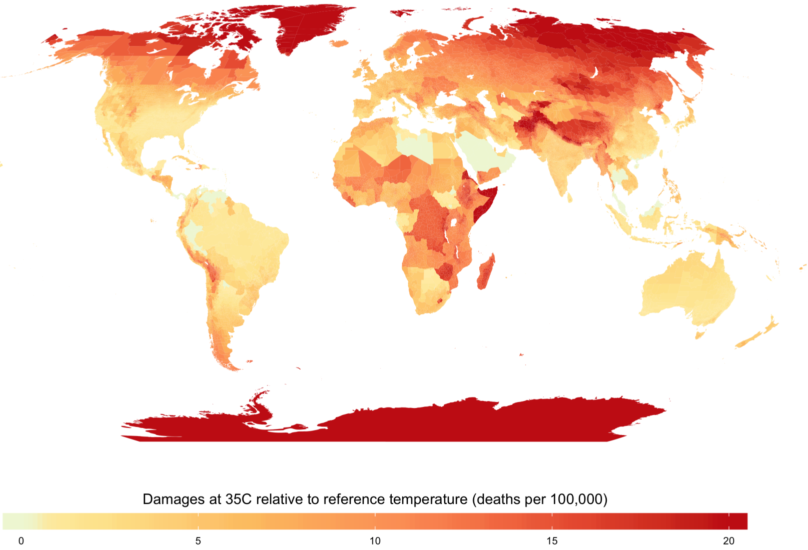
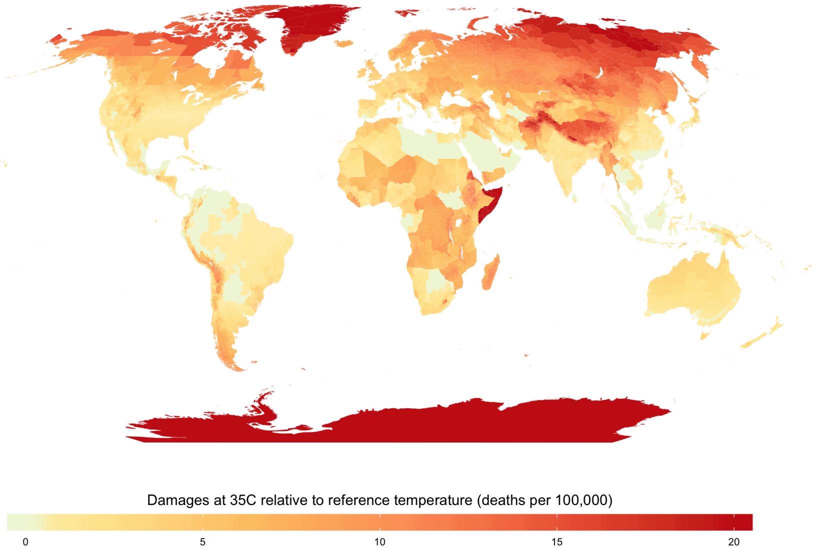


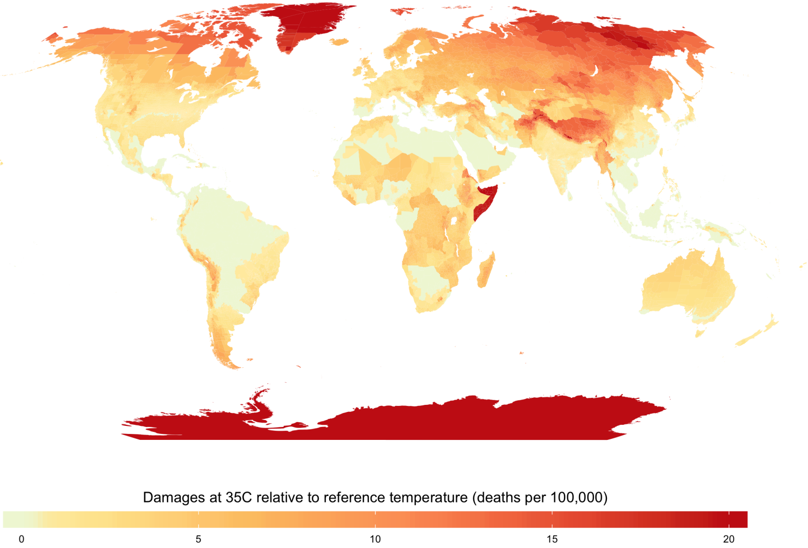
Projecting Sensitivity to Temperature - 2050



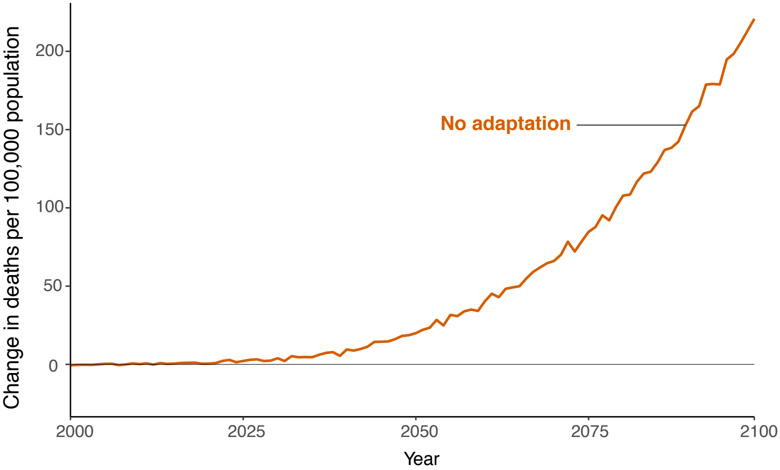
Projecting Sensitivity to Temperature - 2080



Projecting Sensitivity to Temperature - 2100



Projected Impacts for the Globe Under RCP8.5



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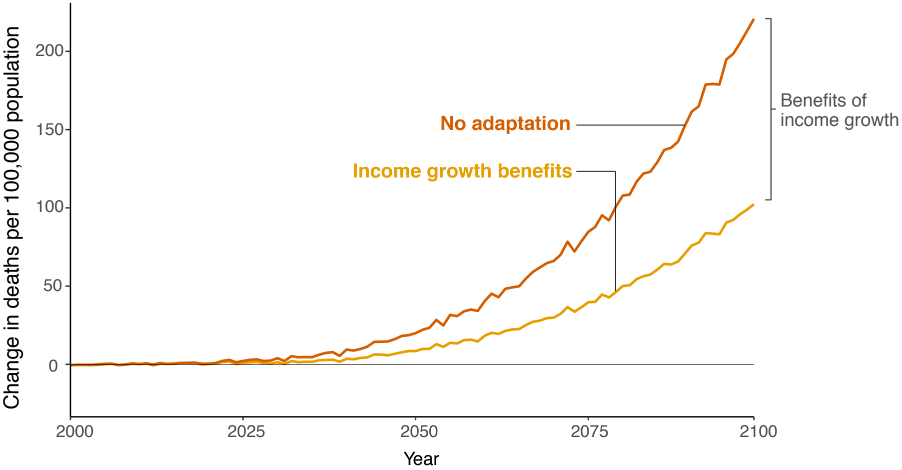

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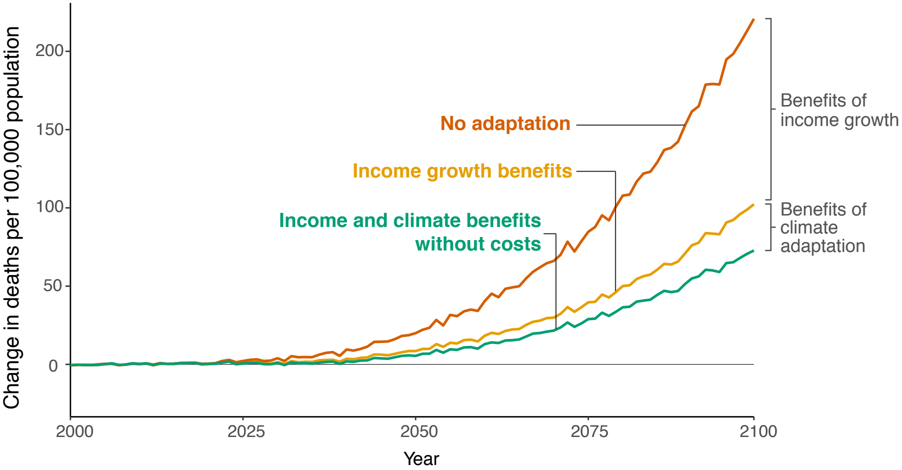

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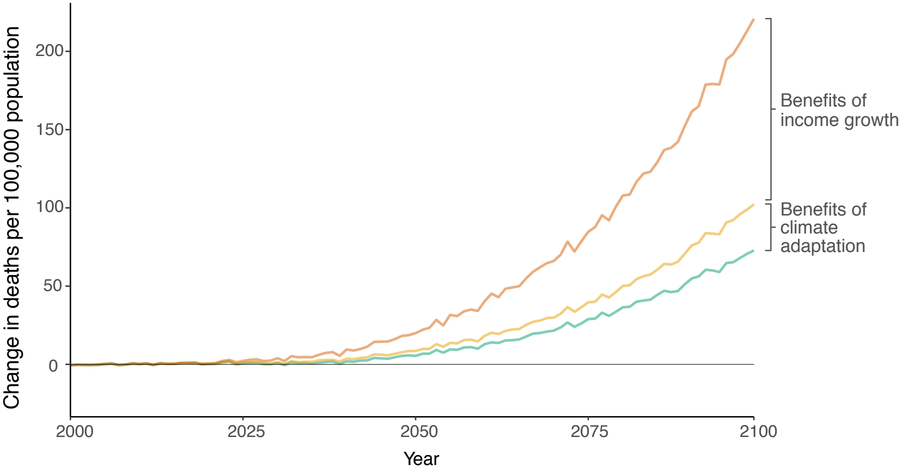

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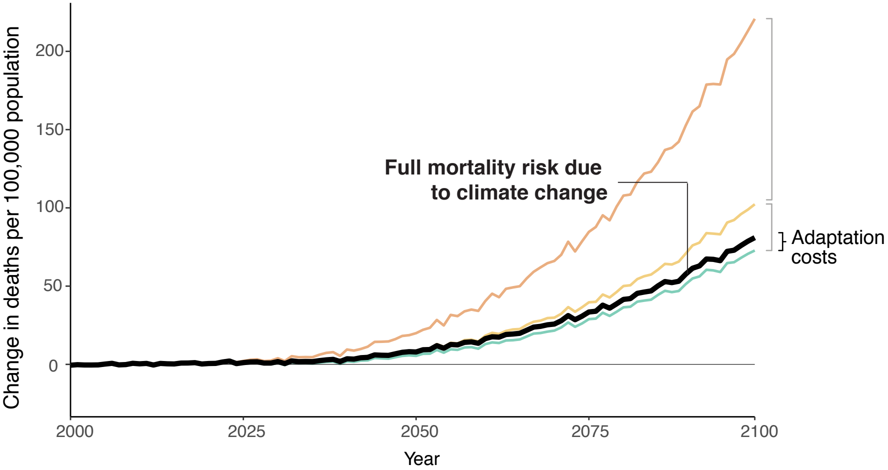

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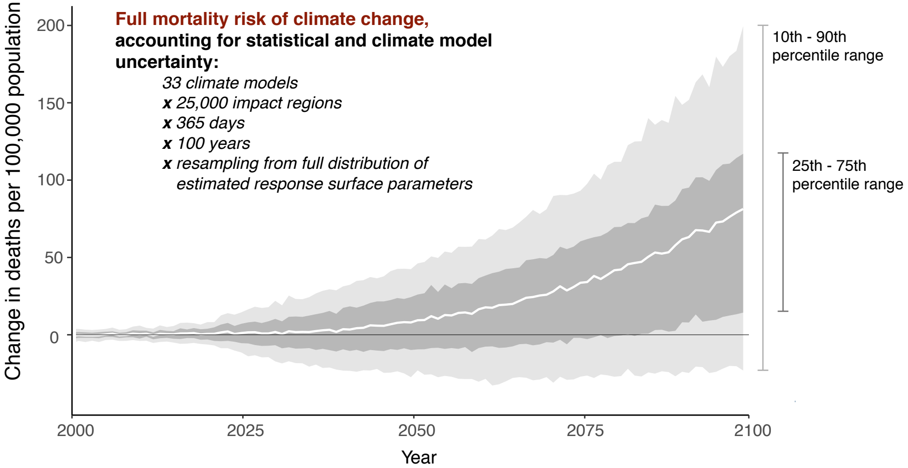
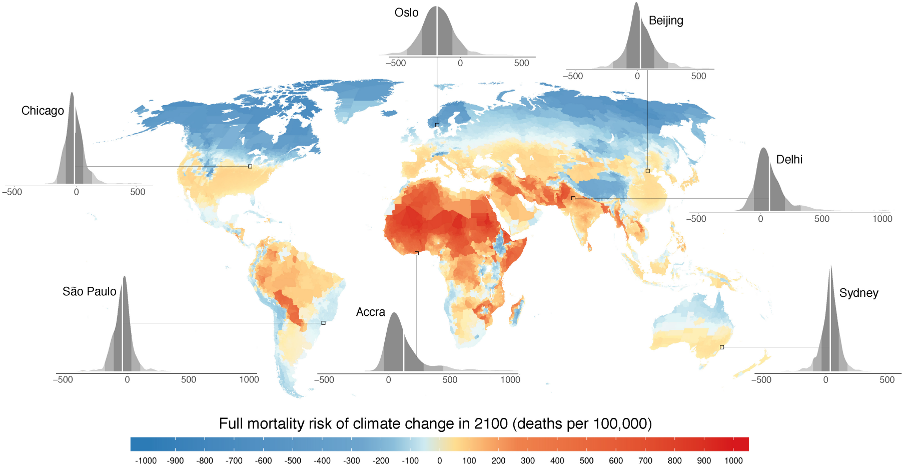
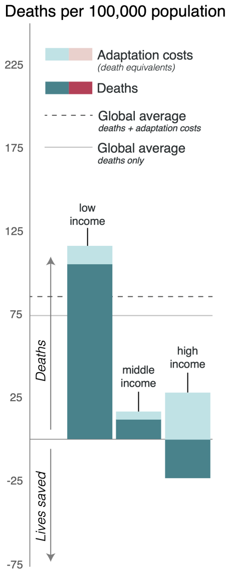


Full Damage: Mortality + Adaptation Cost





Deaths per 100,000 population
Adaptation costs
(death equivalents)
Deaths
Global average
deaths + adaptation costs
Global average
deaths only
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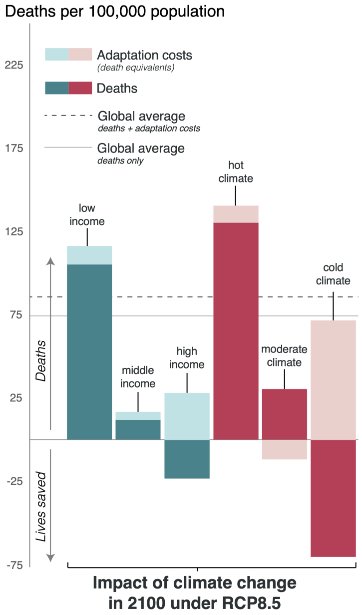
125
75
25
-25
-75
low income
middle income
high income
Deaths
Lives saved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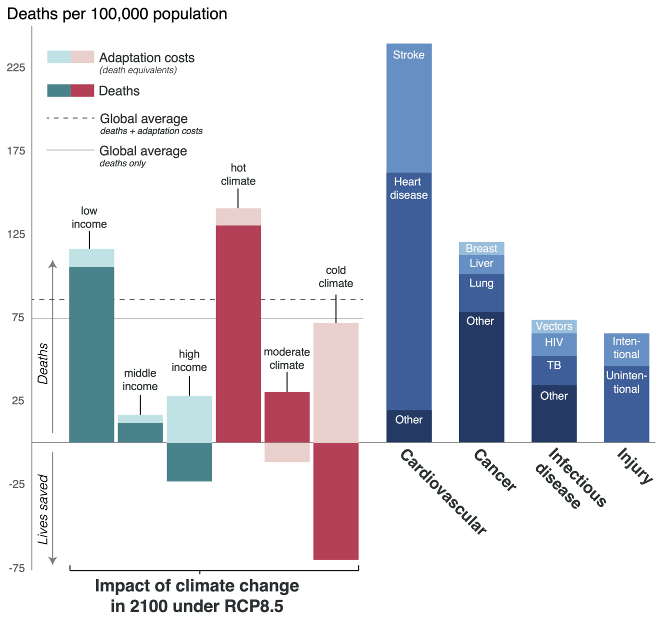
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Liver
Lung
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HIV
TB
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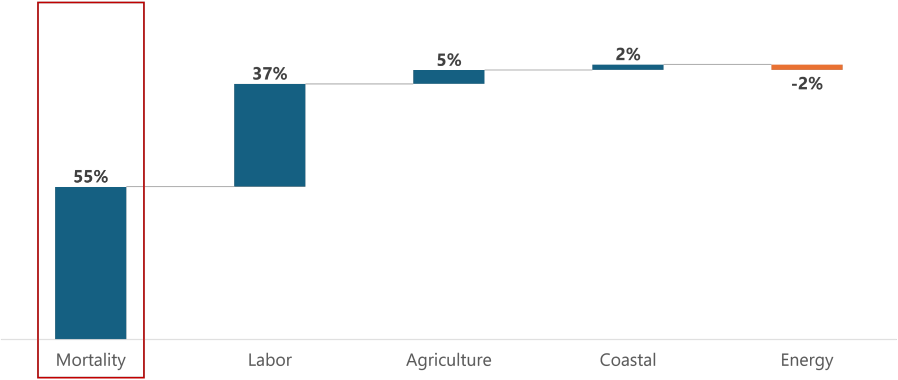
Summary

1. Using data covering 40% of the world's population:
   - We recover a within-location U-shaped effect of temp on mortality
   - Sensitivity to heat is lower in richer and hotter locations
2. We condition on income and climate in a unified approach to (1) estimate response functions where no data exist and (2) project benefits of adaptation into the future.
3. We develop a revealed preference approach to bound adaptation costs
   - The full mortality costs of climate change are the direct impacts plus the costs of adaptation
4. Benefits & costs of adaptation are critical for projections
   - Costs would be $\sim 3\times$ too large if we ignore adaptation benefits

Mortality's Share of Total Damages



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Exciting Areas for Further Research

I. Improved Understanding of the Heterogeneous Mortality-Temperature Relationship

a. Urban Heat Islands (Chakma et al. 2024)

b. Wet Bulb vs. Dry Bulb (Wilson et al. 2024)

c. 60% of World with Missing Data

d. What OTHER (Measurable) Factors Influence the Mortality-Temperature Relationship?

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Definition (Climate Adaptation).

"**Climate adaptation** is generally defined as any behavior, investment or other decision taken in direct response to realized or anticipated changes in the climate. While adaptation often refers to decisions that ameliorate the adverse impacts of climate change, adaptive behavior can also include actions that allow individuals to exploit beneficial opportunities that arise with an evolving climate." (Carleton et al. 2024)

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III. Adaptation by Individuals

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⇒ In the absence of market failures, individuals will make efficient adaptation decisions, optimally choosing between life-preserving expenditures and mortality risk.

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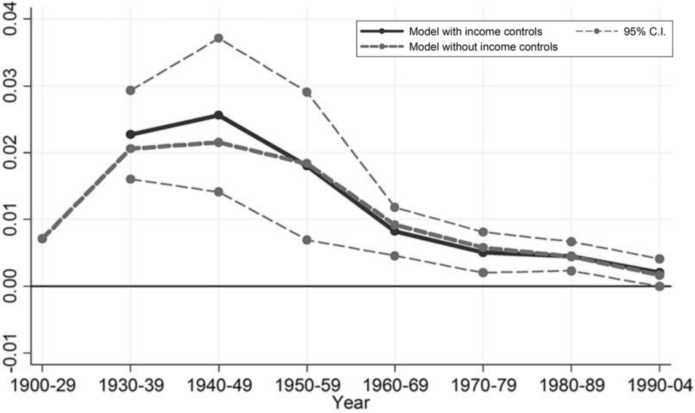
Estimated impact of temperature (days above 90°F) on mortality by 10-year period



Barreca et al. 2016

III. Adaptation by Individuals

	Sample: 1960–2004		
	(1)	(2)	(3)
Temperature above 90°F:			
Number of days above 90°F × log doctors per capita	-0.0015 (0.0016)		
Number of days above 90°F × share with residential AC	...		
Temperature in 80°F–89°F:			
Number of days in 80°F–89°F × log doctors per capita	-0.0004 (0.0003)		
Number of days in 80°F–89°F × share with residential AC	...		

Barreca et al. 2016

III. Adaptation by Individuals

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	(1)	(2)	(3)
Temperature above 90°F:			
Number of days above 90°F × log doctors per capita	-0.0015 (0.0016)	. . .	
Number of days above 90°F × share with residential AC	. . .	-0.0212*** (.0054)	
Temperature in 80°F–89°F:			
Number of days in 80°F–89°F × log doctors per capita	-0.0004 (0.0003)	. . .	
Number of days in 80°F–89°F × share with residential AC	. . .	-.0048*** (.0010)	

Barreca et al. 2016

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Barreca et al. 2016

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Temperature above 90°F:			
Number of days above 90°F × log doctors per capita	-0.0015 (0.0016)	. . .	.0000 (.0010)
Number of days above 90°F × share with residential AC	. . .	-0.0212*** (.0054)	-.0210*** (.0059)
Temperature in 80°F–89°F:			
Number of days in 80°F–89°F × log doctors per capita	-0.0004 (0.0003)	. . .	.0002 (.0003)
Number of days in 80°F–89°F × share with residential AC	. . .	-.0048*** (.0010)	-.0049*** (.0011)

Barreca et al. 2016

III. Adaptation by Individuals

Image Source: Britannica, Freepik, Harvard, UCLA

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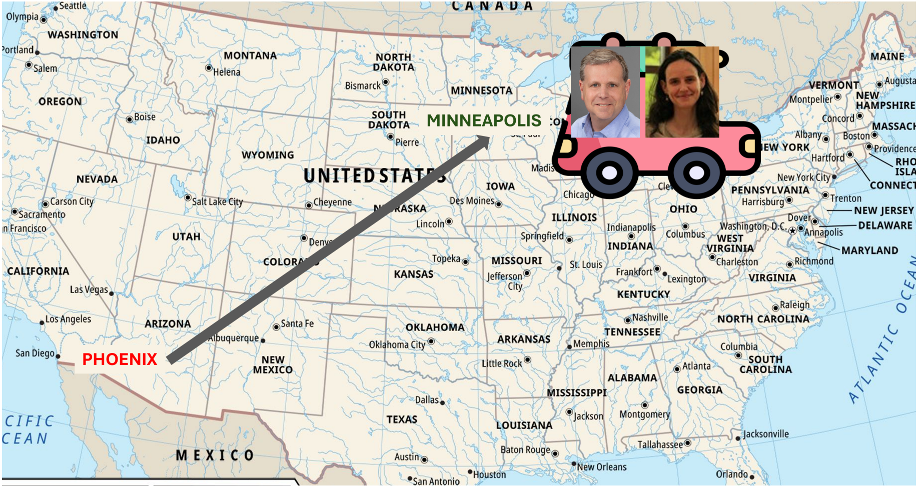

Image Source: Britannica, Freepik, Harvard, UCLA

III. Adaptation by Individuals

⇒ Imperfect markets. Carleton et al. (2024) write in a recent paper:

> "However, in practice, private adaptation is constrained by many frictions, including imperfect information and inaccurate beliefs, as well as limits to property rights, credit markets, and insurance, which often disproportionately affect low income individuals and countries."

IV. Adaptation Policy

⇒ Correct market failure that individuals face (e.g., information interventions)

⇒ Devote public resources to adaptation opportunities with increasing returns to scale or that involve public goods and/or externalities

⇒ Estimate the returns to particular adaptation activities (e.g., cooling centers, AC, migration etc.). By definition this can never be comprehensive. How do we know we are studying the important ones?

⇒ Use economic theory (e.g. people/firms perfectly optimize and no frictions) to estimate total returns to all adaptations

⇒ Return on investment to compare to alternative uses of public resources

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Discussion on "Global Warming and Mortality"

Michael Greenstone (University of Chicago)

The Determinants of Mortality

The National Bureau of Economic Research (NBER)

January 10, 2025