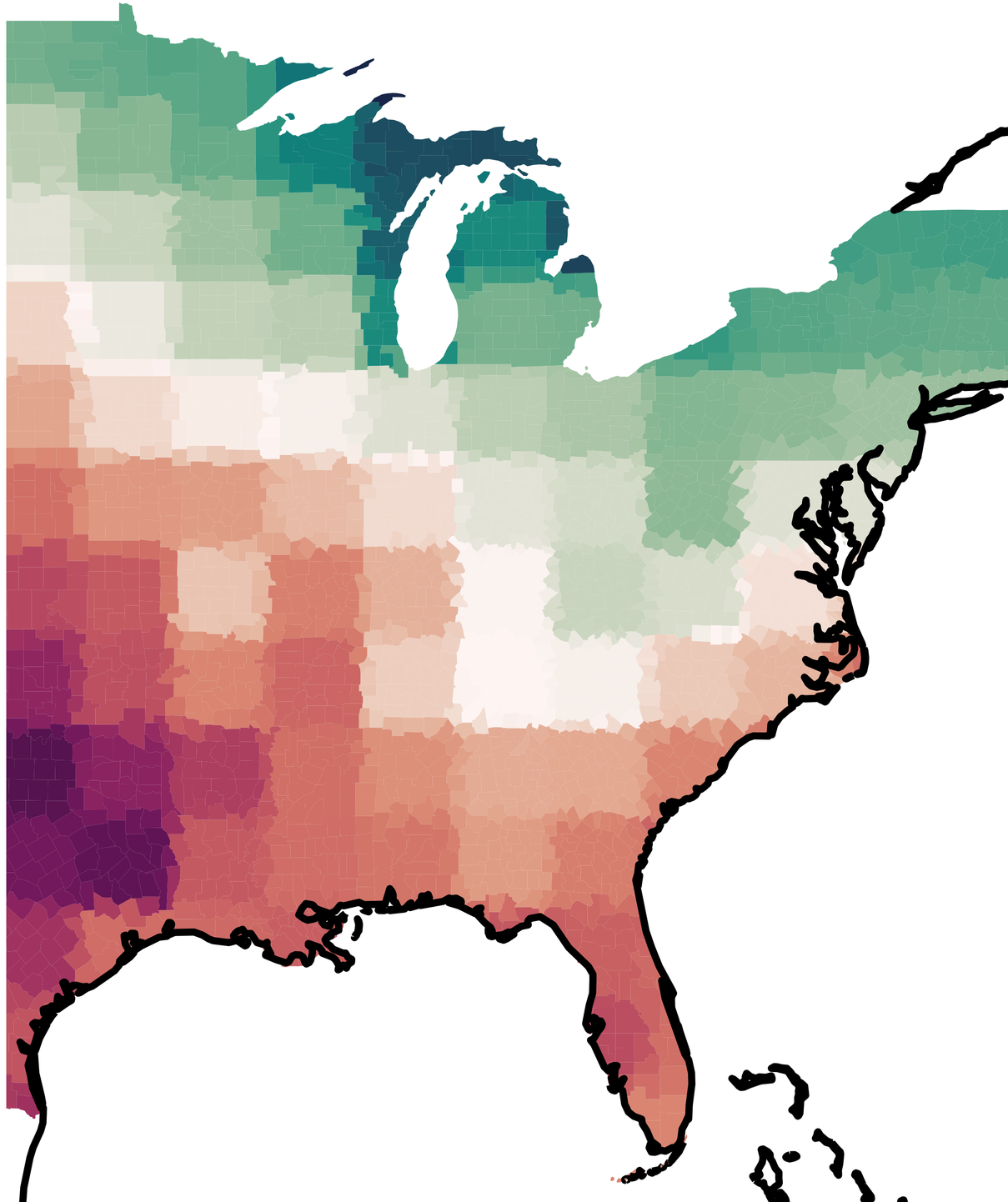
Understanding the Sources of Climate Uncertainty in Projections of Climate Impacts

Kevin Schwarzwald and Nathan Lenssen

Columbia Climate School
Lamont-Doherty Earth Observatory

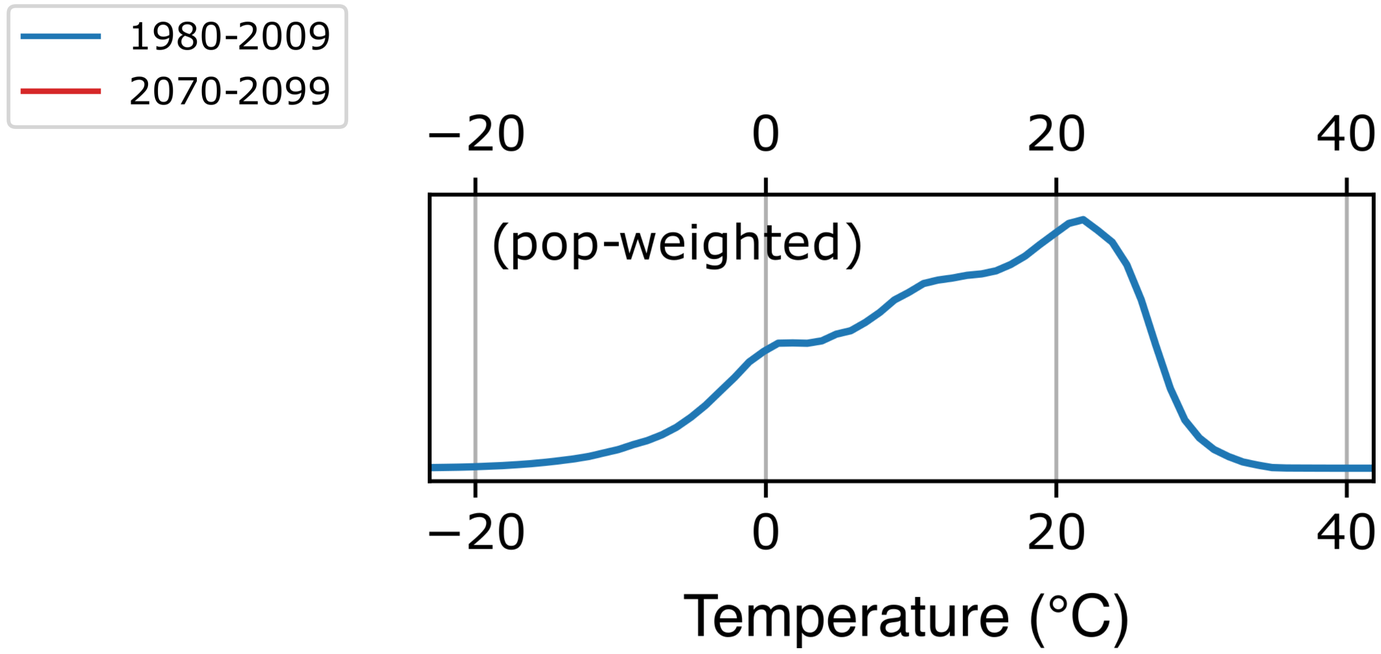


EGU23, April 25 2023, Vienna

What do we mean by Climate Impact Projections?

Studies that:

1. Take historical weather data

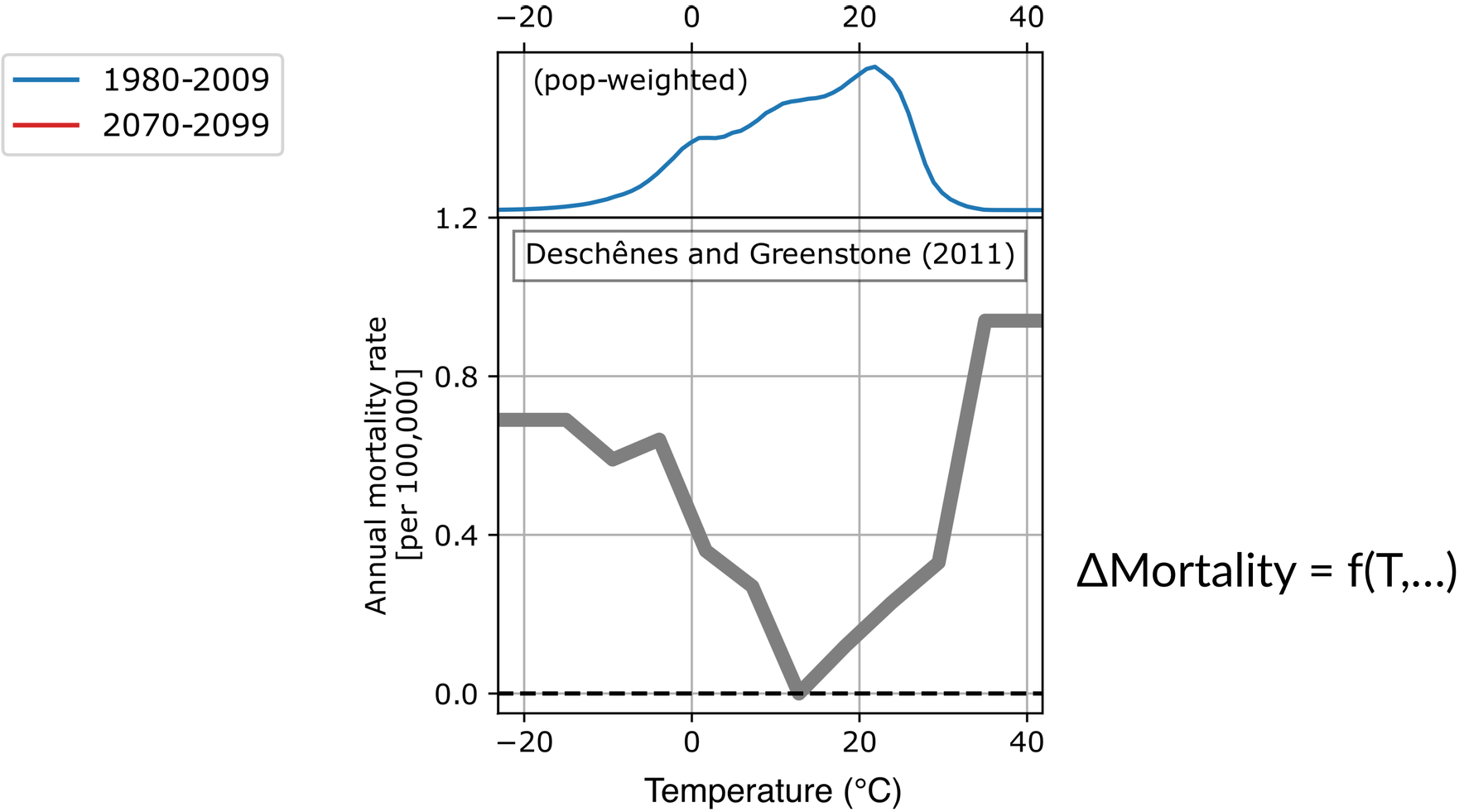


(Population-weighted continental USA historical temperature distribution)

What do we mean by Climate Impact Projections?

Studies that:

2. Find a relationship between that data and some societal variable of interest (a „dose-response function“)



ΔMortality = f(T,...)

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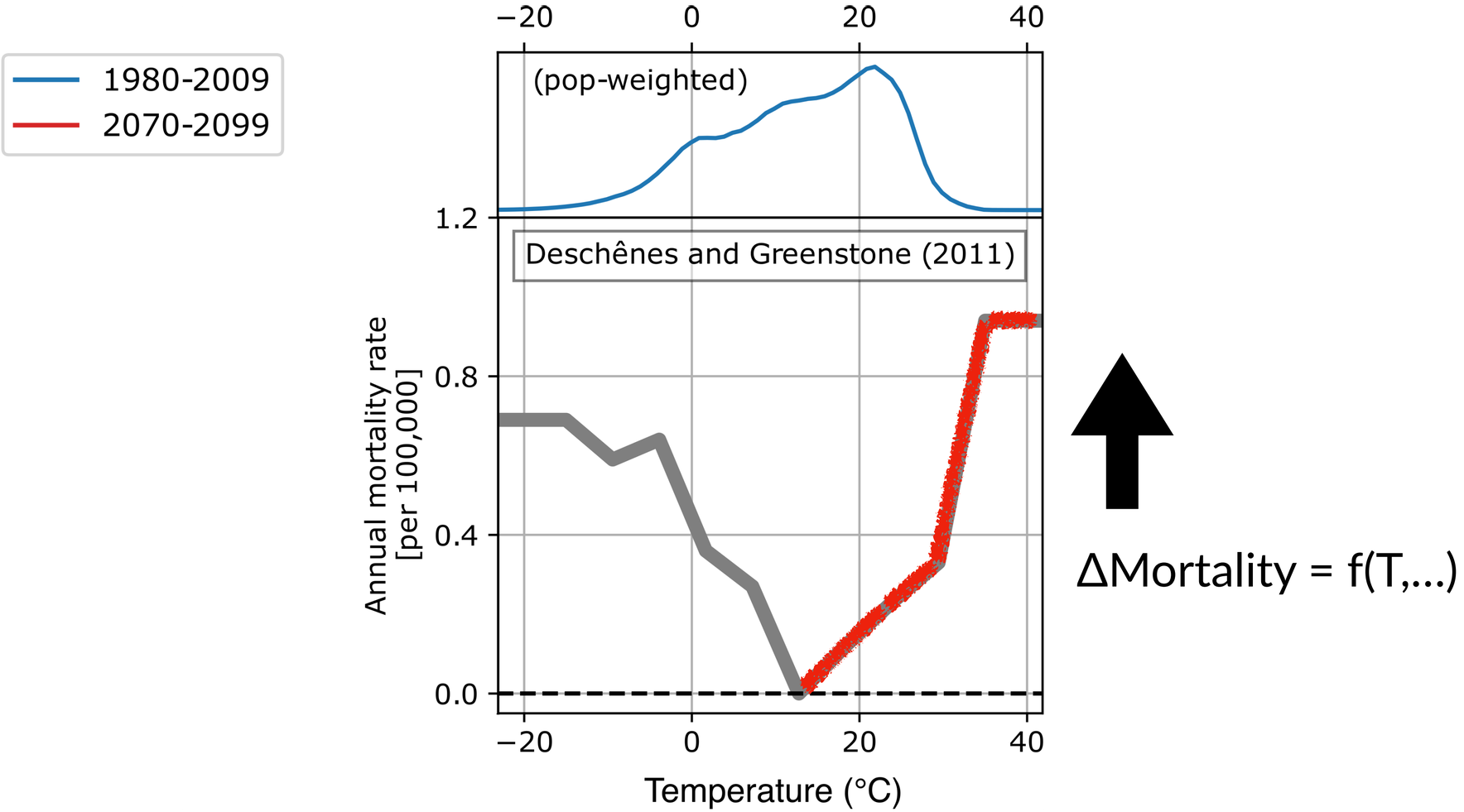

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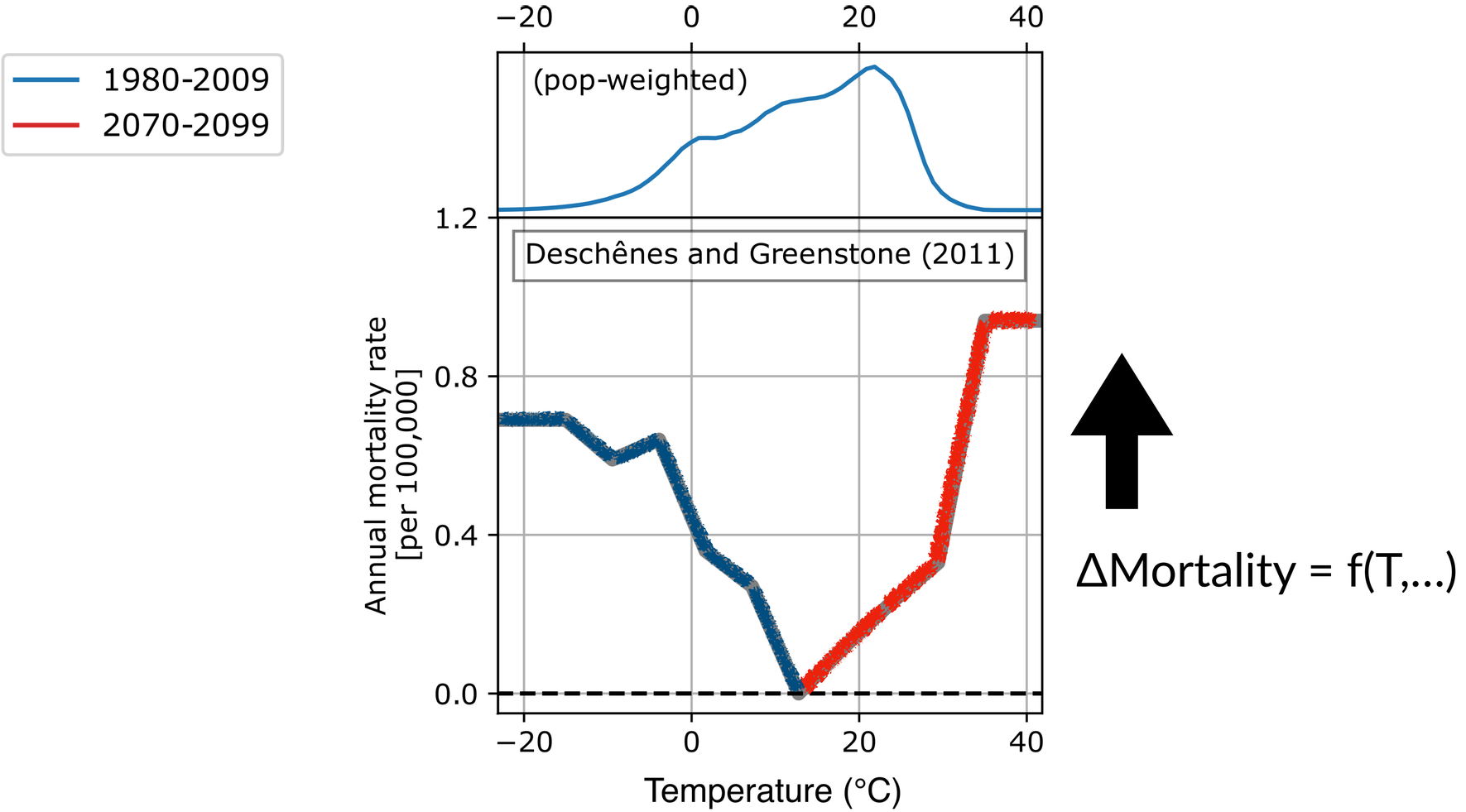
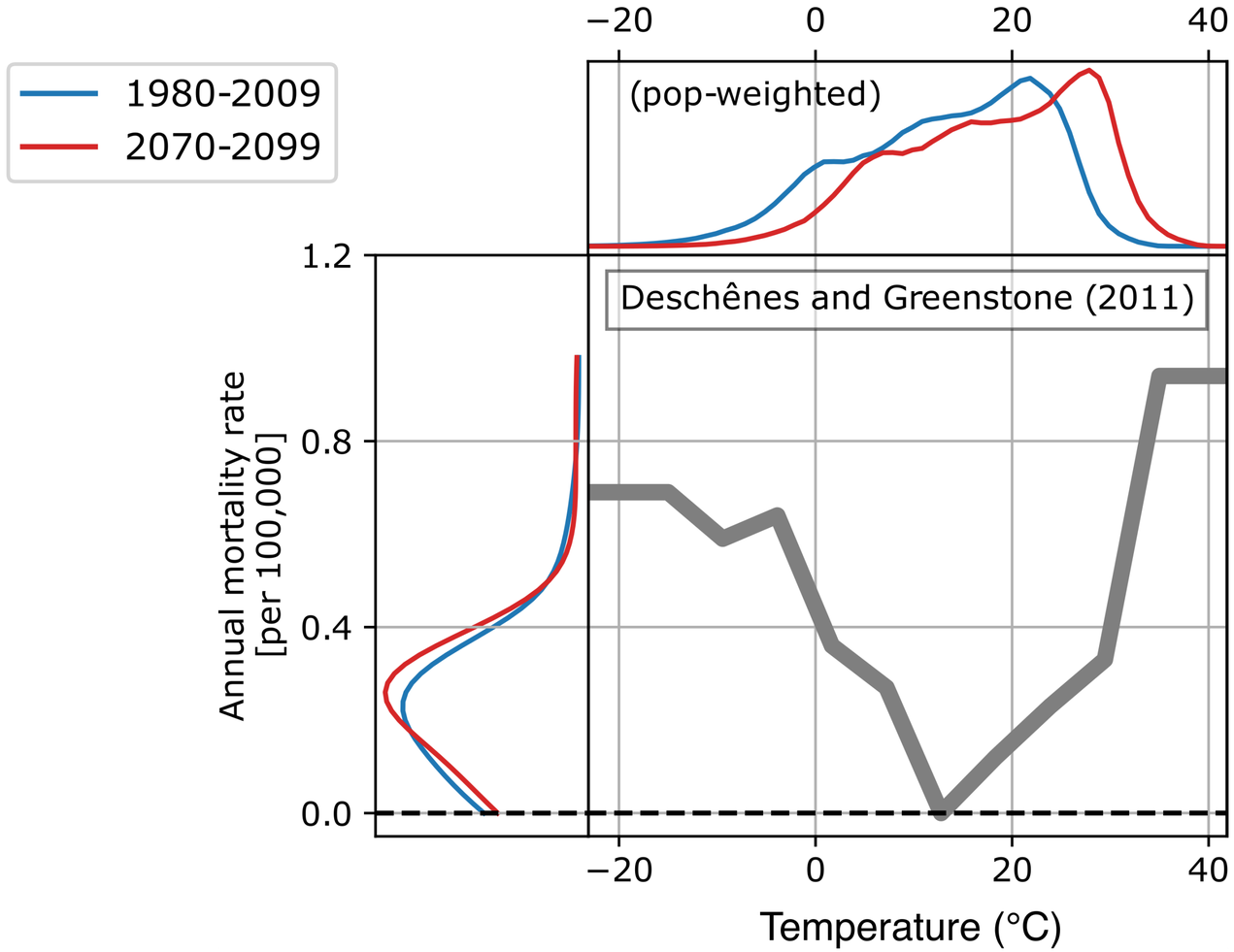


ΔMortality = f(T,...)

What do we mean by Climate Impact Projections?

Studies that:

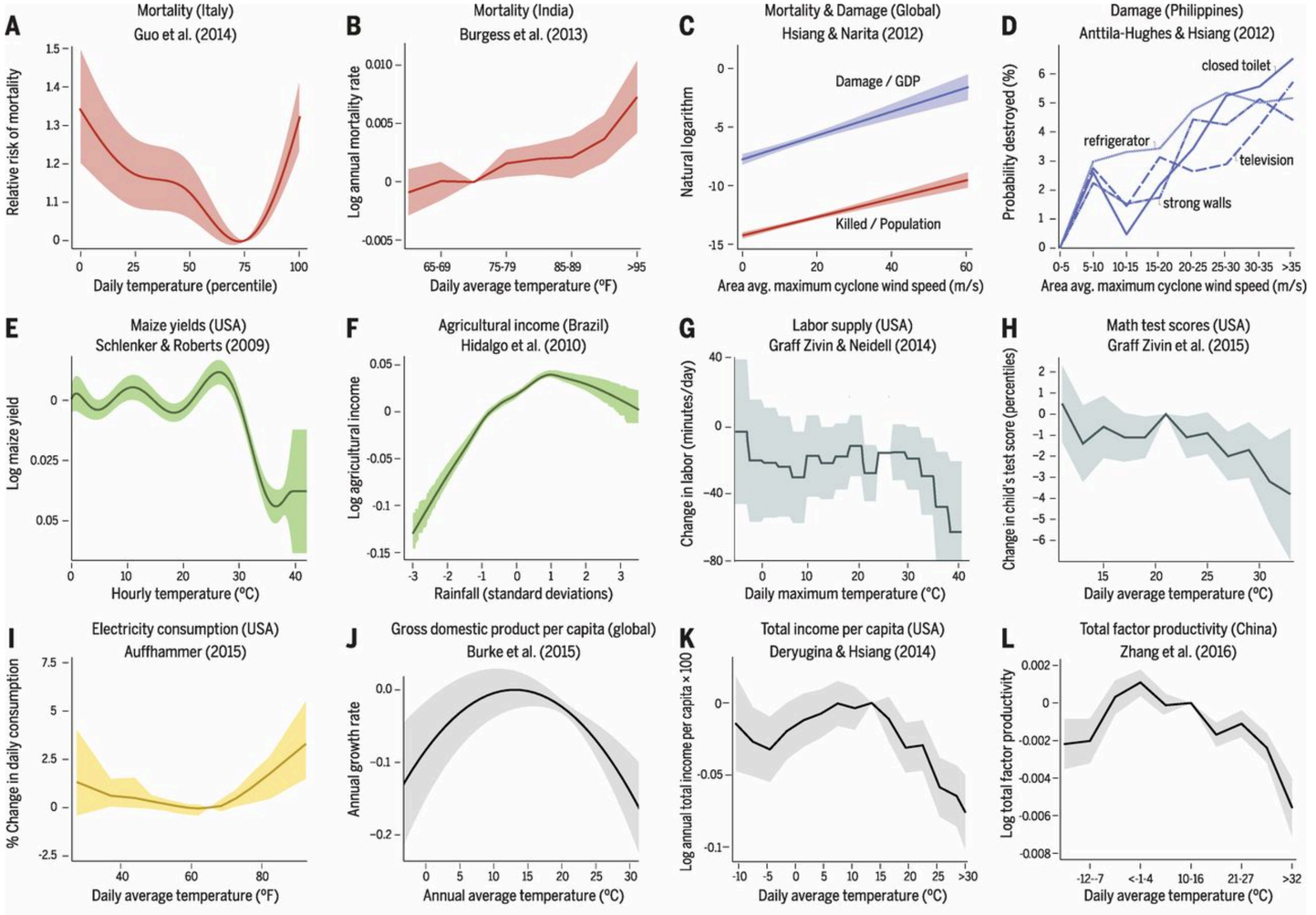
3. Project that relationship in the future using climate projections



ΔMortality = +3% under climate change due to heat, in continental USA

What do we mean by Climate Impact Projections?

Exist for many variables; used e.g. to estimate Social Cost of Carbon



(diagram from Carleton and Hsiang 2016)

What do we mean by Uncertainty?

Looking at the three criteria from before…

1. Take historical weather data
2. Find a relationship between that data and some societal variable of interest
3. Project that relationship in the future using climate projections

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What do we mean by Uncertainty?

Sources of climate uncertainty in projections (e.g. Hawkins & Sutton 2009)

- Scenario uncertainty
- Model uncertainty
- Internal uncertainty

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Sources of climate uncertainty in projections (e.g. Hawkins & Sutton 2009)

- Scenario uncertainty - outcomes differ due to differing plausible assumptions about the future

- Model uncertainty

- Internal uncertainty

What do we mean by Uncertainty?

Sources of climate uncertainty in projections (e.g. Hawkins & Sutton 2009)

- Scenario uncertainty

- Model uncertainty - outcomes differ due to different model responses to the same inputs

- Internal uncertainty

What do we mean by Uncertainty?

Sources of climate uncertainty in projections (e.g. Hawkins & Sutton 2009)

- Scenario uncertainty
- Model uncertainty
- Internal uncertainty - outcomes differ due to internal variability of the climate system / models

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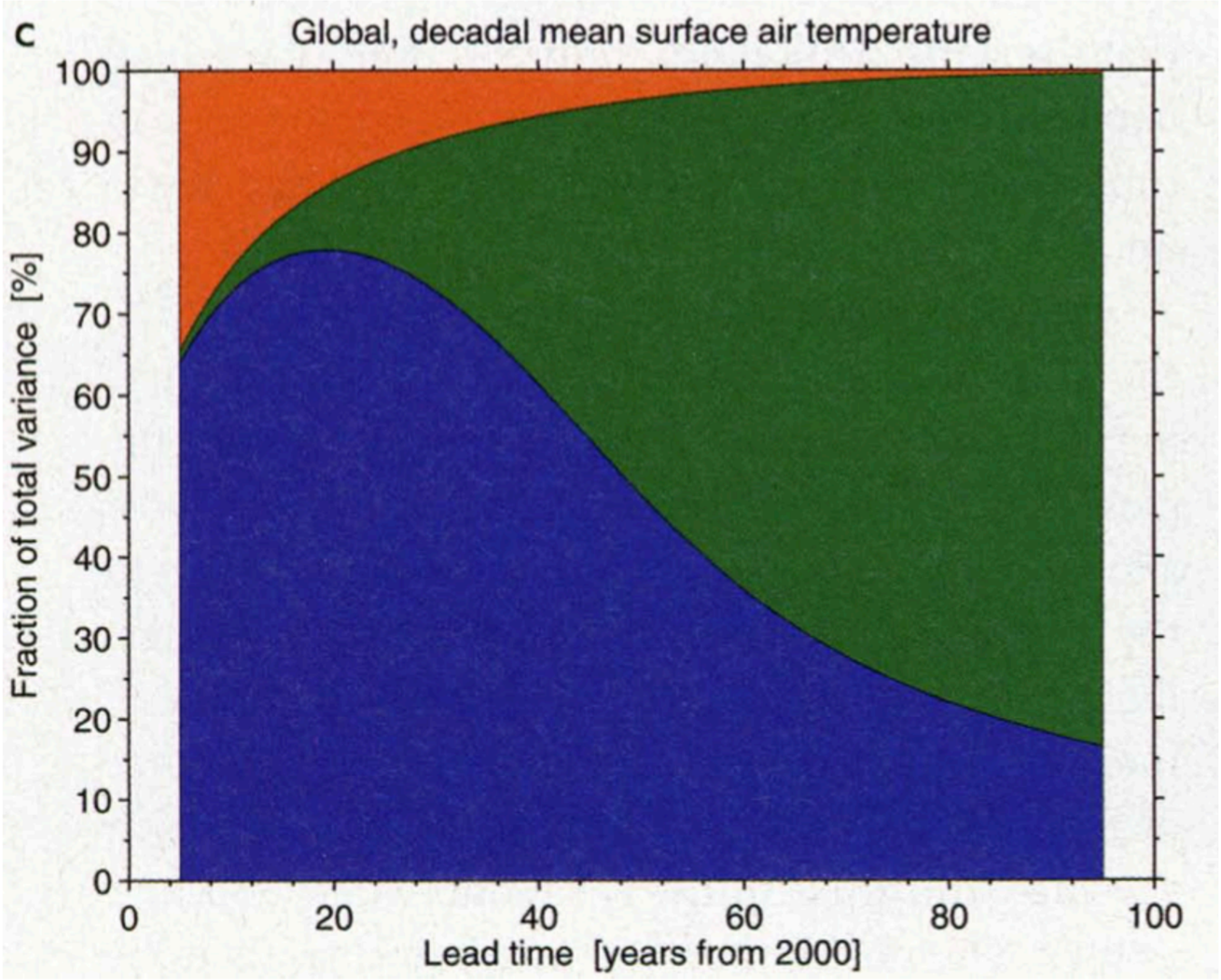

(from Hawkins and Sutton 2009)

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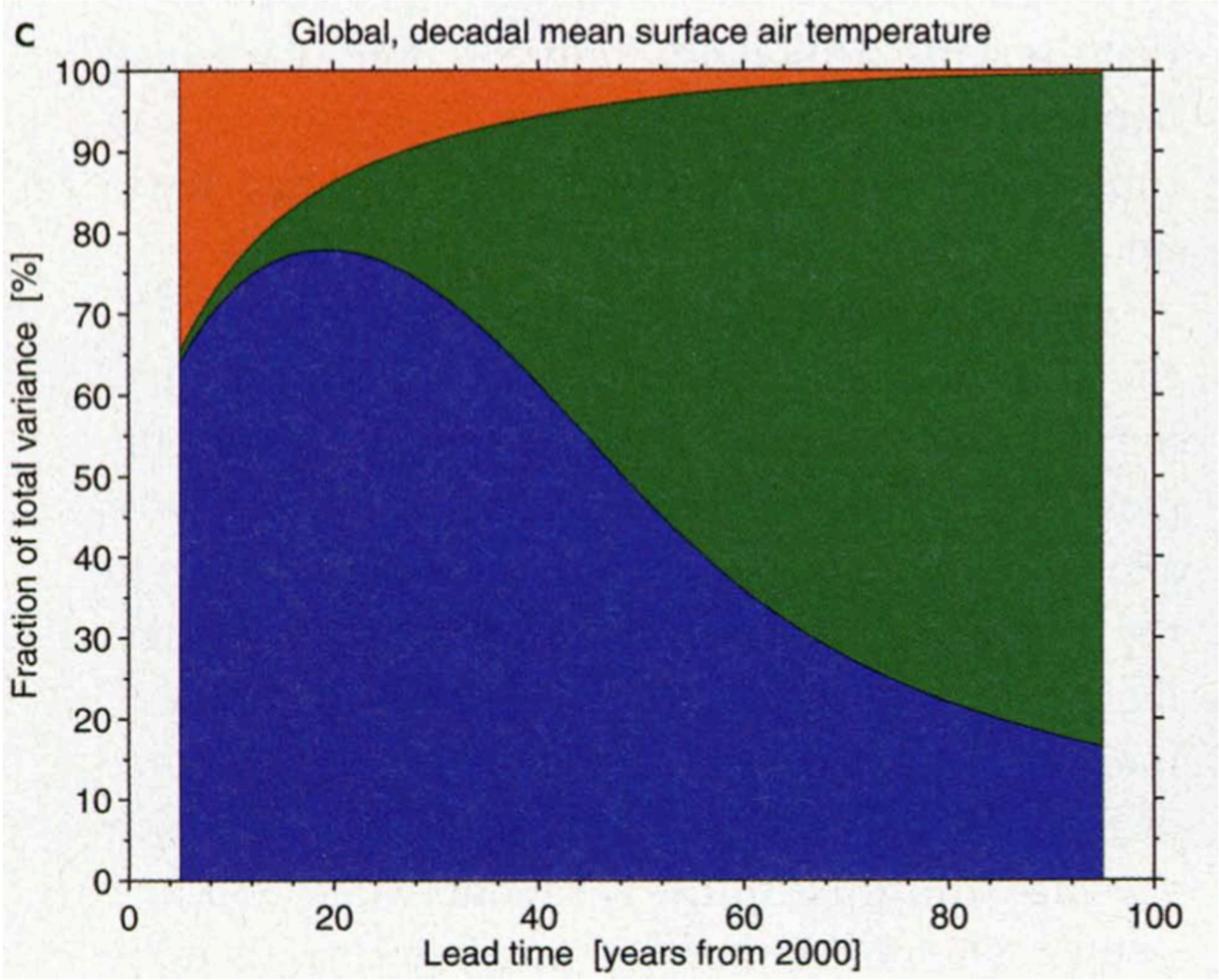
Relative importance likely different for impacts studies due to non-linearities vs. climate!



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Impact shown for a set of dose-response functions using *CMIP3* models by Burke et al. (2014); many impacts studies now use an ensemble of models / scenarios

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Effect on impacts projections has yet to be explicitly quantified. Now feasible using Single Model Initial-condition Large Ensembles (LEs - Deser et al. 2020)

Single Model Initial-Condition Large Ensembles (LEs)

Running the same climate model, with the same inputs (scenario), multiple times to sample internal variability

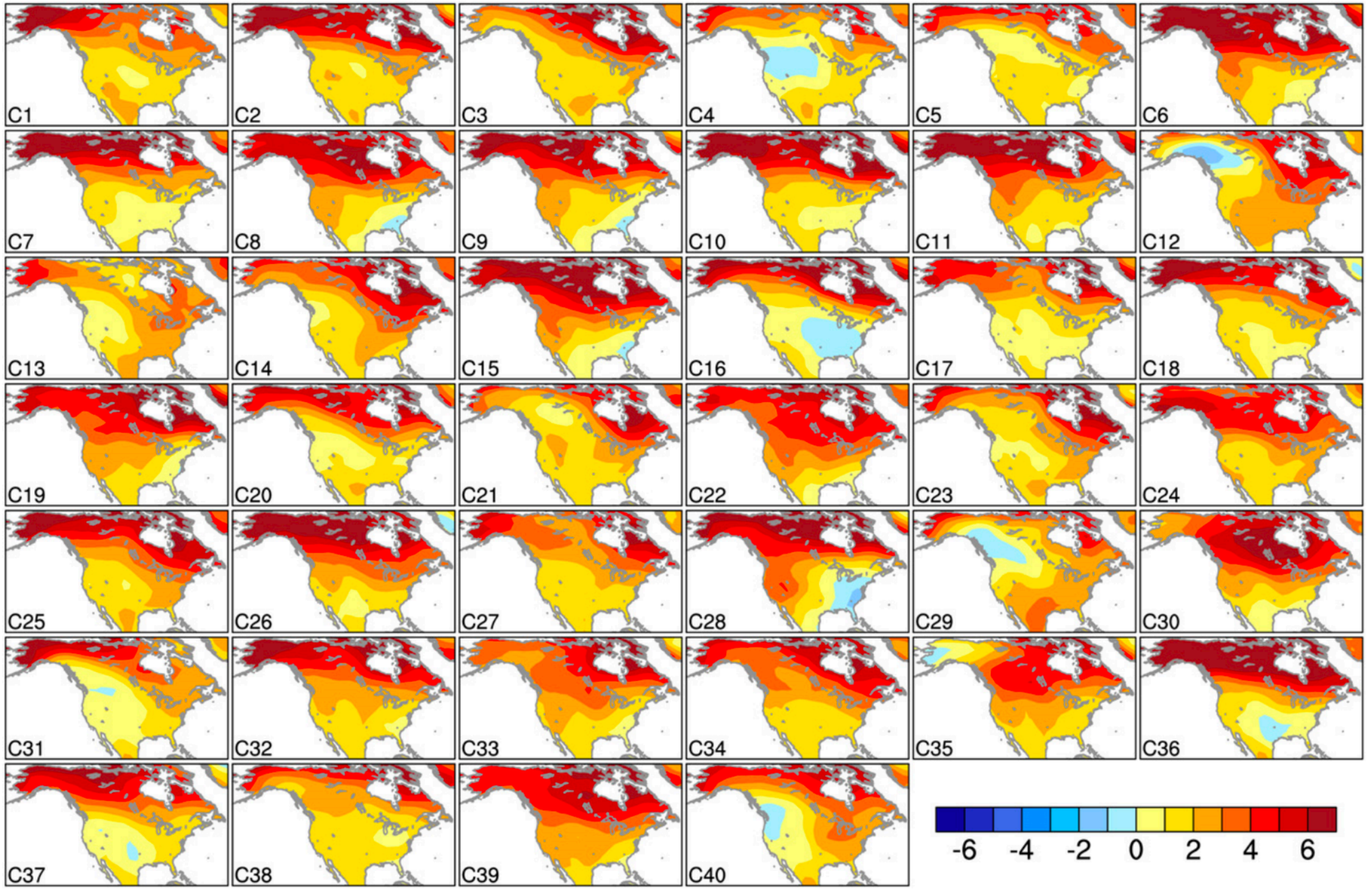

FIG. 1. Winter SAT trends [2010–60; °C (51 yr)$^{-1}$] from each of the 40 CCSM3 ensemble members.

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Plan

A sensitivity analysis of several well-known dose-response functions to all three sources of climate uncertainty

Does internal variability matter, and if so, under what conditions?

Outline

1. Choice of dose-response functions
2. Partitioning climate uncertainty in projections using these dose-response functions
3. How to fully incorporate climate uncertainty into climate impacts projections

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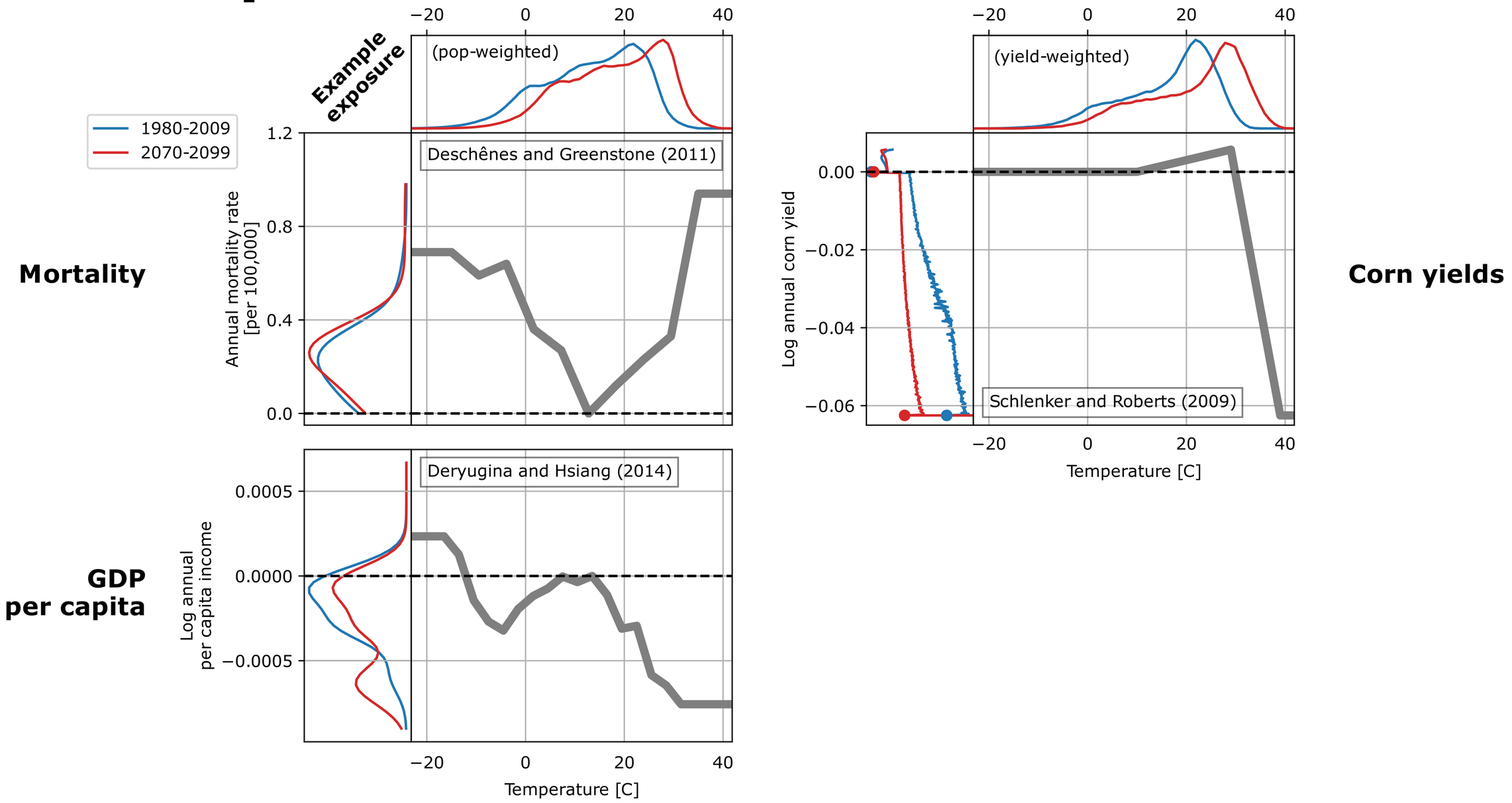
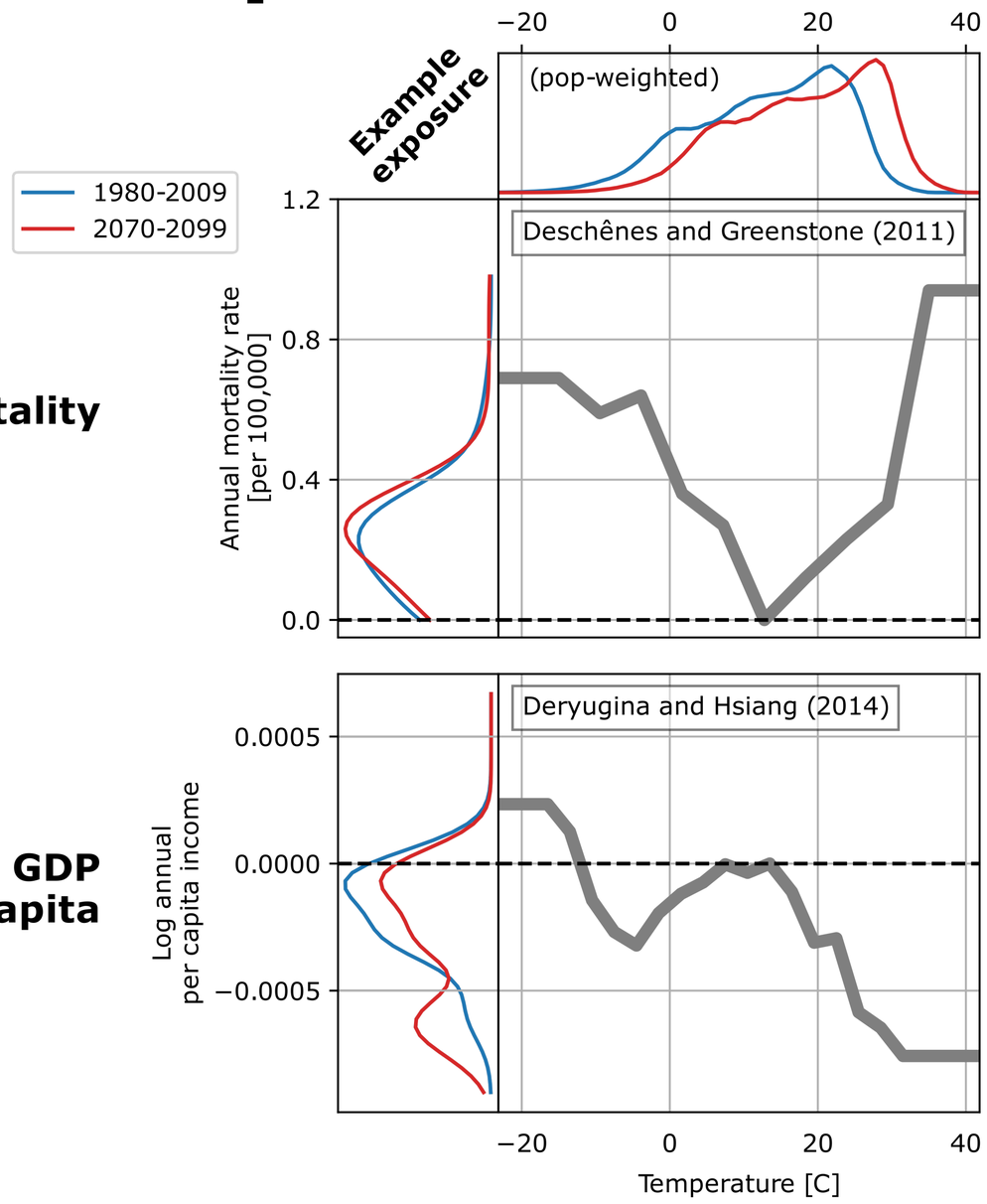
Dose-response functions

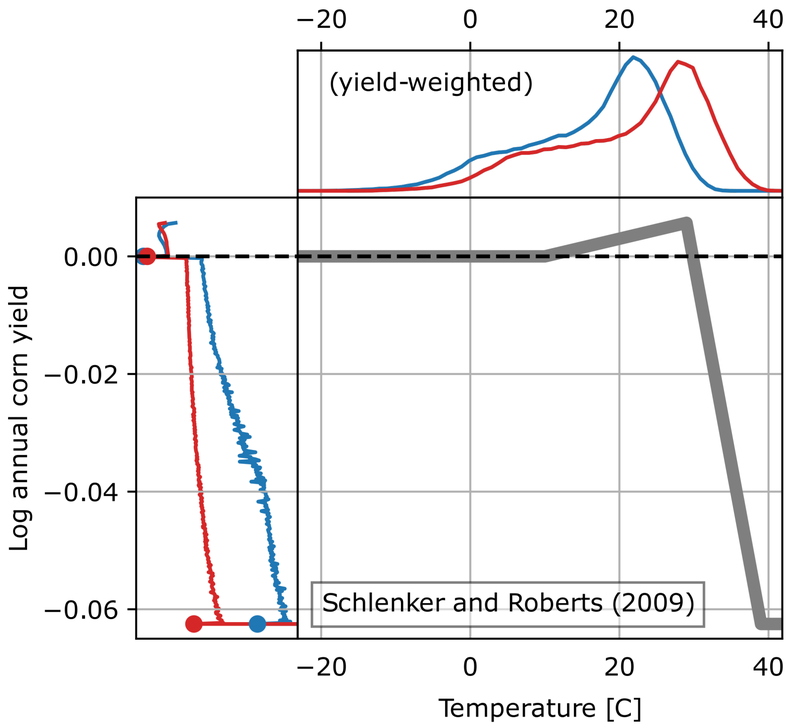


Dose-response functions

Mortality



GDP per capita



Corn yields

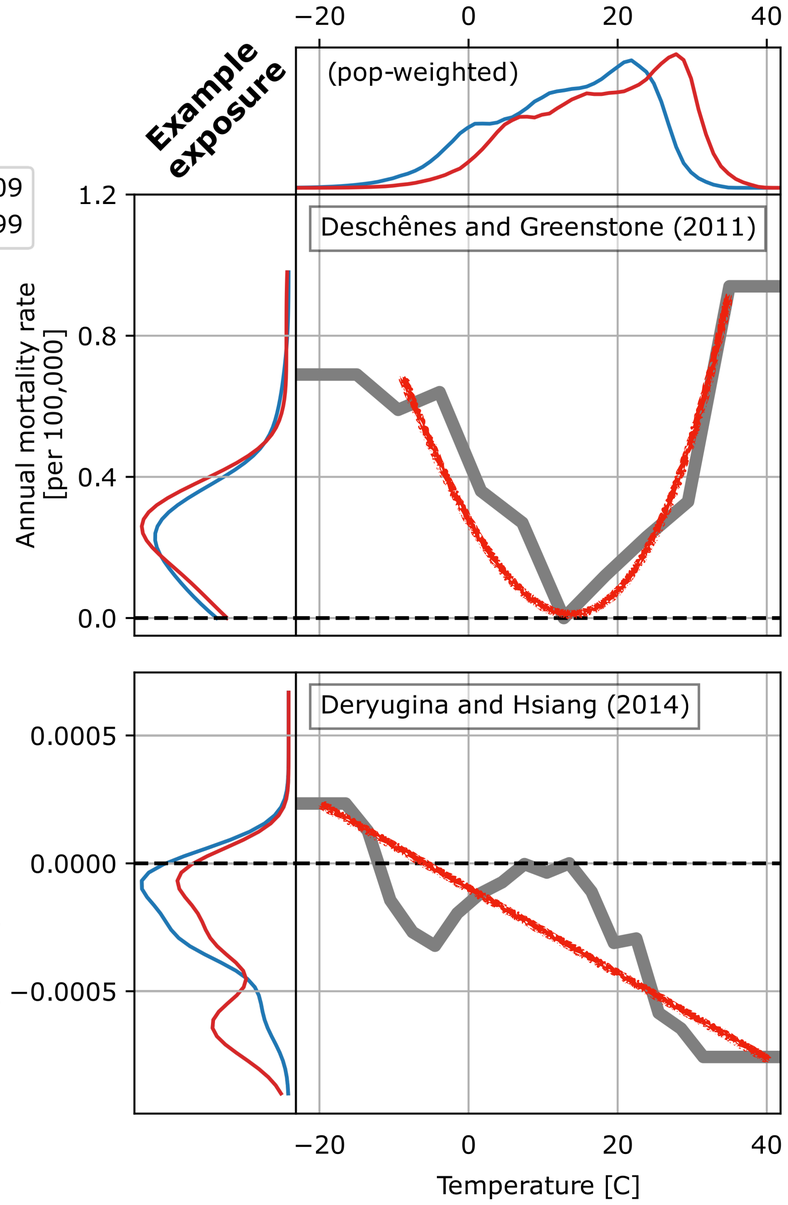
„Simple models“

outcome = f(T)

estimated over continental USA

Dose-response functions

e.g., Agricultural income (Hidalgo et al. 2010)

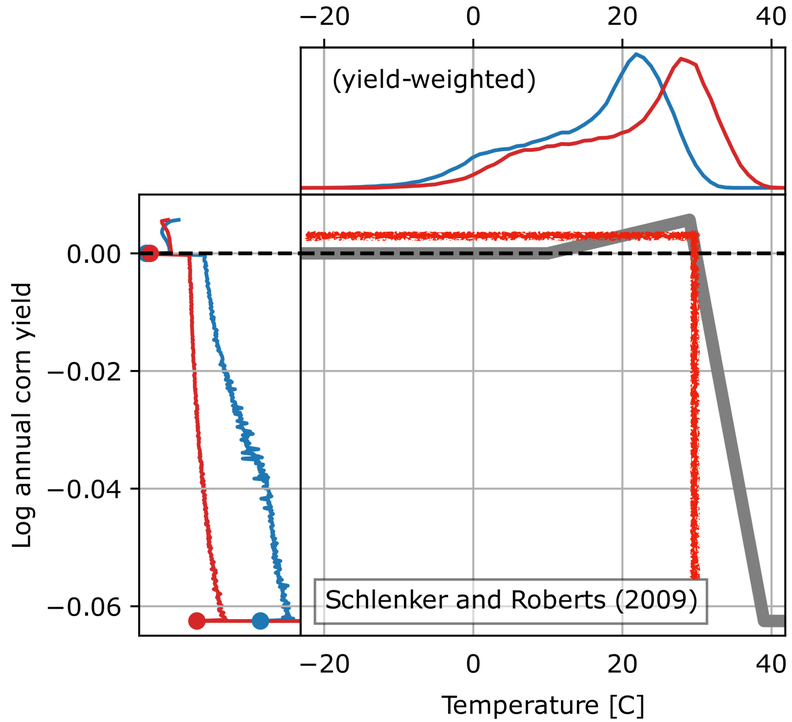


Mortality

e.g.,
- Migration (Bohra-Misra et al. 2014)
- Electricity consumption (Auffhammer 2015)

GDP per capita

e.g.,
- Cyclone damage (Hsiang and Narita 2012)
- Tropical conflict risk (Hsiang et al. 2011)



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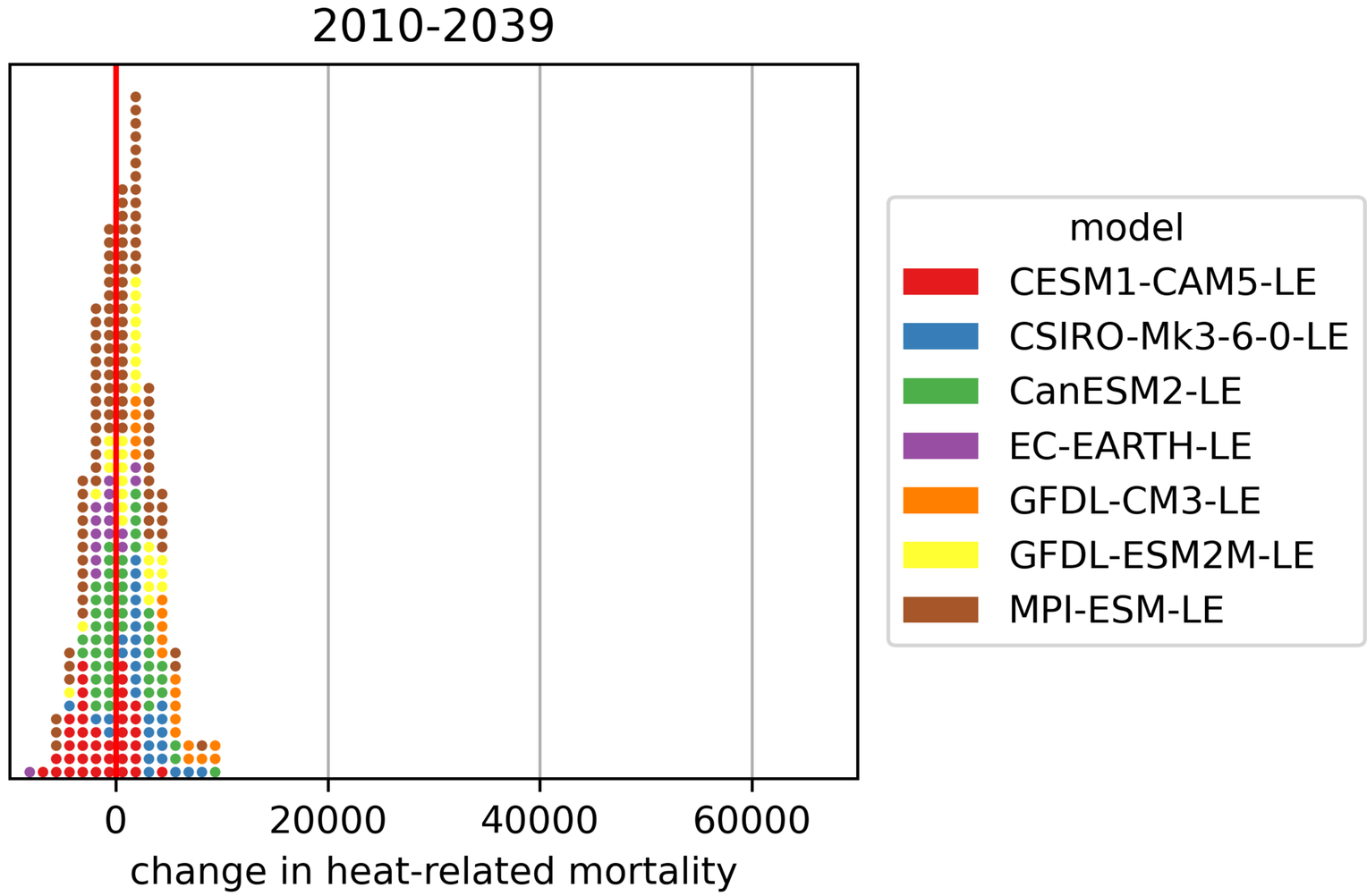
Building impacts projections

Example mortality projections for continental USA - each dot is based on a single LE run



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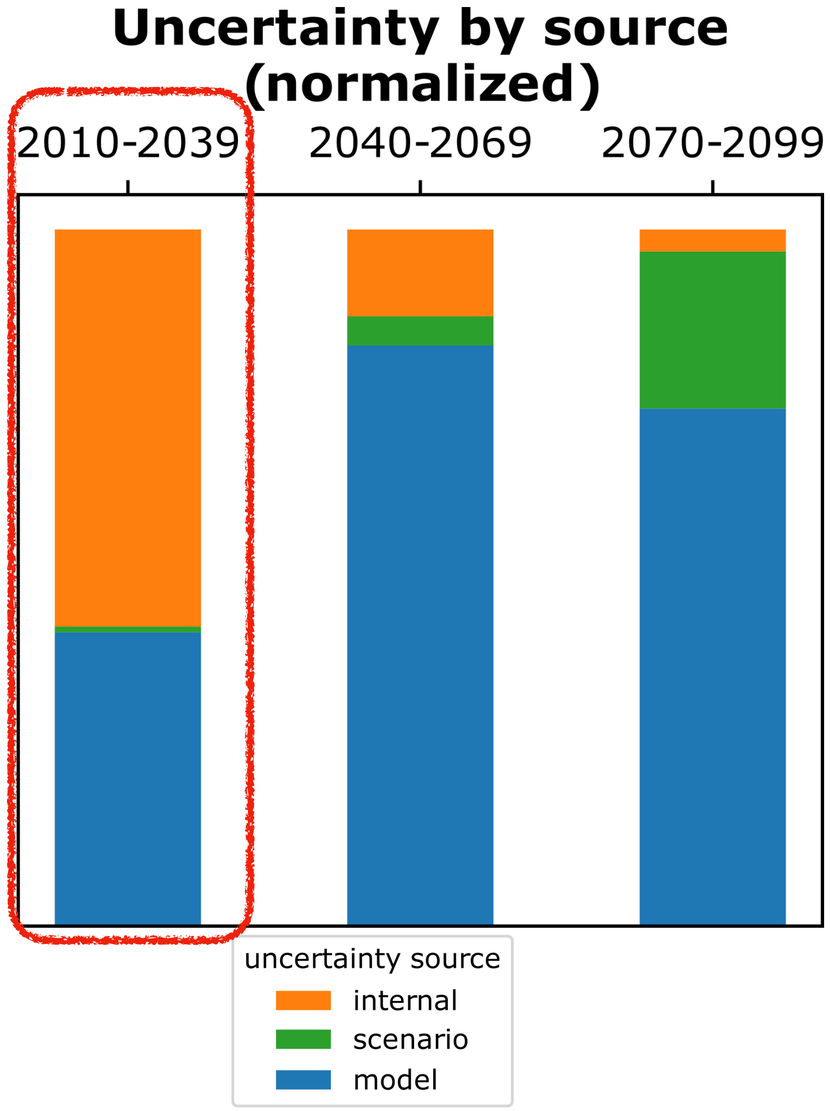

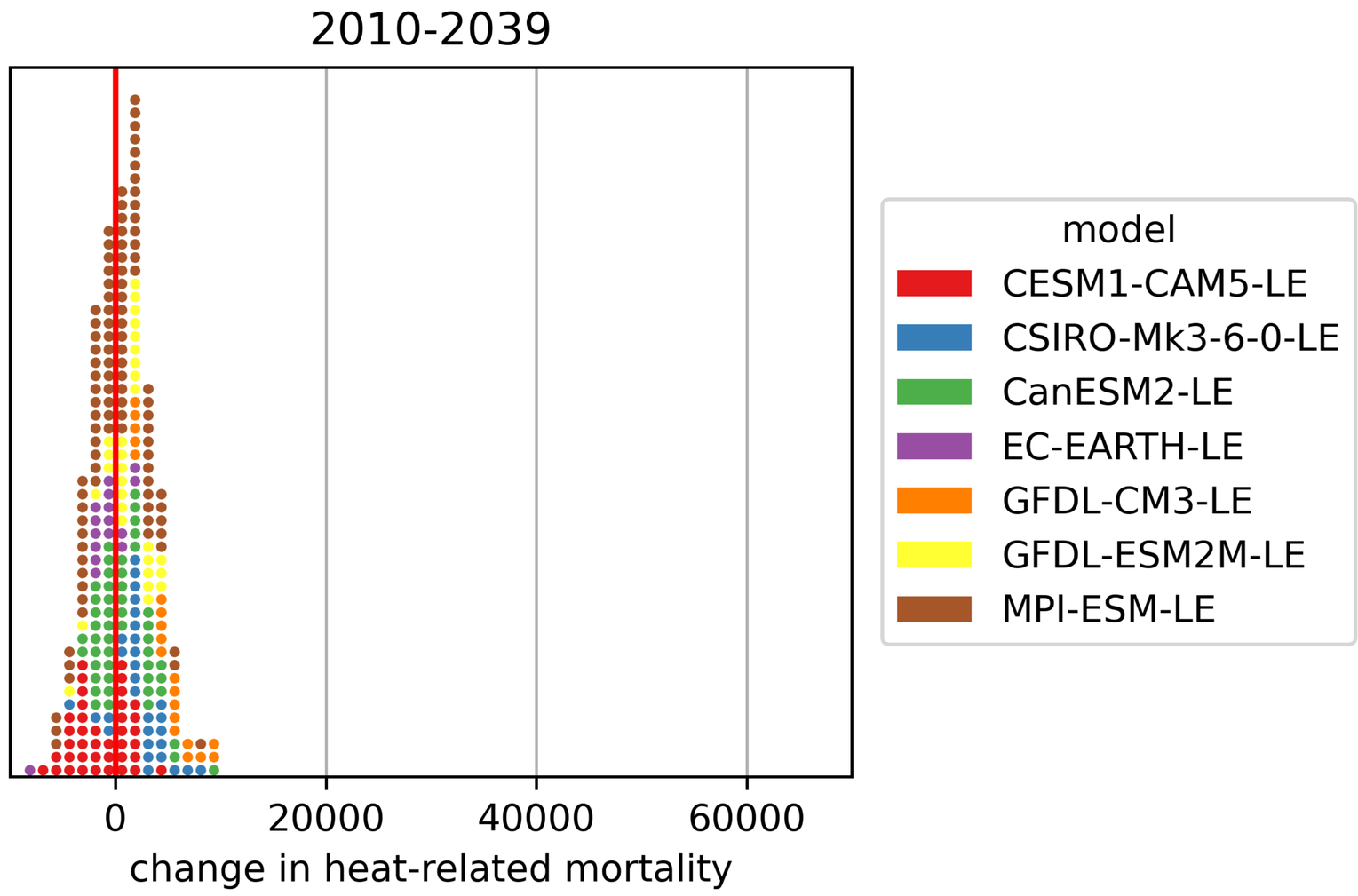

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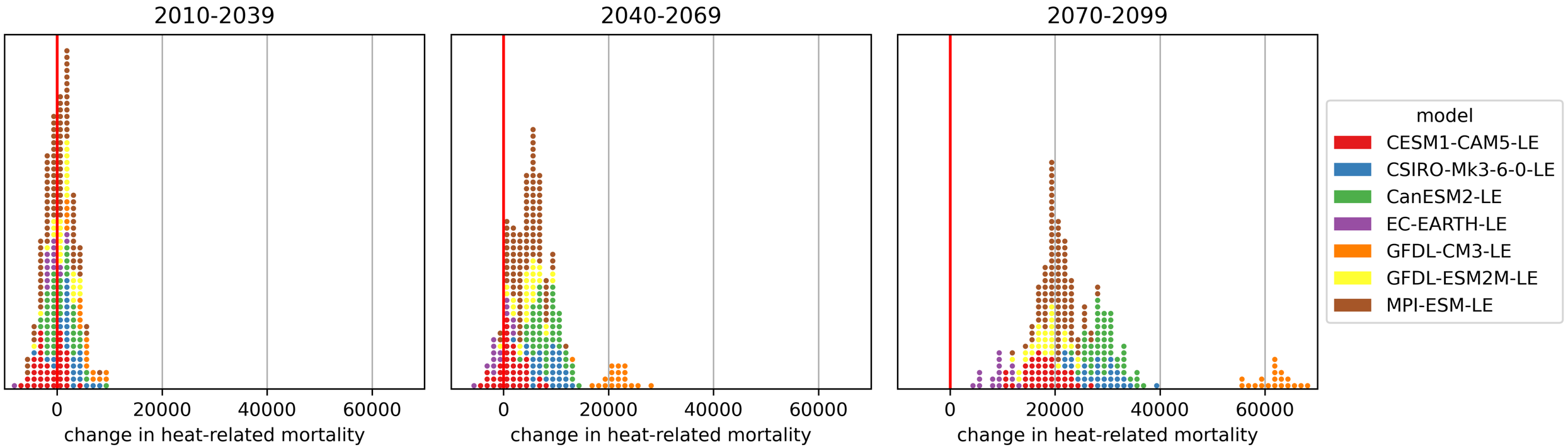

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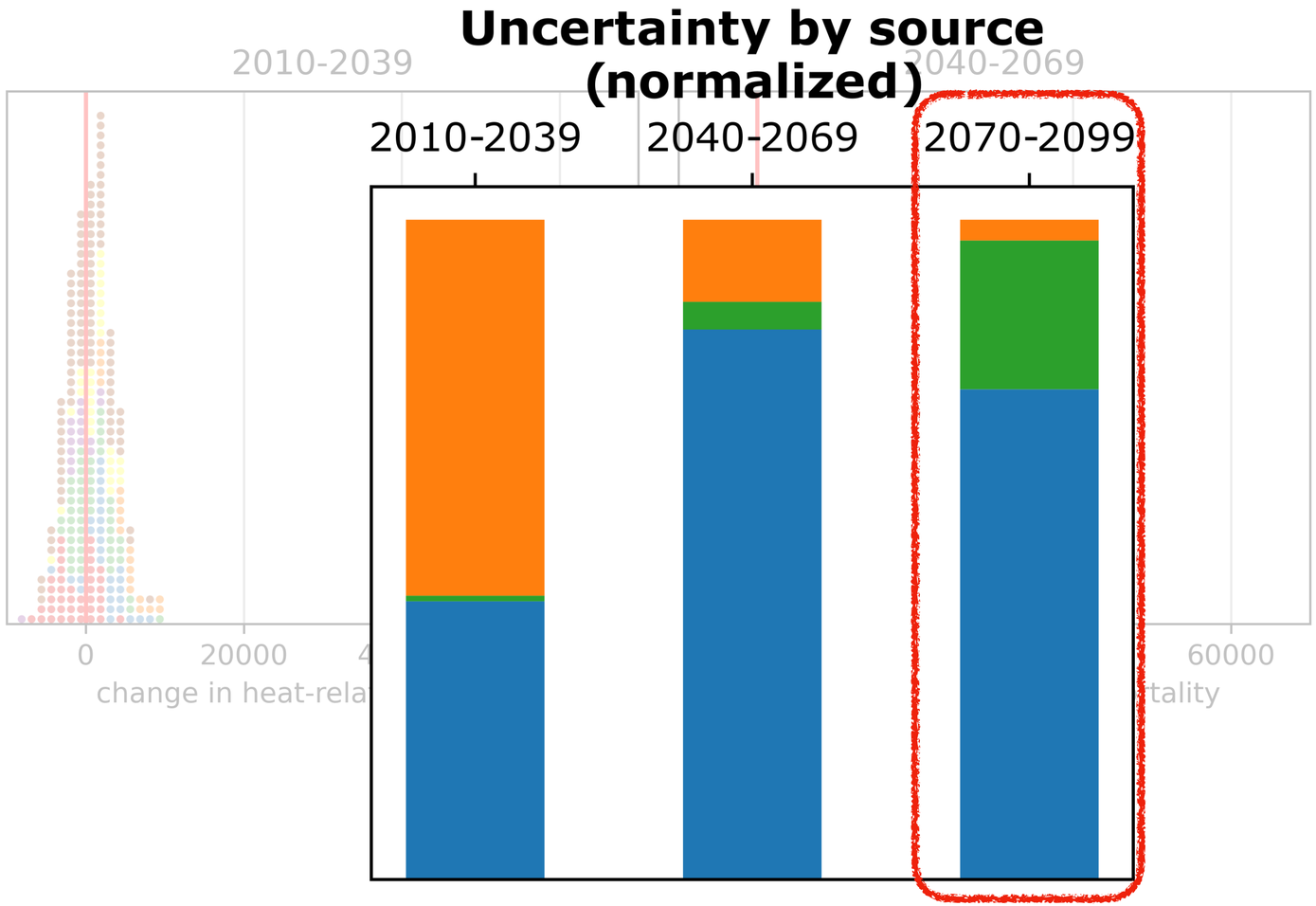
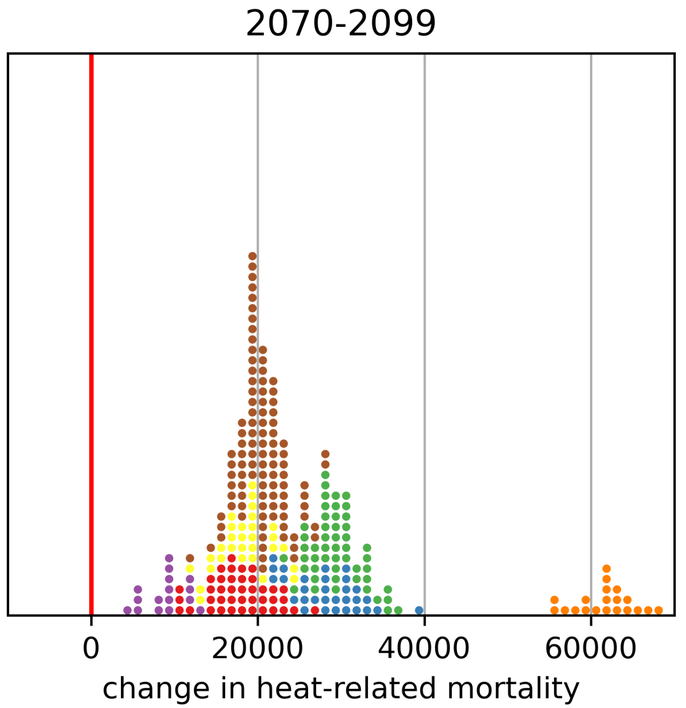
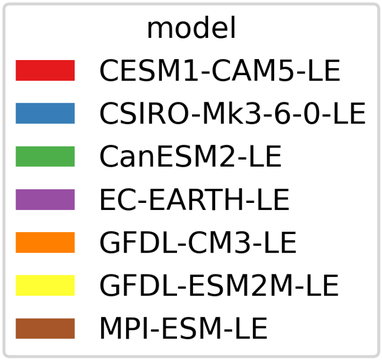
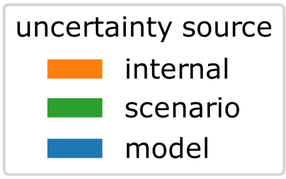
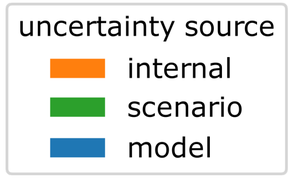


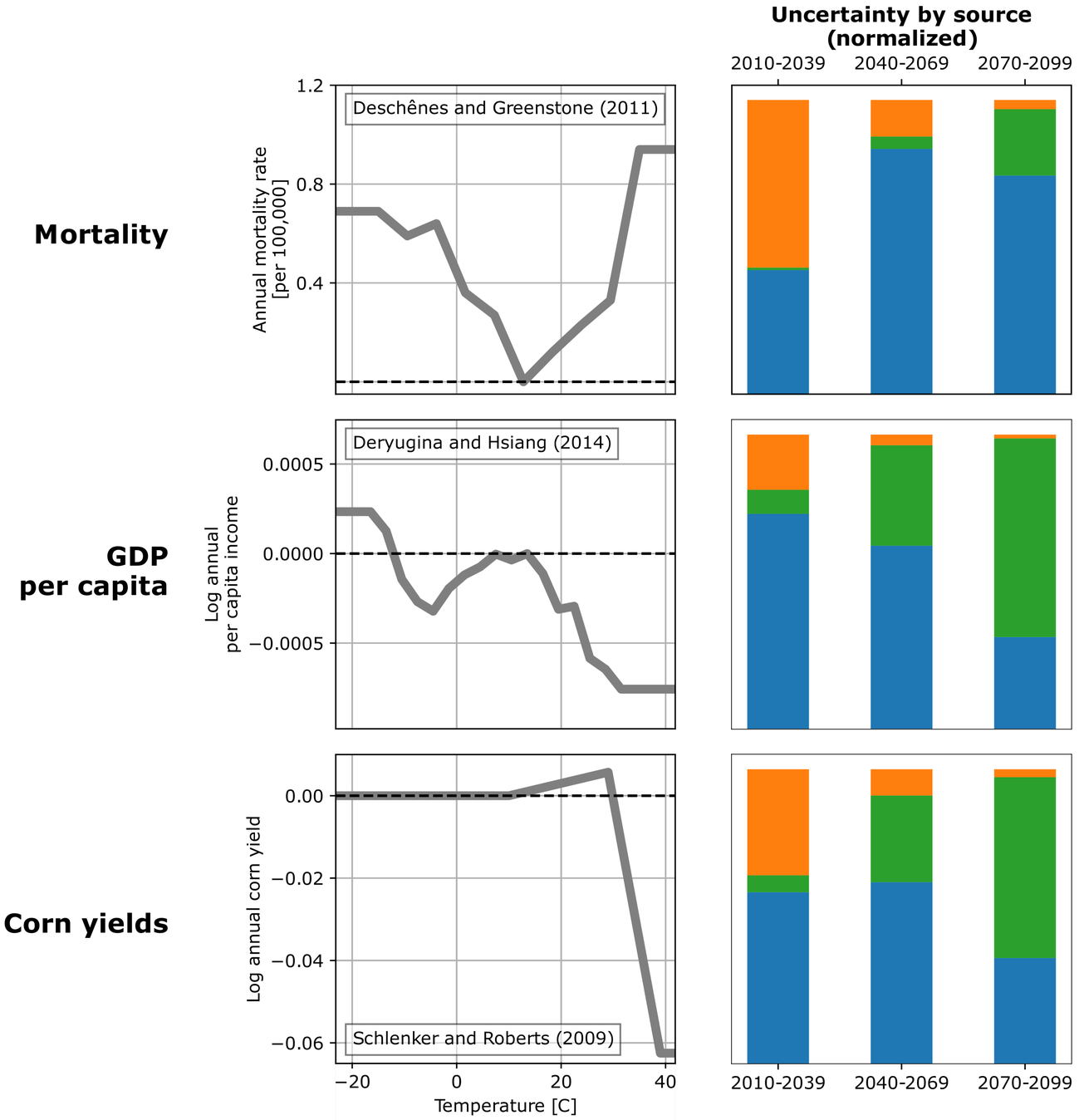






Uncertainty partitioning depends on shape of dose-response function





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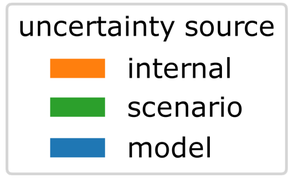

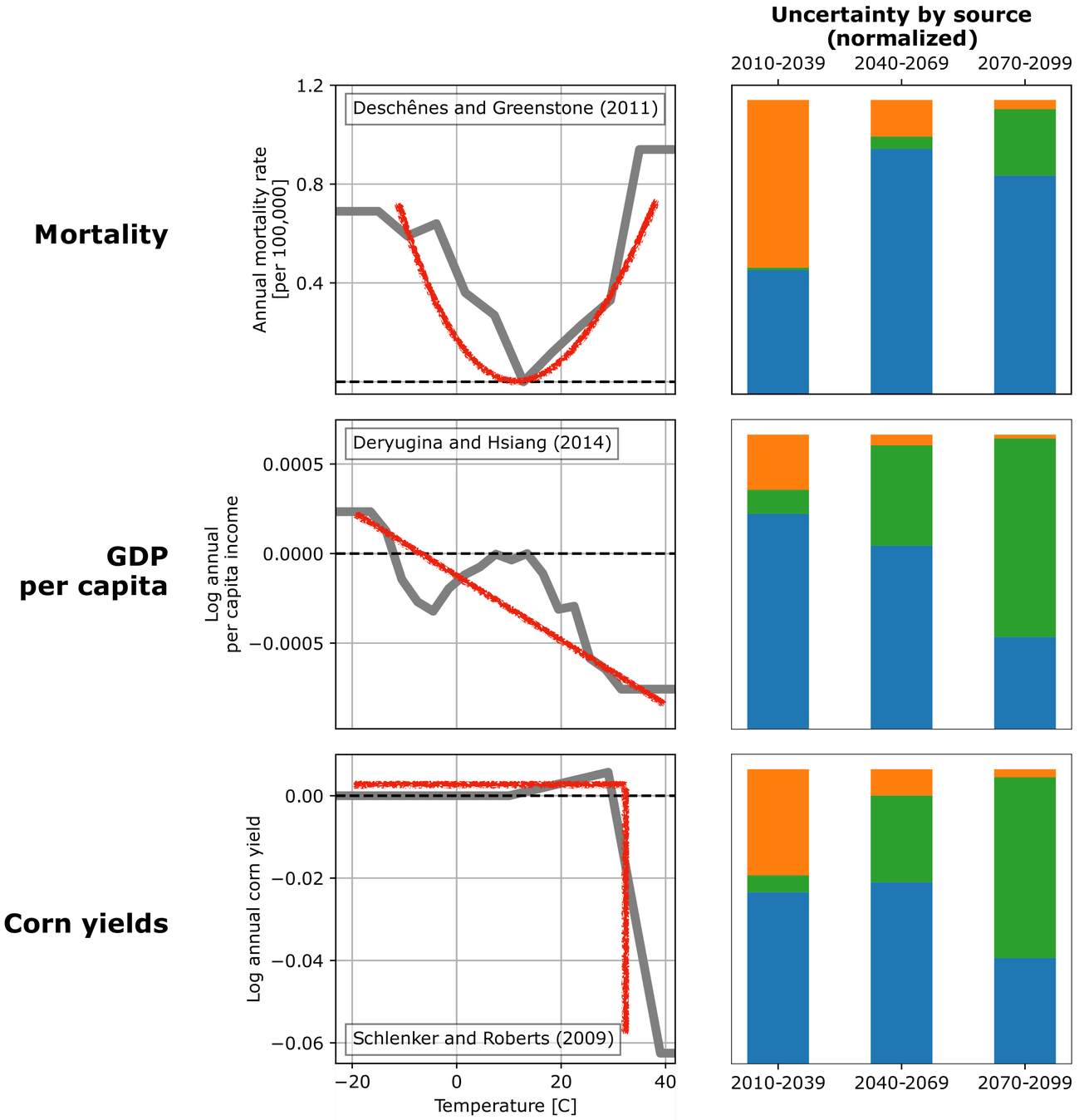

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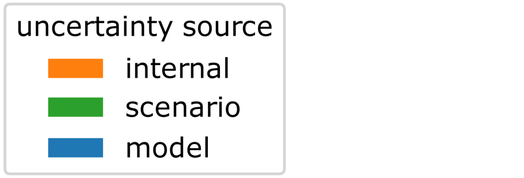
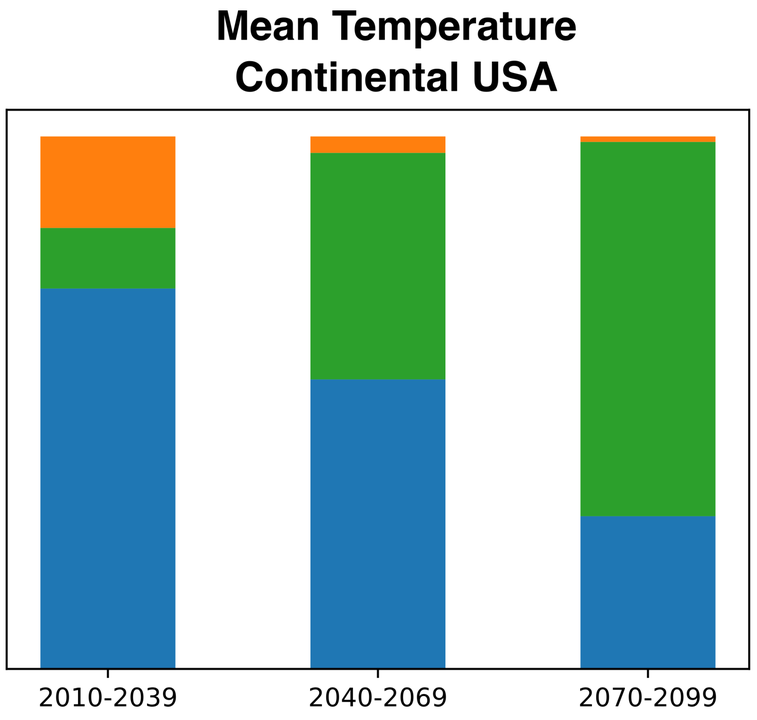
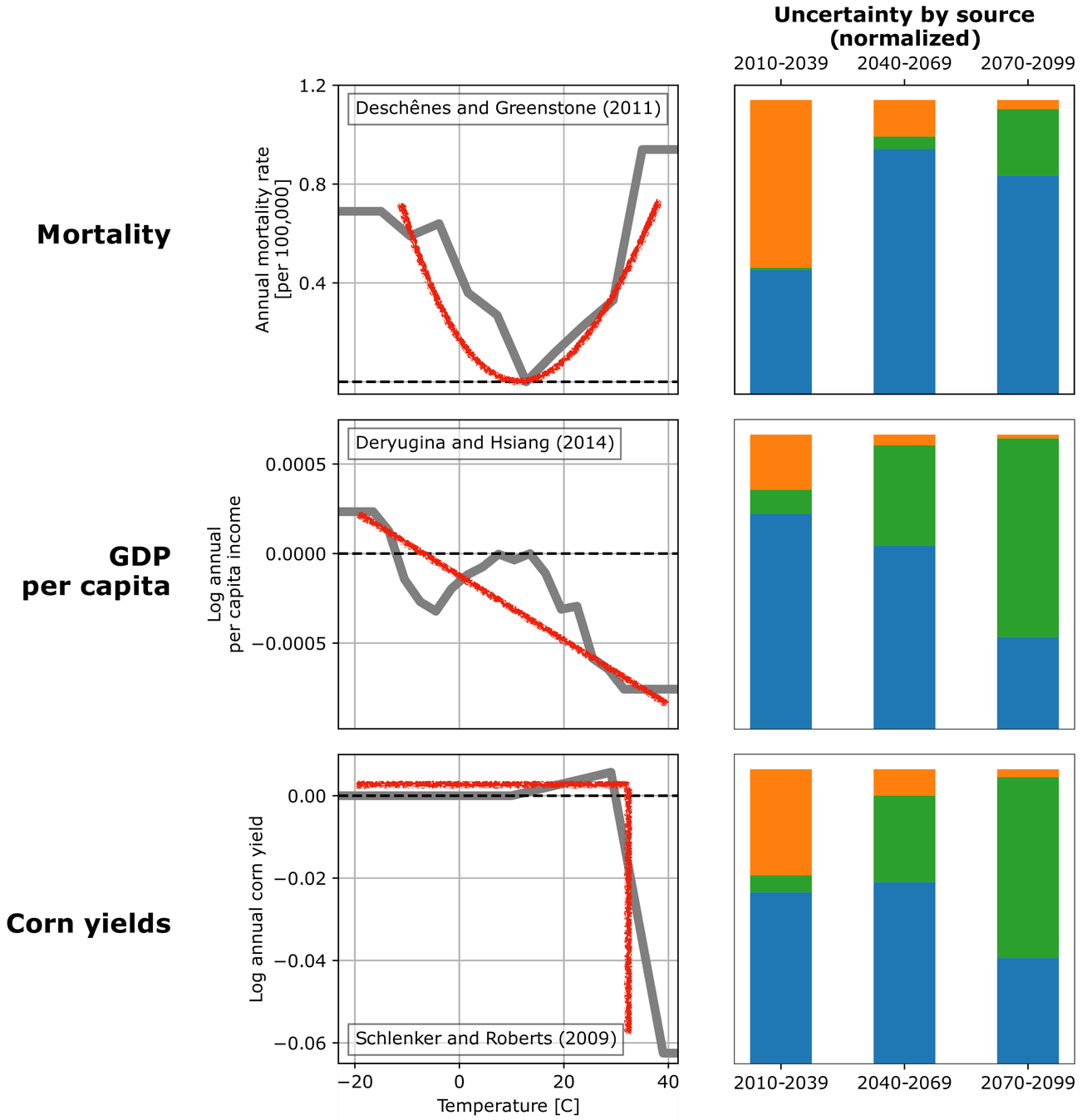
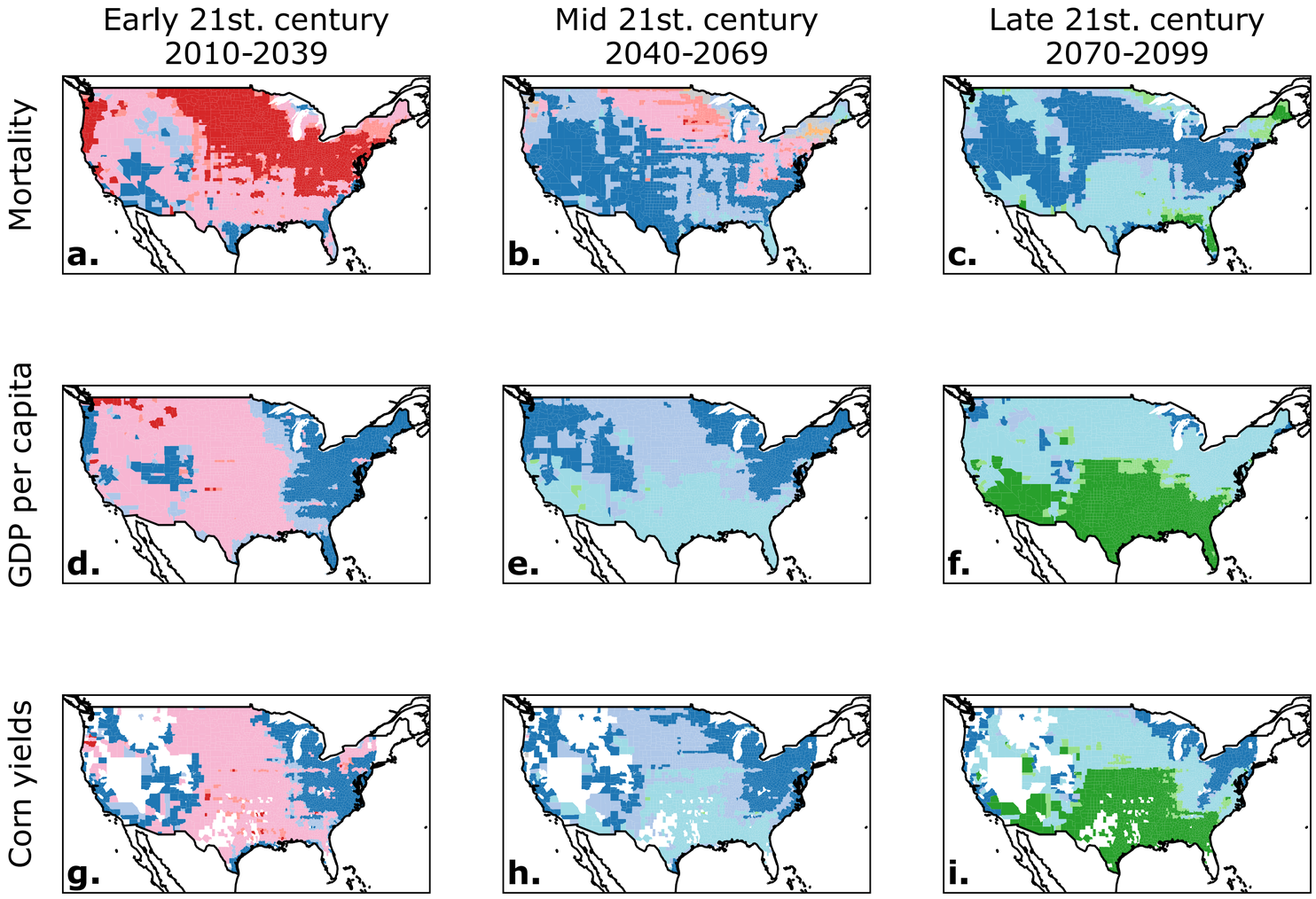
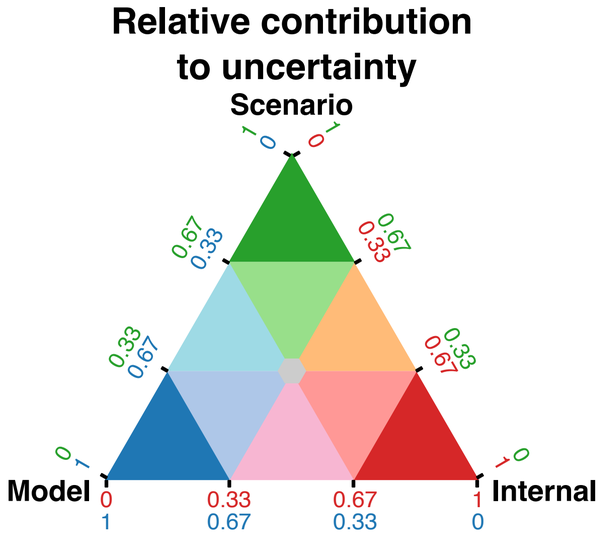






Geography of uncertainty





Interaction between geography of climate variability and human variables (population, corn production,…) matters!

Outline

1. Choice of dose-response functions
2. Partitioning climate uncertainty in projections using these dose-response functions
3. How to fully incorporate climate uncertainty into climate impacts projections

Sources of uncertainty

Relative importance of source of uncertainty (scenario, model, internal) depends on:

- Timeframe of interest
- Shape of dose-response function
- Geography

Sources of uncertainty

Ignoring internal variability can result in underestimating worst-case impacts!

Internal variability

- Near-term (decision-relevant?) impacts projections
- Non-linear relationships
- Areas with known existing strong internal variability

Scenario uncertainty

- Long-term impacts projections
- Monotonic dose-response functions
- Areas with few existing patterns of internal variability

Thank you!

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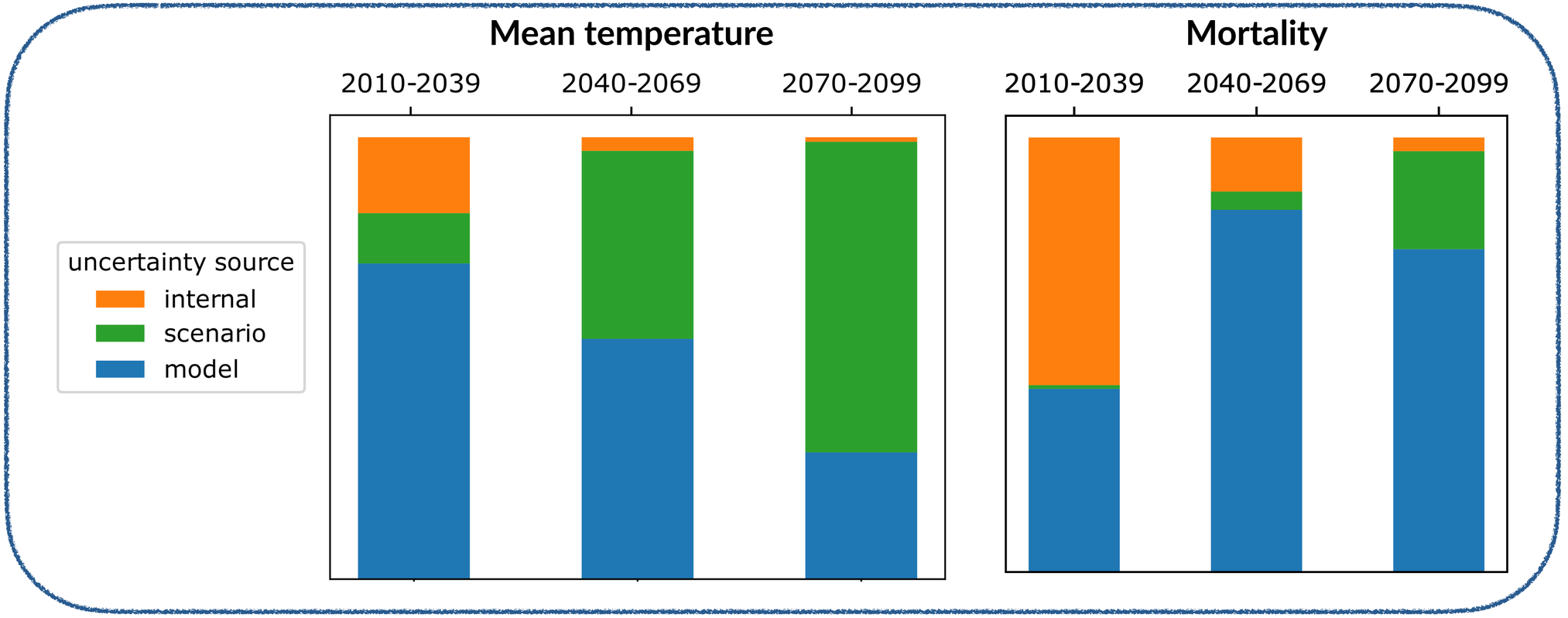
`xagg` - raster data to polygons for python



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RESEARCH ARTICLE | ENVIRONMENTAL SCIENCES

The importance of internal climate variability in climate impact projections

Kevin Schwarzwald[a,1] and Nathan Lenssen[a,b]

Edited by Timothy Palmer, University of Oxford, Oxford, United Kingdom; received May 10, 2022; accepted August 18, 2022

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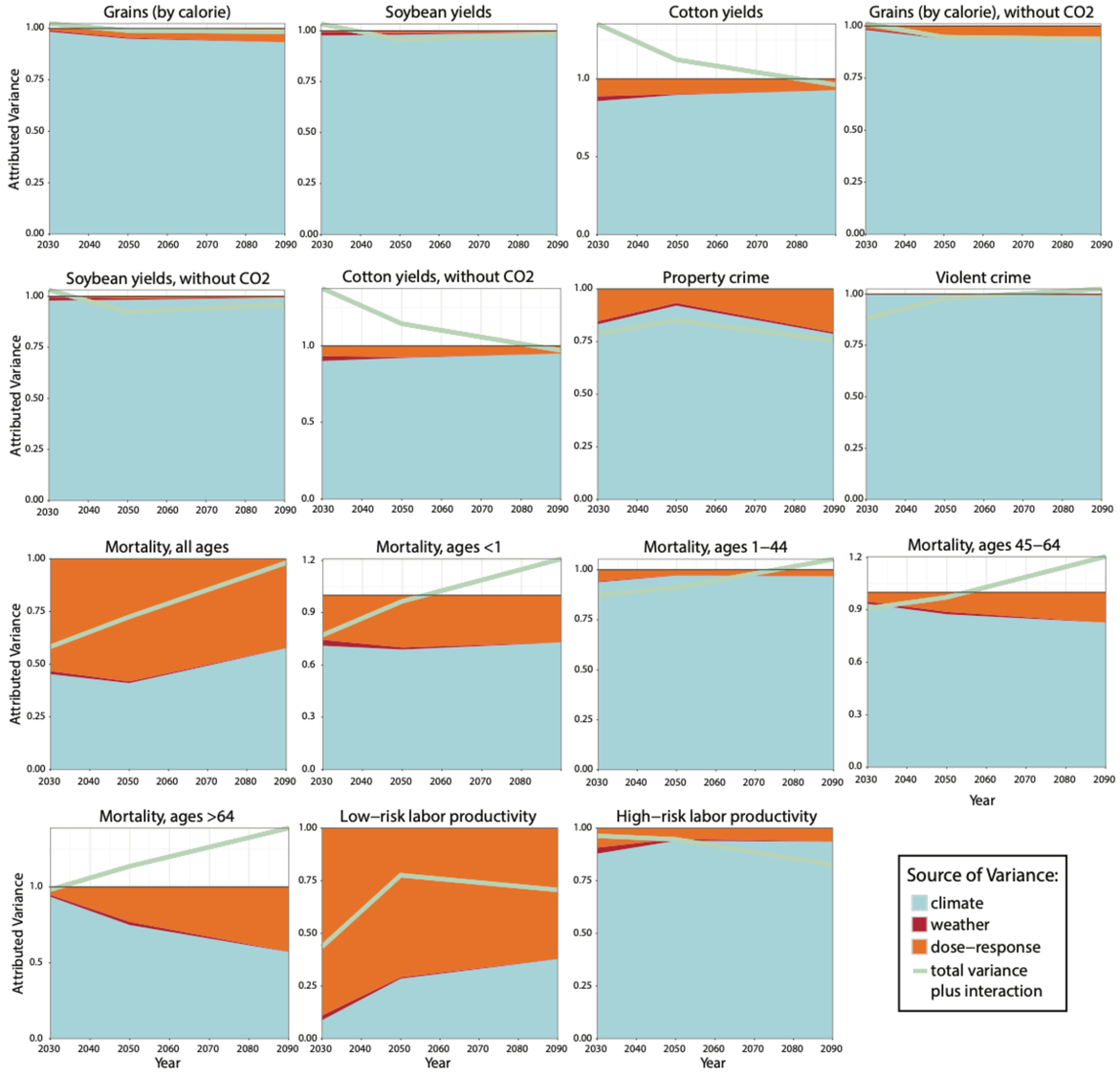
Extra Slides

Is climate uncertainty important?

Climate uncertainty >> dose-response uncertainty in projections of many climate damages…

Figure from Hsiang, Solomon, Robert Kopp, Amir Jina, James Rising, Michael Delgado, Shashank Mohan, D. J. Rasmussen, et al. 2017. "Estimating Economic Damage from Climate Change in the United States." *Science* 356 (6345): 1362–69. https://doi.org/10.1126/science.aal4369.

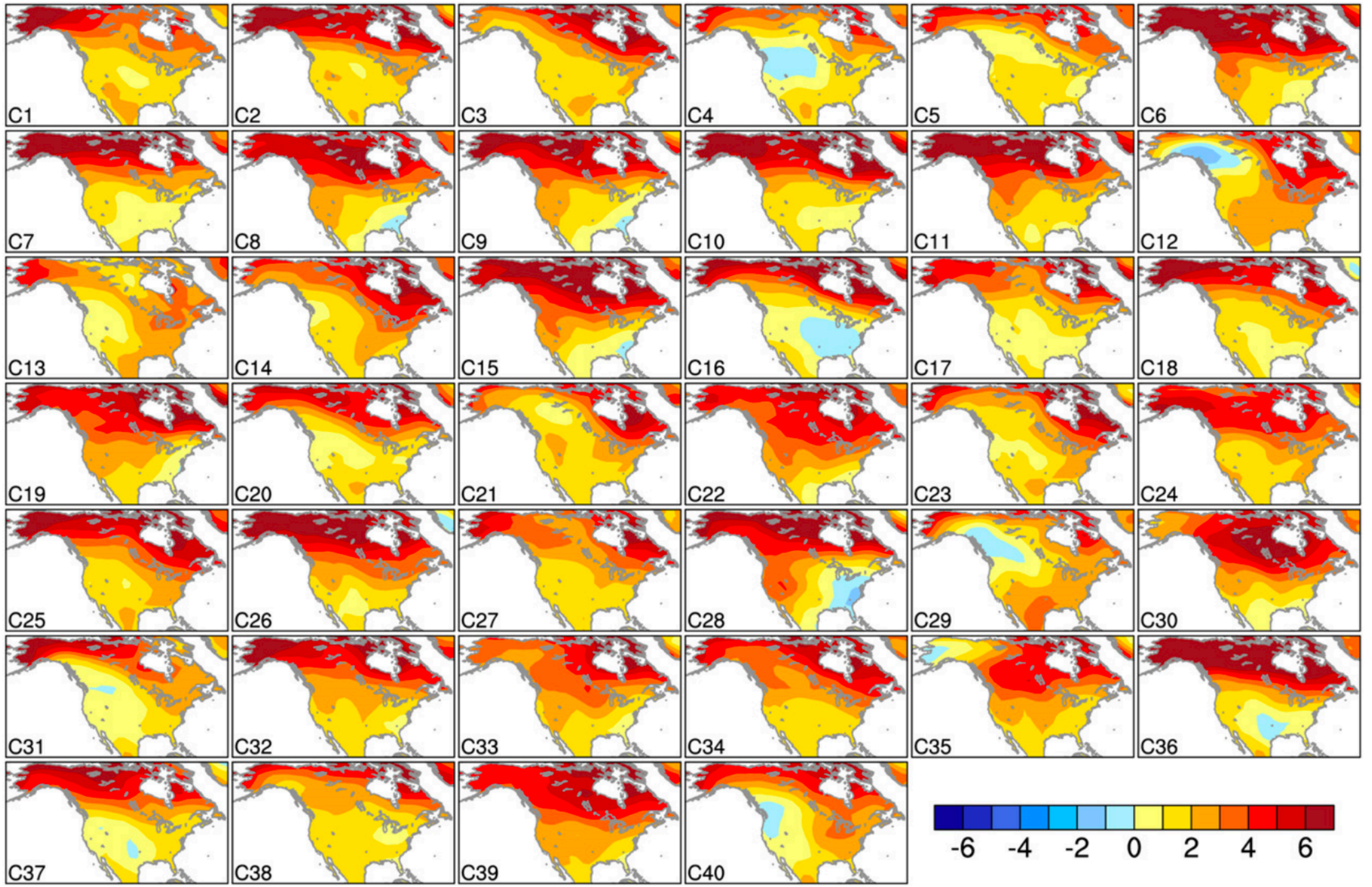


Supplementary Figure S7: **Decomposing sources of uncertainty for damages over time.** Same as Figure S6 but for multiple time periods and normalizing variances to by the sum of variances from climate models, weather, and econometric uncertainty. Approach is same as ref. (*43*). Green line indicates the total variance once the "interaction" component Λ is accounted for. Λ can be read as the difference between 1 and the green line at each moment, it is possible for $\Lambda < 0$.

Single Model Initial-Condition Large Ensembles (LEs)

Running the same climate model, with the same inputs (scenario), multiple times to sample internal variability

Initialization either:
- „Micro“: bit-flipping initial conditions
- „Macro“: branching off from a long control run



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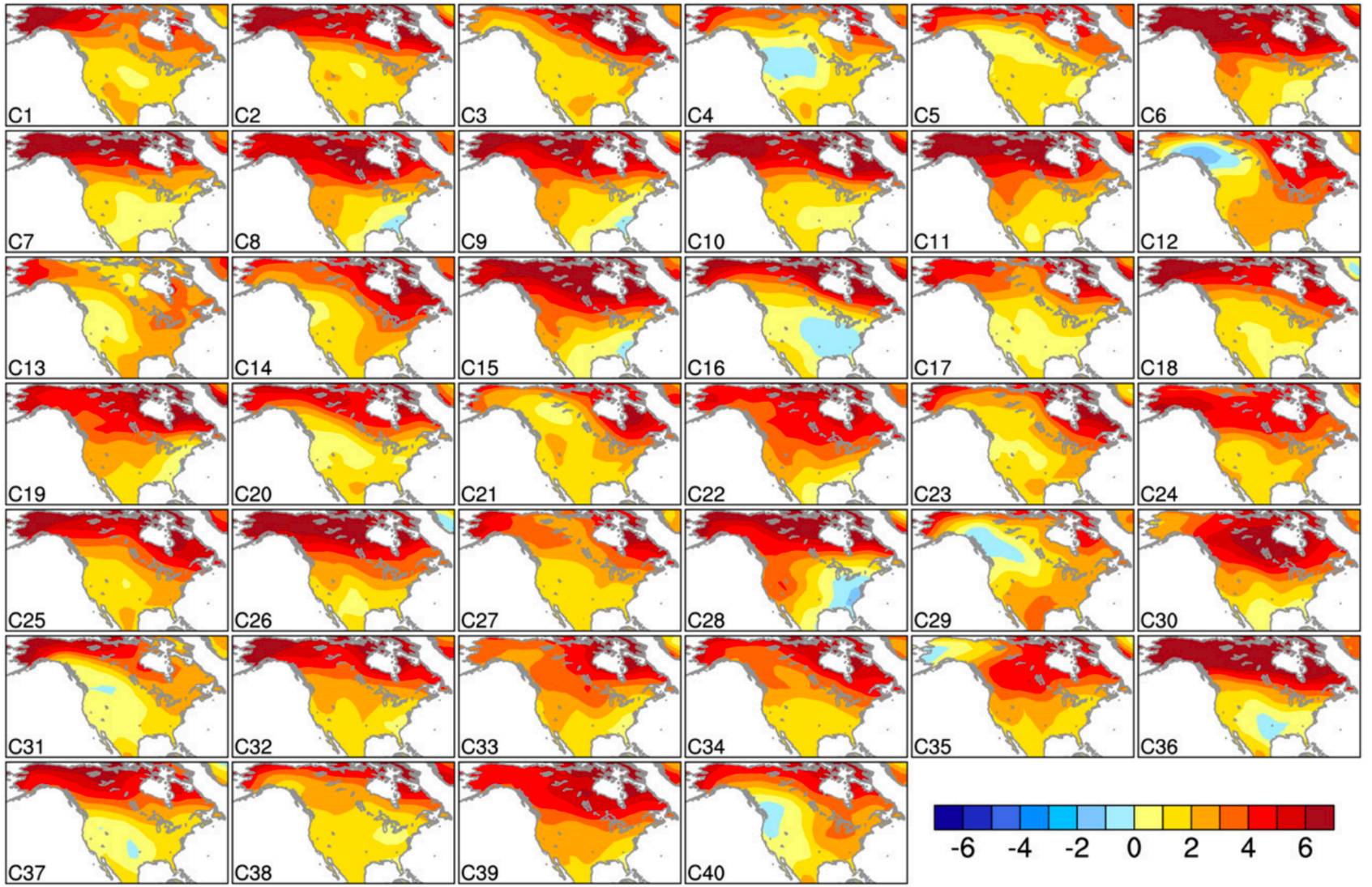
Single Model Initial-Condition Large Ensembles (LEs)

Some limitations (of this generation):

- CMIP5 generation
- Some only have monthly data
- One scenario (RCP8.5)



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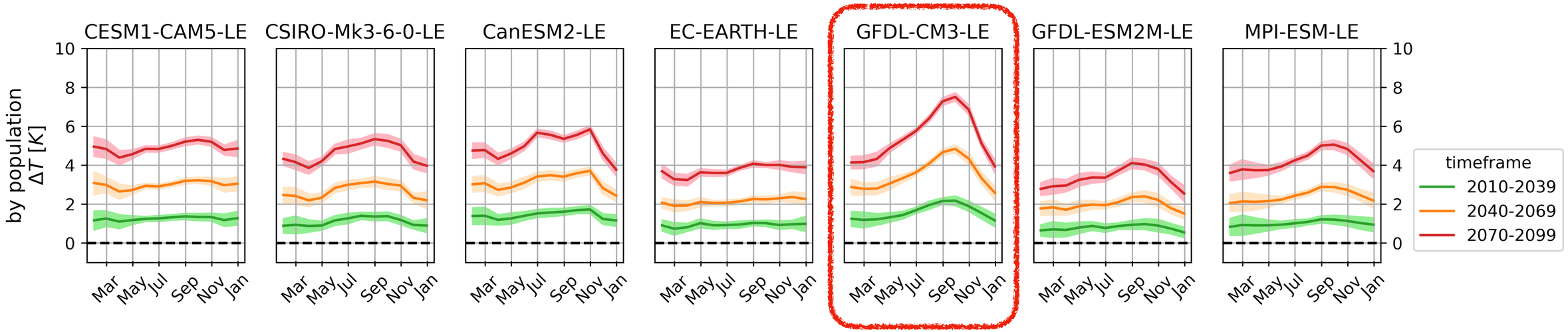
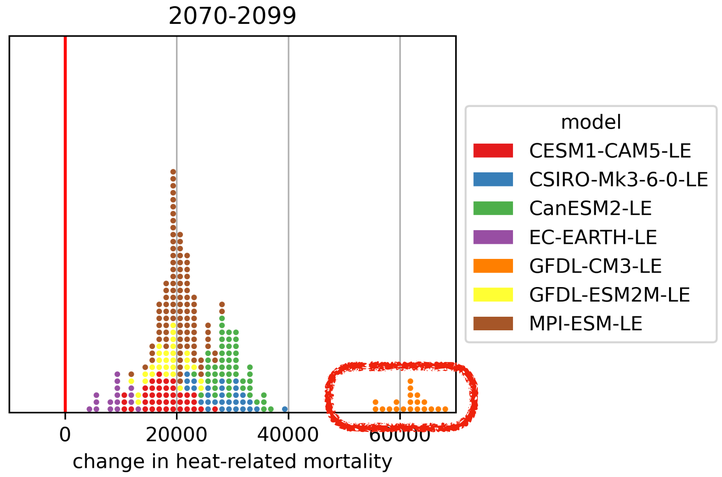
GFDL-CM3's odd changing seasonal cycle

The outlier in mortality projections due to dramatically increasing summertime temperatures…





Schwarzwald, Kevin, and Nathan Lenssen. 2022. "The Importance of Internal Climate Variability in Climate Impact Projections." *Proceedings of the National Academy of Sciences* 119 (42): e2208095119. https://doi.org/10.1073/pnas.2208095119.