Prepared for the Risky Business Project

American Climate Prospectus

Economic Risks in the United States

Trevor Houser
Rhodium Group

Robert Kopp
Rutgers University

Solomon Hsiang
UC Berkeley

Roger Muir-Wood
RMS

Kate Larsen
Rhodium Group

DJ Rasmussen
Rhodium Group

Amir Jina
Columbia University

Paul Wilson
RMS

Michael Delgado
Rhodium Group

Michael Mastrandrea
Stanford University

James Rising
Columbia University

Shashank Mohan
Rhodium Group

Climate Change Impacts/Integrated Assessment | Snowmass, CO | July 22, 2014

www.climateprospectus.org

Overview

An Independent Assessment for a Climate Risk Committee

Analytical Support for the Risky Business Project (riskybusiness.org)

Next Generation

Bloomberg Philanthropies

THE PAULSON INSTITUTE

“If you can’t measure it, you can’t manage it”…

- Mike Bloomberg

Research Objectives

1. Where possible, micro-found the damage function for the United States using the highest-quality, identified, empirical measurements
2. Make the calculation transparent (and hopefully open source)
3. Make updating the calculation easy
4. Leverage state-of-the-art physical climate models to describe the spatial structure of impacts
5. Quantify uncertainty and risk
6. Make the results interpretable and relatable to ordinary citizens
7. Finish in 12 months

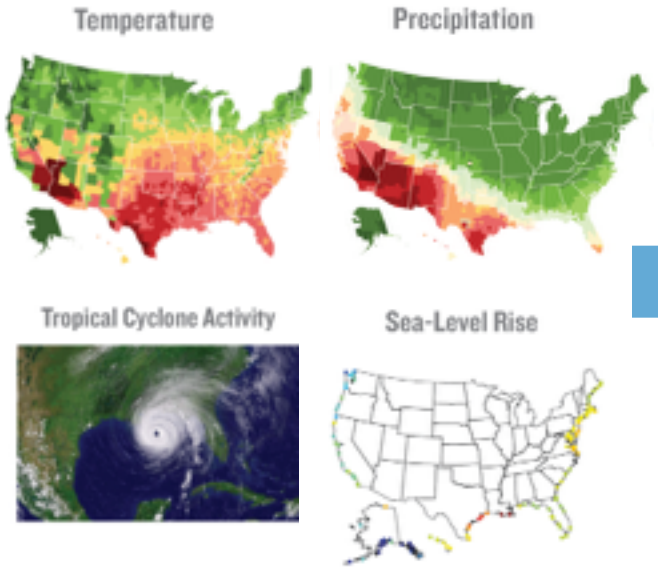
Scope of coverage

Far from comprehensive

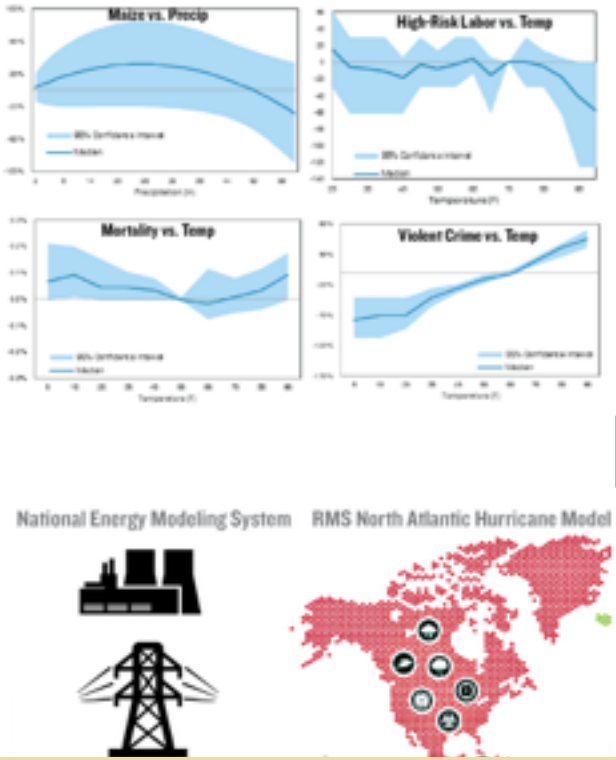
Research approach

Spatial Empirical Adaptive Global-to-Local Assessment System (SEAGLAS)

Downscaled, probabilistic Physical Climate Projections



Impact estimates based on meta-analysis of econometric research



Integrated Economic Analysis with CGE model, consideration of potential adaptations

Note: We did not try to construct a full IAM. In particular, we made the simplifying assumption of a constant spatial and sectoral economic structure

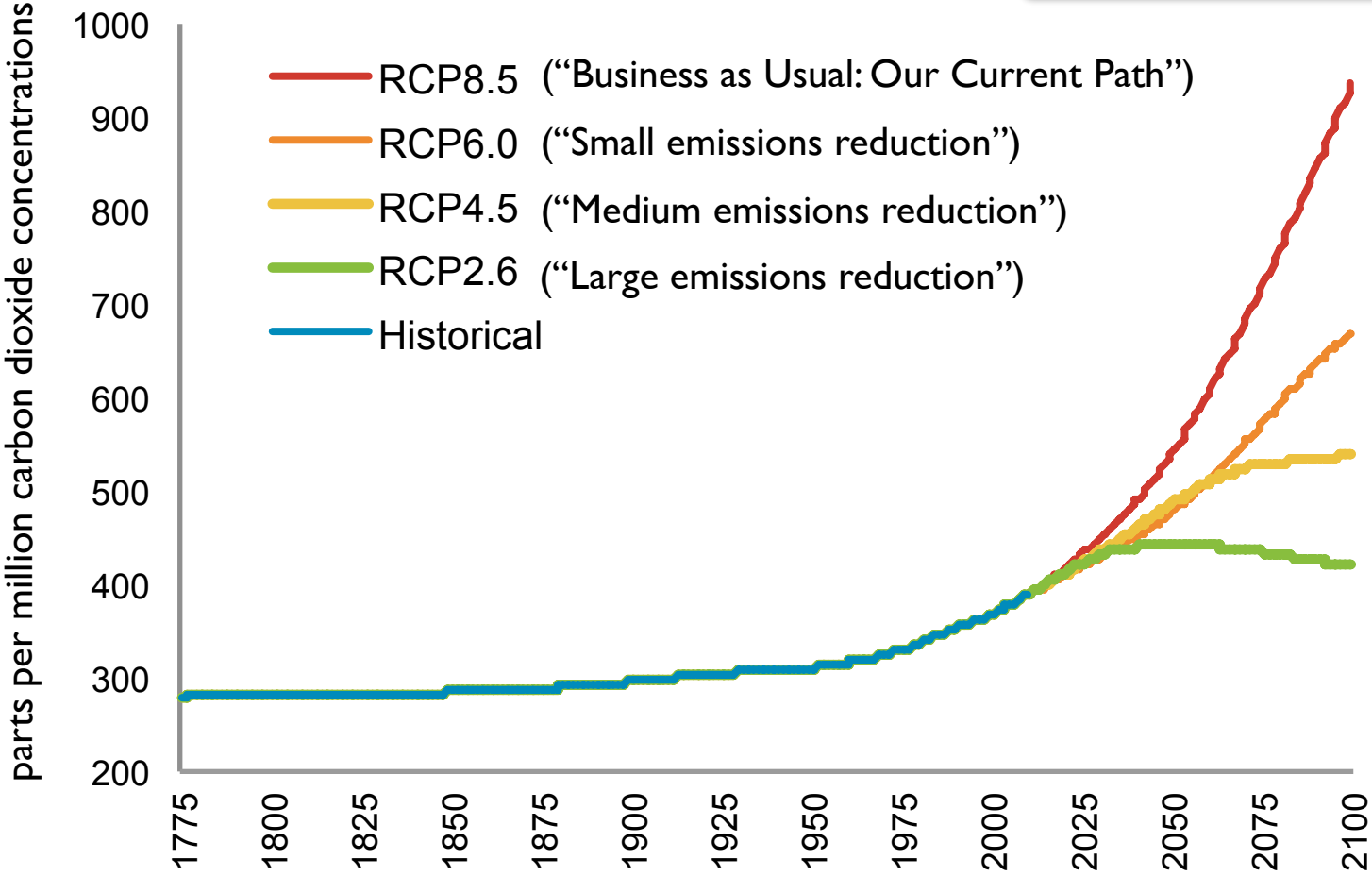
Complementary detailed sectoral models

Physical Science Projections

Multiple emissions pathways reflect different socio-economic, technological and policy futures.

Sources of uncertainty

- Socio-economic/Emissions
- Global climate response
- Regional climate response
- Natural variability
- Tipping points & the unknown

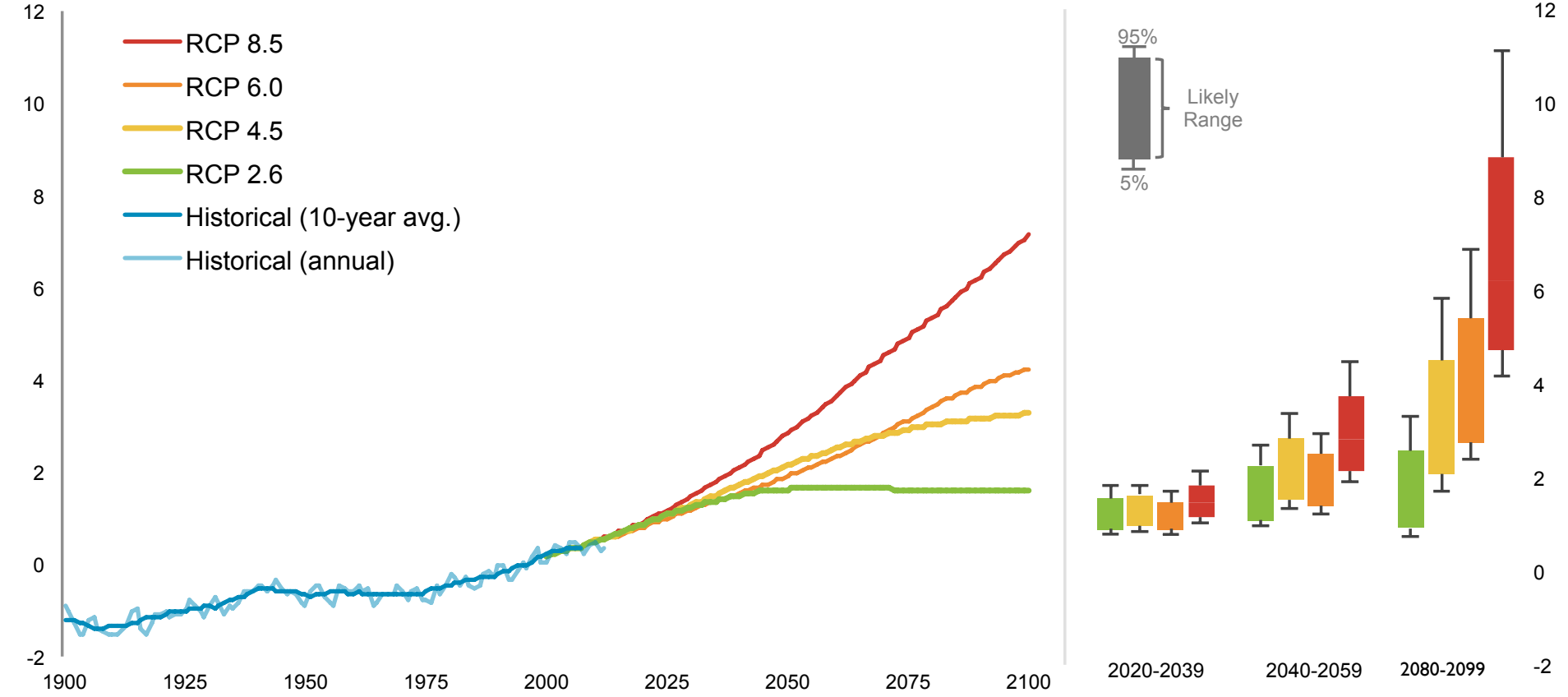


The global temperature response to greenhouse gas forcing is uncertain.

Sources of uncertainty

- Socio-economic/Emissions
- Global climate response
- Regional climate response
- Natural variability
- Tipping points & the unknown

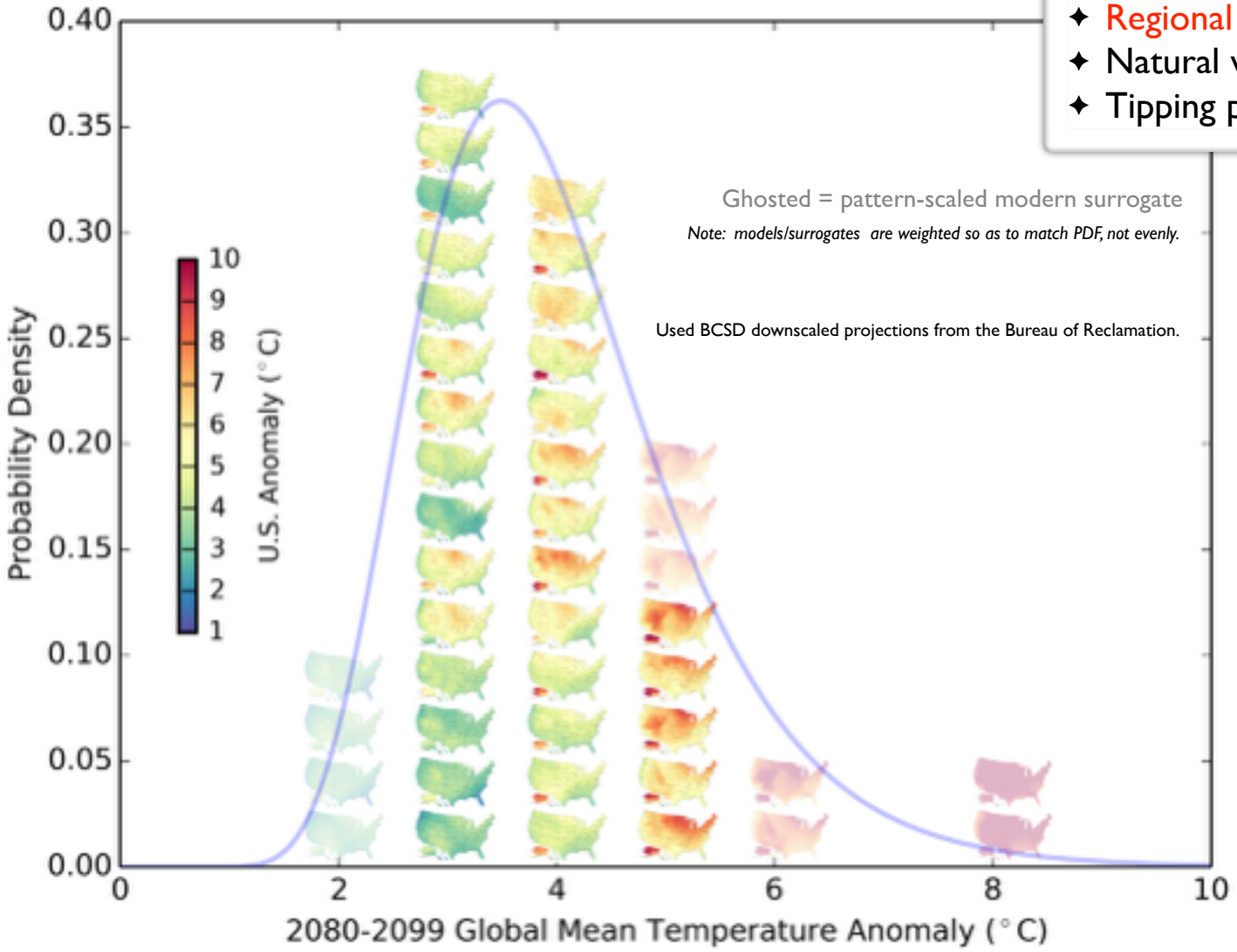
Temperature projections (°F) from the MAGICC simple climate model, courtesy Malte Meinshausen



As is the regional response that accompanies global warming…

Sources of uncertainty

- Socio-economic/Emissions
- Global climate response
- Regional climate response
- Natural variability
- Tipping points & the unknown

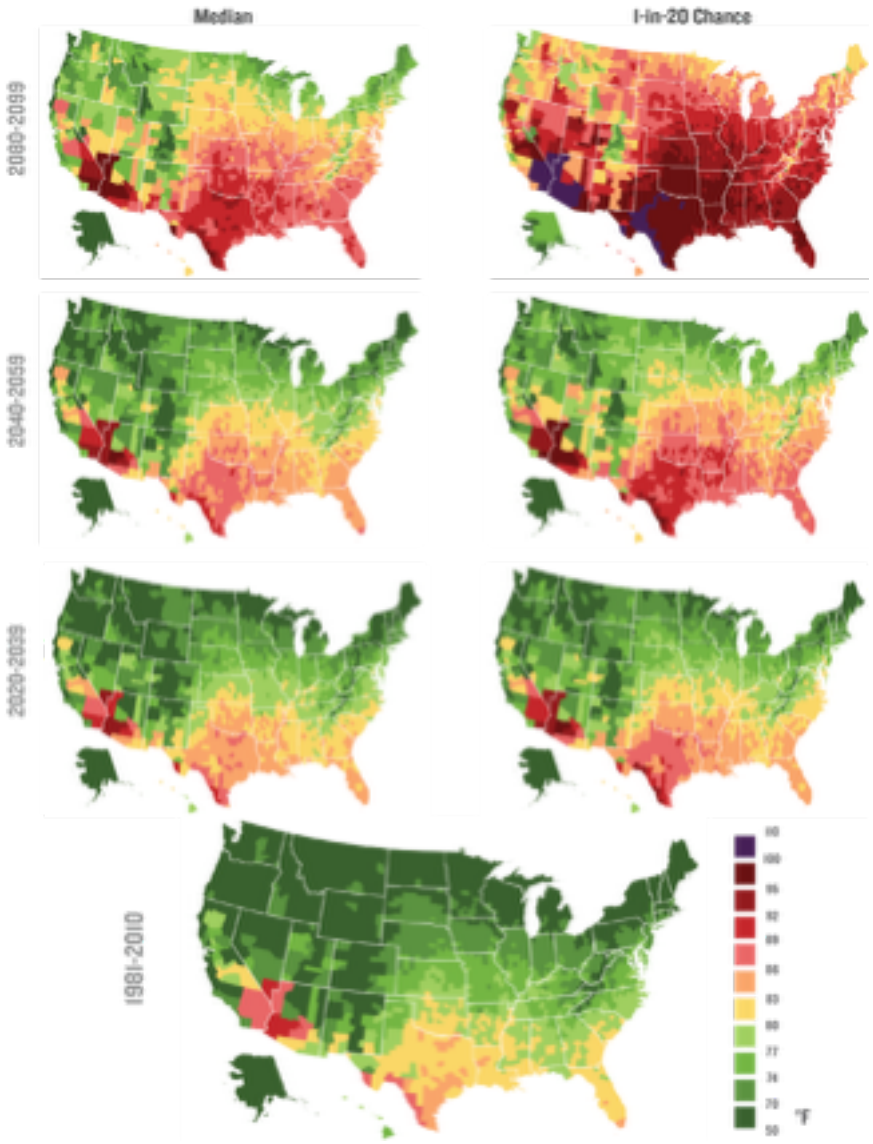


Probability distribution developed from simple climate model and downscaled global climate model projections with the surrogate/model mixed ensemble method of Rasmussen & Kopp (in prep.).

which gives rise to uncertain projections of temperature change…

Sources of uncertainty

- Socio-economic/Emissions
- Global climate response
- Regional climate response
- Natural variability
- Tipping points & the unknown



Median and 1-in-20 chance summer temperature projections (°F), RCP 8.5 (high emissions)

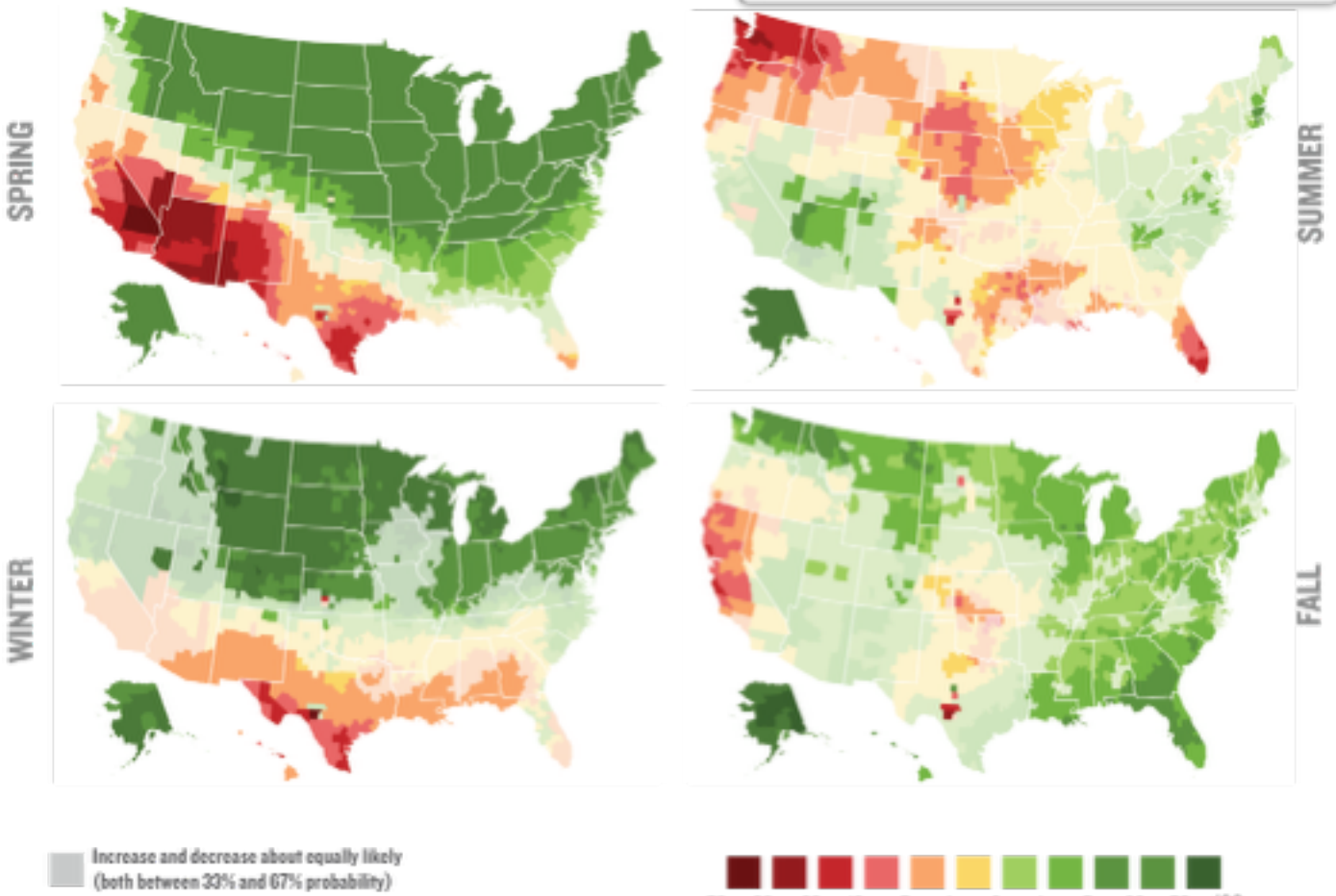
...and of precipitation change.

Sources of uncertainty

- Socio-economic/Emissions
- Global climate response
- Regional climate response
- Natural variability
- Tipping points & the unknown

Median projected % precipitation change, RCP 8.5 (high emissions) in 2080-2099.

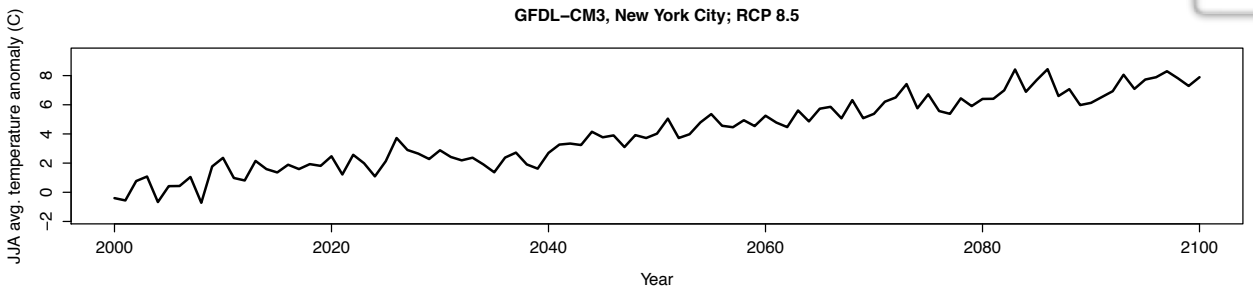
In the faded regions, an increase and an decrease are both about equally likely.

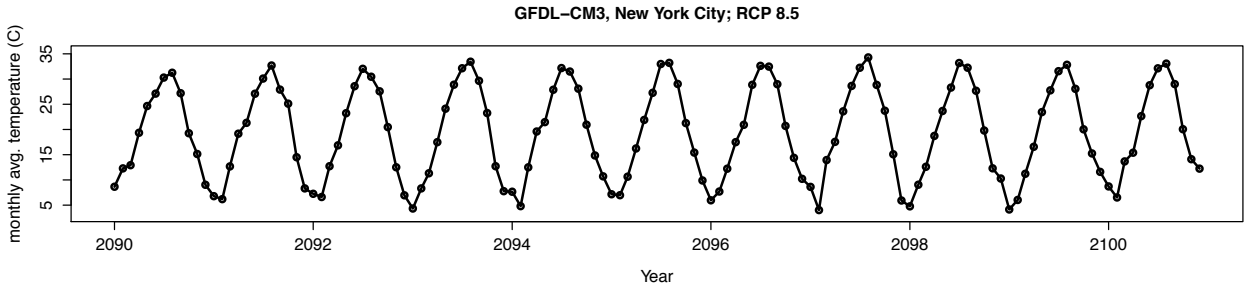


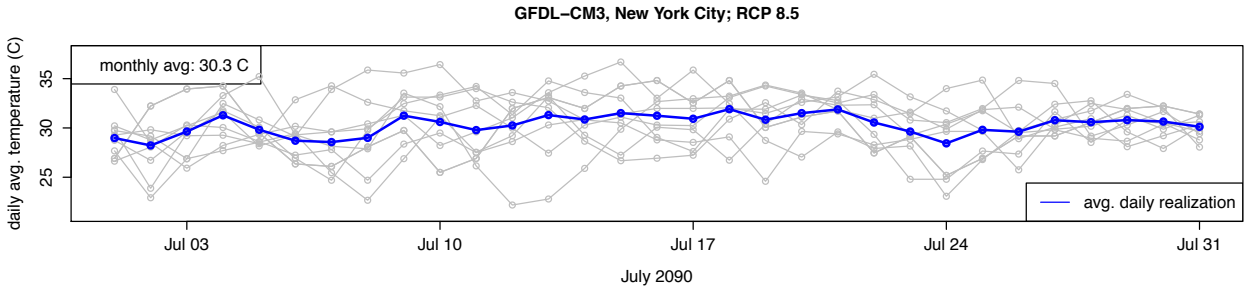
Natural variability occurs at time scales ranging from the daily to the decadal.

Sources of uncertainty

- Socio-economic/Emissions
- Global climate response
- Regional climate response
- Natural variability
- Tipping points & the unknown







Meta-analysis of Econometric Research

Distributed Meta-Analysis System

Researcher 1

Researcher 2

Researcher 3

American Climate Prospectus

dmas.berkeley.edu

(Rising & Hsiang, 2014)

Distributed Meta-Analysis System

Researcher 1

Researcher 2

Researcher 3

Researcher 4

Bayesian updating

Revised American Climate Prospectus

dmas.berkeley.edu

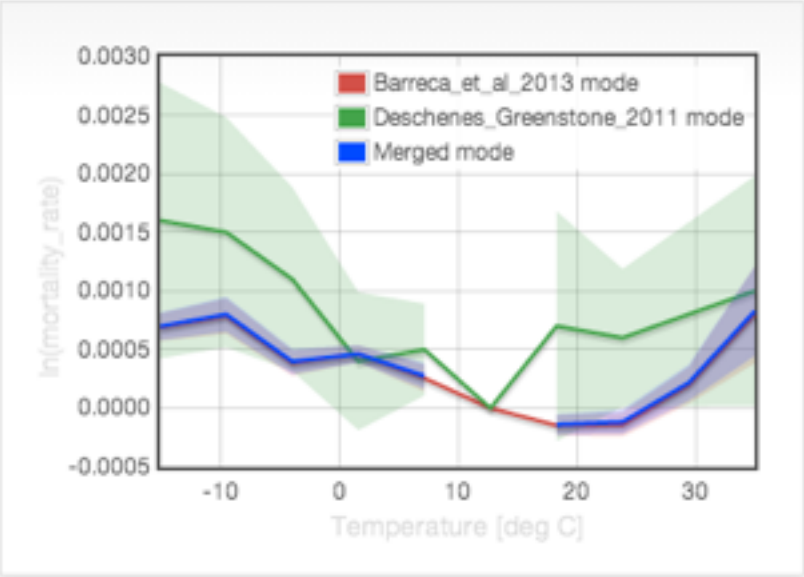
(Rising & Hsiang, 2014)

DMA System | Welcome | About | FAQ | Exchange | Contact | Library | Moderation | Profile | Logout

ACRA_mortality_temperature_AGE 〉 ACRA_mortality_temperature | in your library

ACRA_mortality_temperature

Morttality temperature response function



Export CSV | Export PNG | Export SVG BETA

No Distribution

Pooling | Hierarchical Normal | Hierarchical Thetas

Hierarchical Refresh

Show Unmerged

	Enabled	Weight BETA	
Deschenes_Greenstone_2011	☑		1
Barreca_et_al_2013	☑		1

☑ All Reset

[Submit New Model | Submit from Library | Submit from Scaffold BETA | Download]

Collection managed by Amir Jina.

Categories: ACRA Health

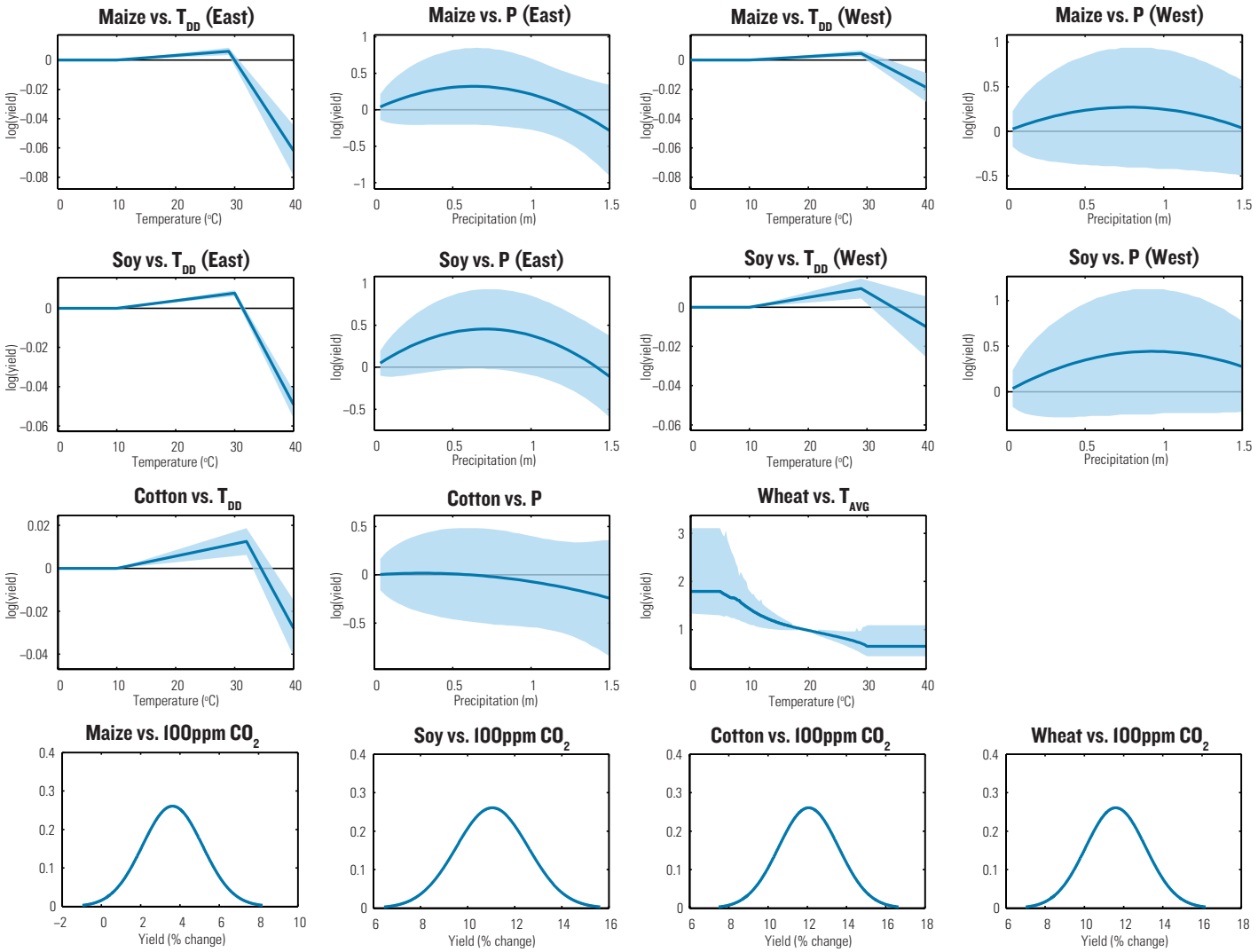
Our criteria for inclusion

1. **Nationally representative**
2. **Analyze recent time-periods in US history**
3. **Robust to unobserved factors that differ across spatial units (jurisdictions, counties, or states)**
4. **Identify responses to high-frequency climatic variables (days or weeks)**
5. **Identify responses to the full distribution of temperature and rainfall measures**
6. **Account for temporal displacement**
7. **Account for seasonal patterns and trends in the outcomes**
8. **Ecologically valid (not laboratory studies)**

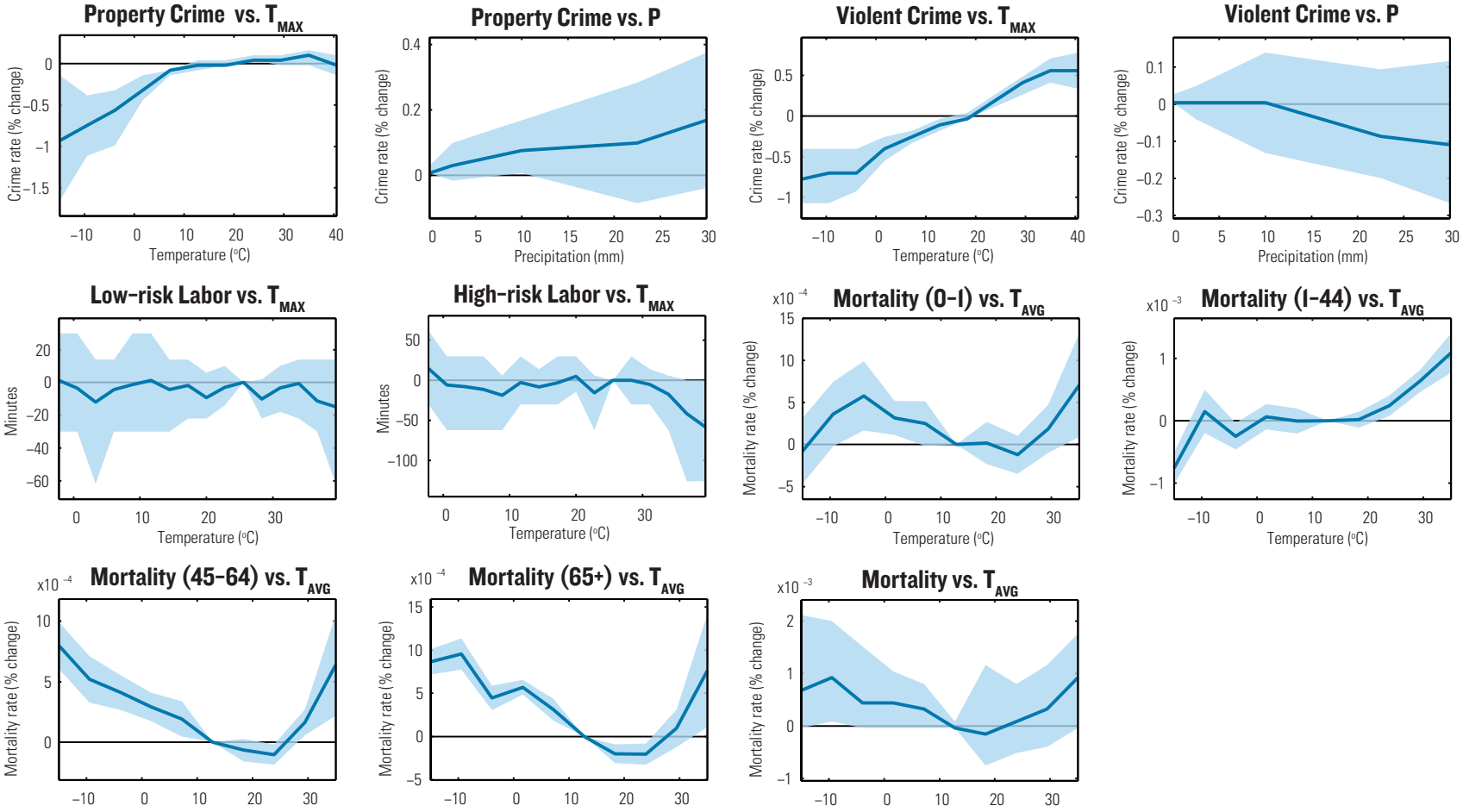
Sectors where we apply this approach

- **Agriculture (maize, soy, cotton, wheat)**
  - Schlenker and Roberts (PNAS, 2009) - Cotton, Soy, Maize
  - Hsiang et al. (2013) - Wheat
  - McGrath and Lobell (ERL, 2013) - Carbon fertilization
  - Fisher et al. (AER, 2012) - Crop storage
- **Labor productivity (extensive margin only)**
  - Graff Zivin and Neidell (JLE, 2014)
- **Heat- and cold-related mortality (age resolved)**
  - Deschenes and Greenstone (AEJ, 2011)
  - Barreca et al. (2013)
- **Crime (violent and property)**
  - Jacob et al. (JHR, 2007)
  - Ranson (JEEM, 2014)
- **Electricity demand (residential)**
  - Auffhammer and Aroonruengsawat (CC, 2011)

Impact functions – agriculture

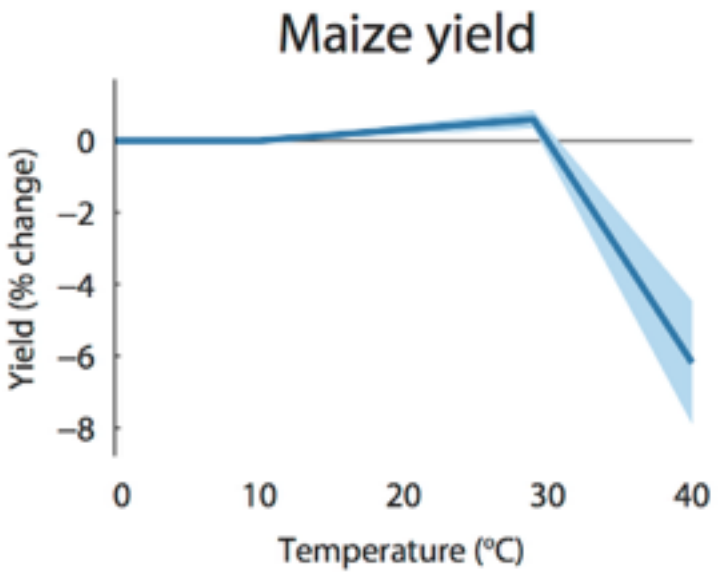


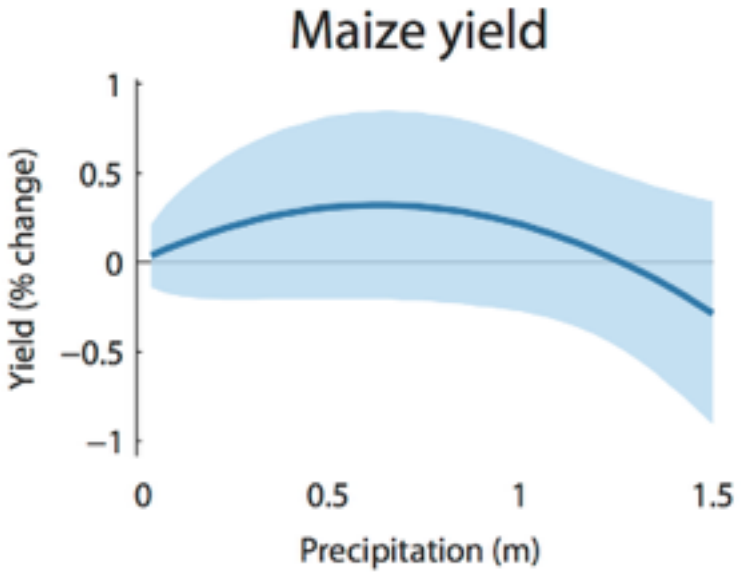
Impact functions – other sectors

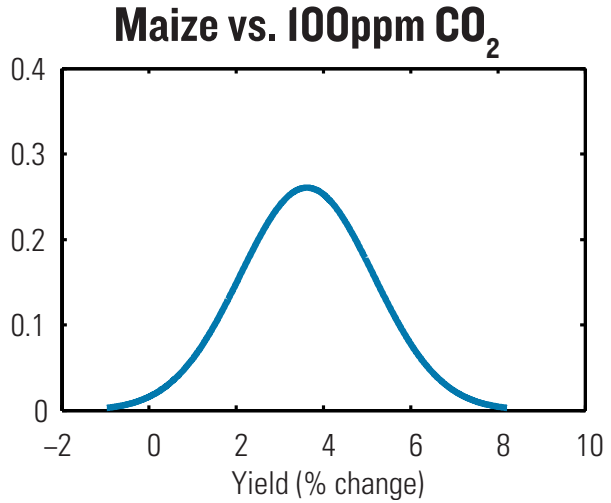


Direct impacts

Agriculture example: Dose-response

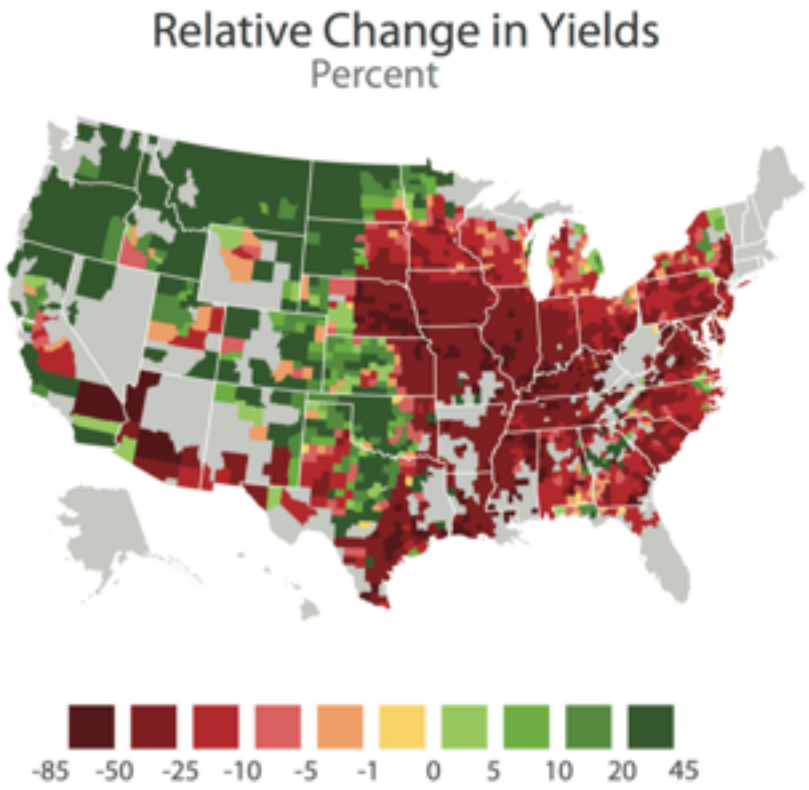


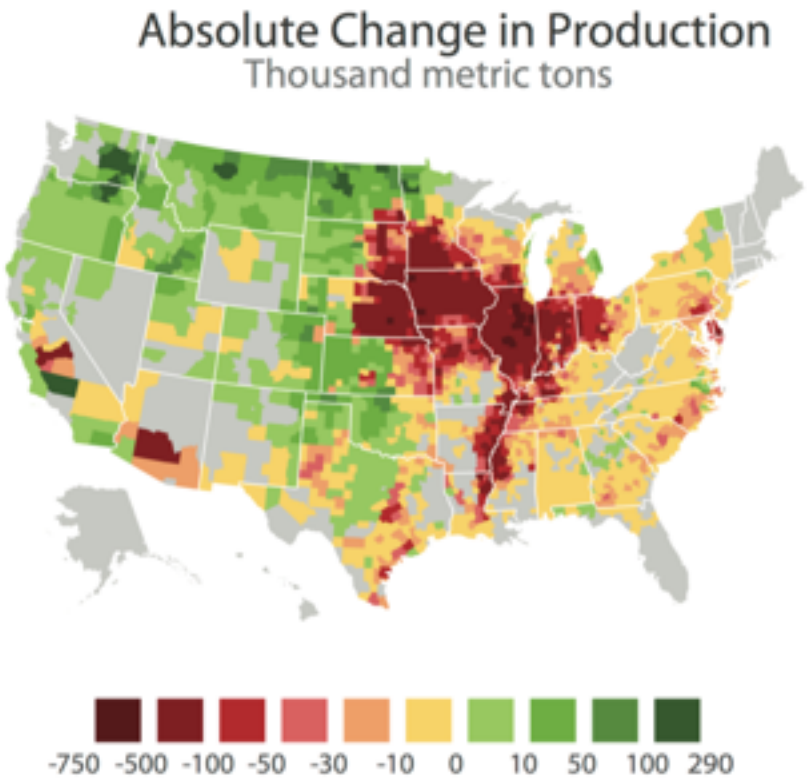




Agriculture example: Median in RCP 8.5

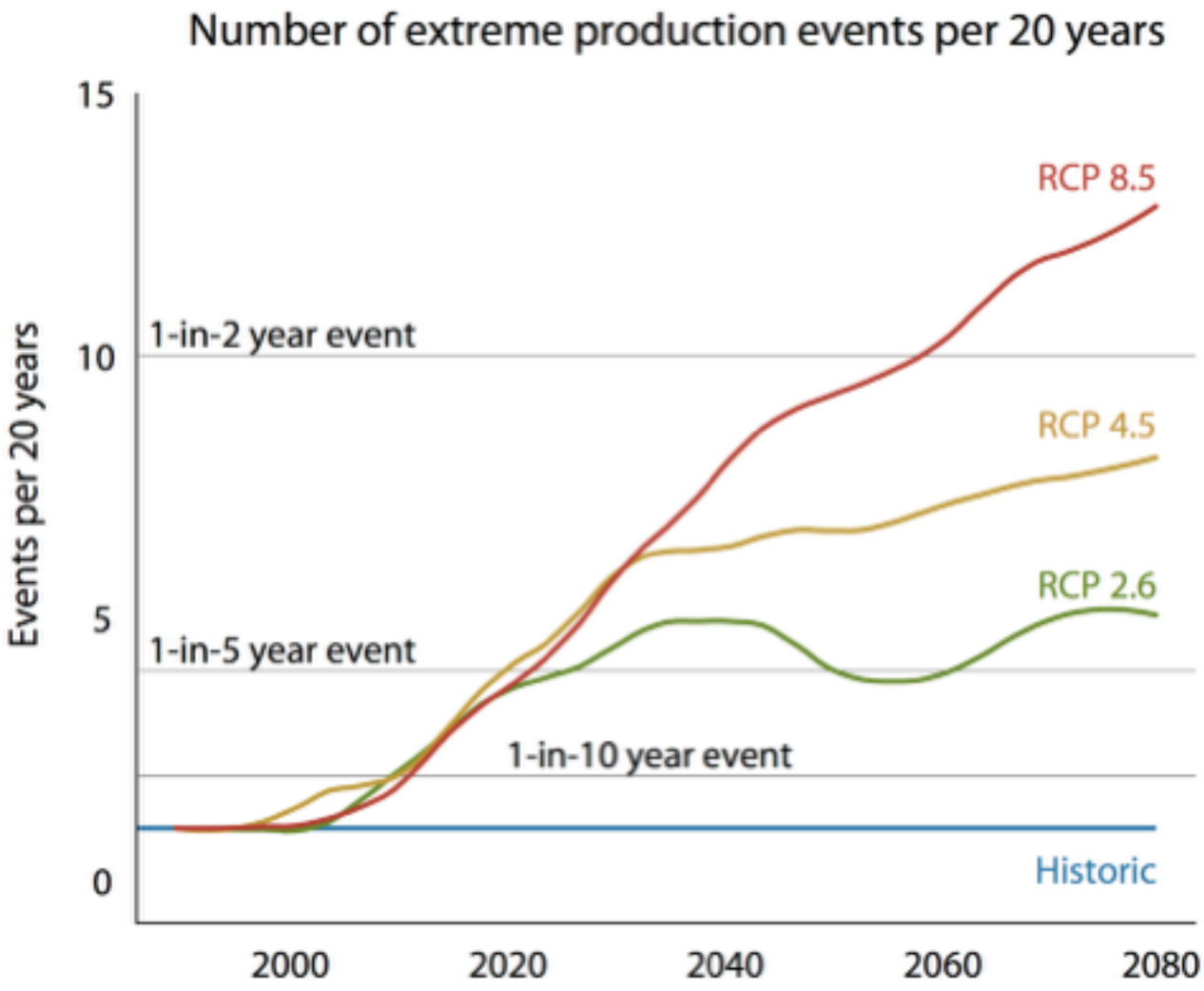
2080-2099



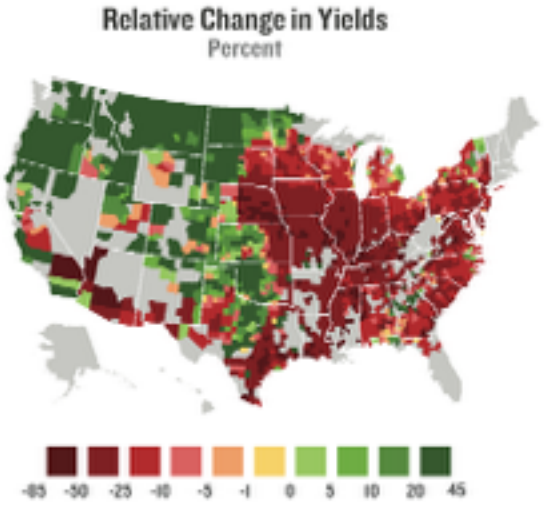


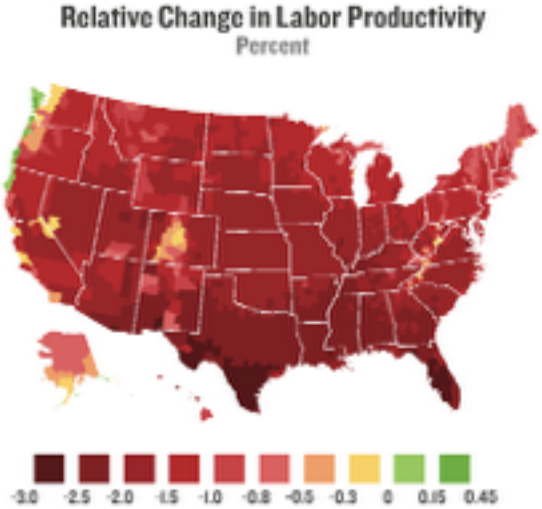
(assuming current economy)

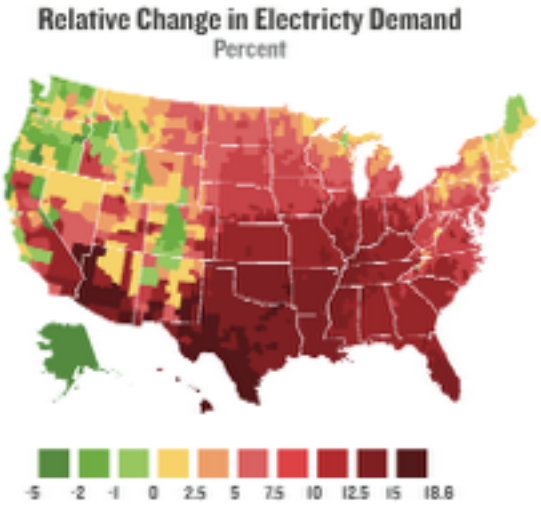
Agriculture example: Expected number of events

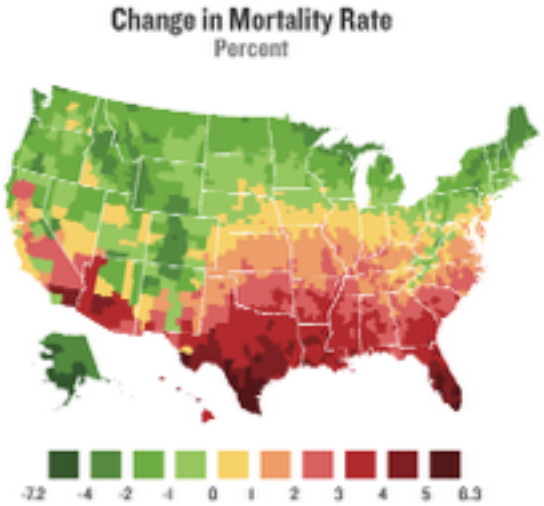


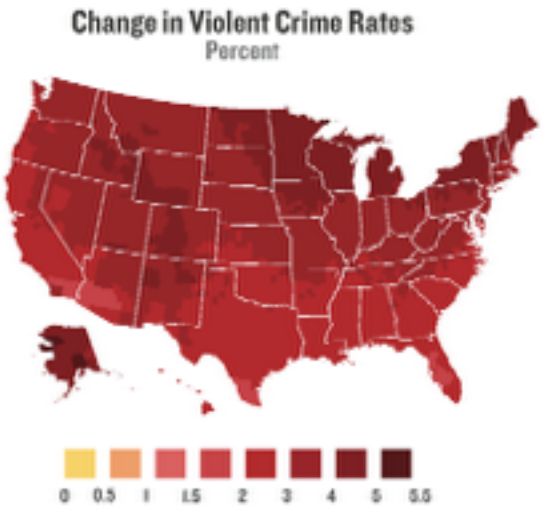
Distribution of impacts: RCP 8.5, median









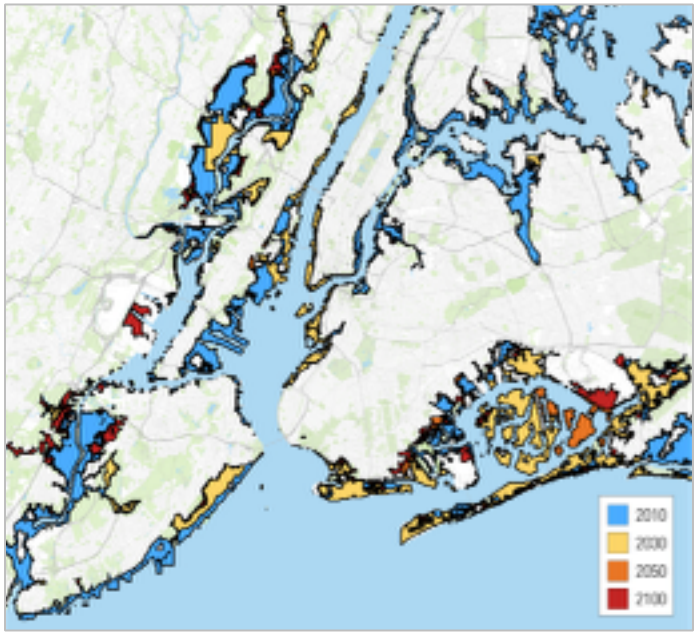


Coastal impacts

Tropical Cyclone Activity

Sea-Level Rise

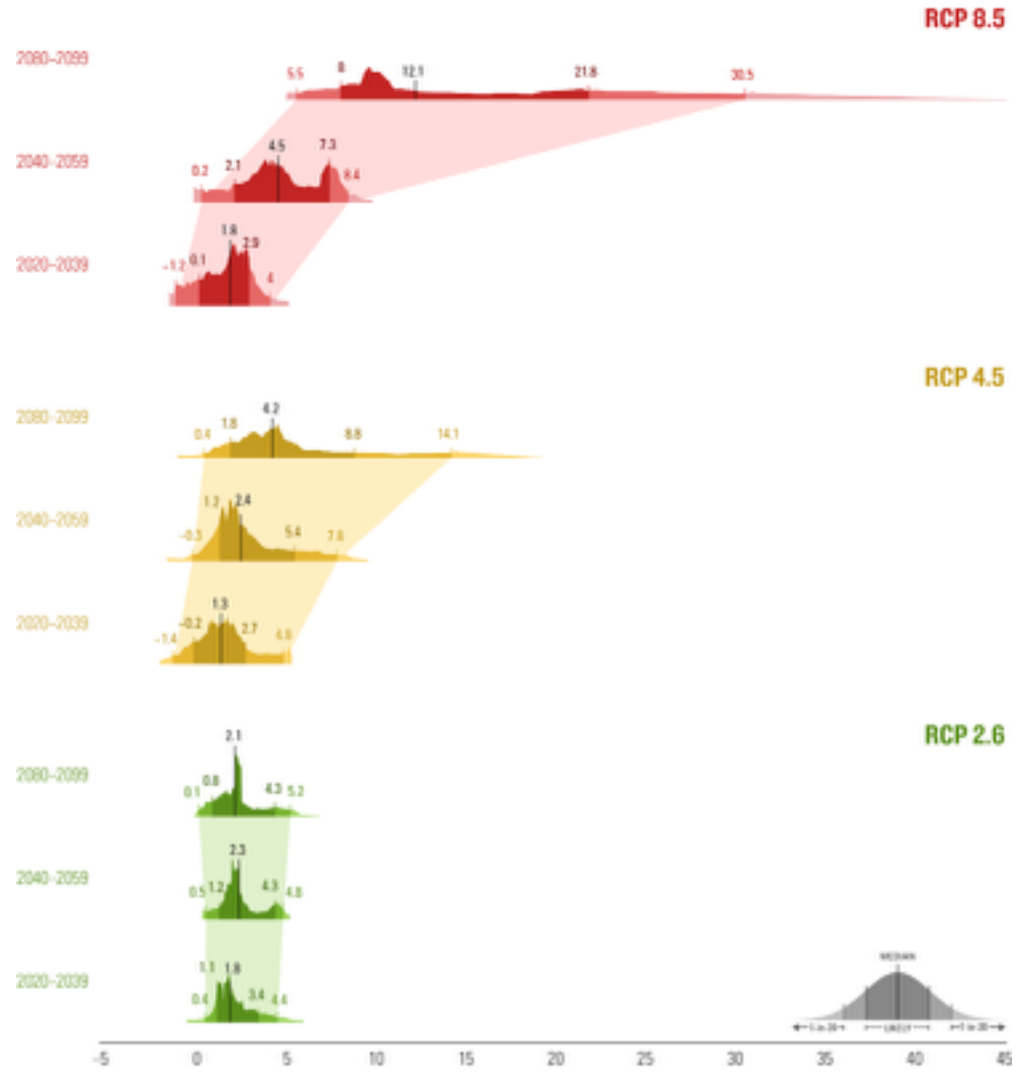
RMS North Atlantic Hurricane Model



Energy demand

% increase in annual residential + commercial energy expenditures

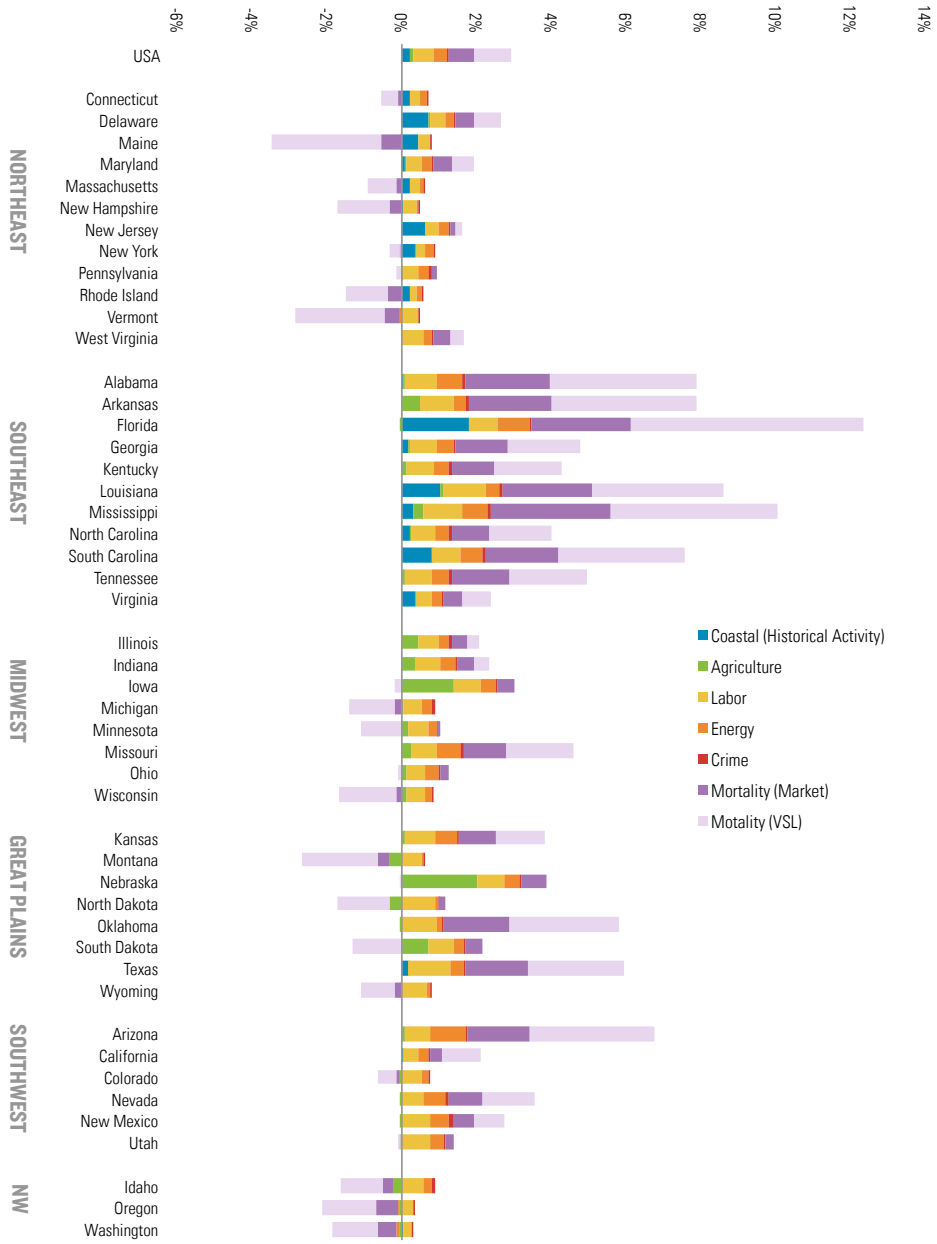
Impact function calibrated against RHG–National Energy Modeling System



National aggregate impacts

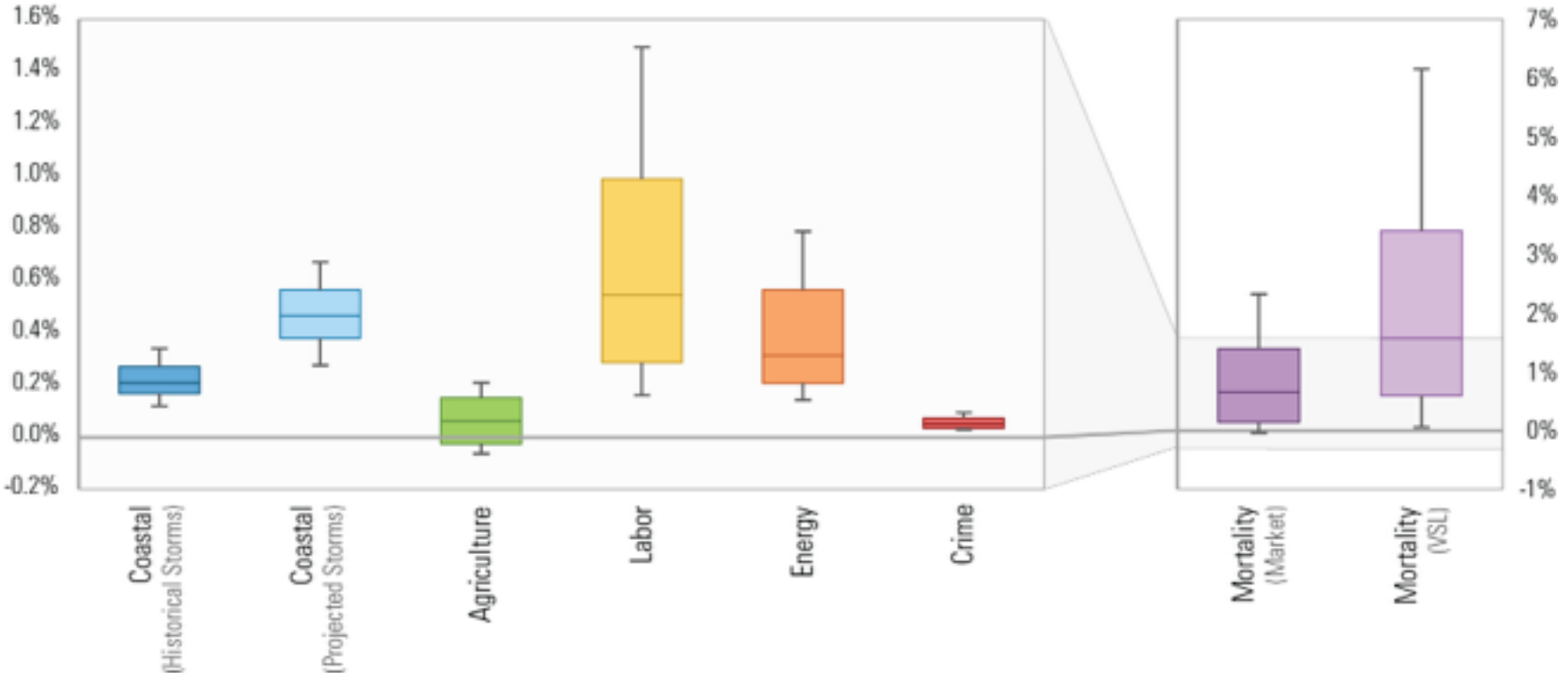
Total cost and sectoral breakdown differ by region

RCP 8.5, median case, 2080-2099

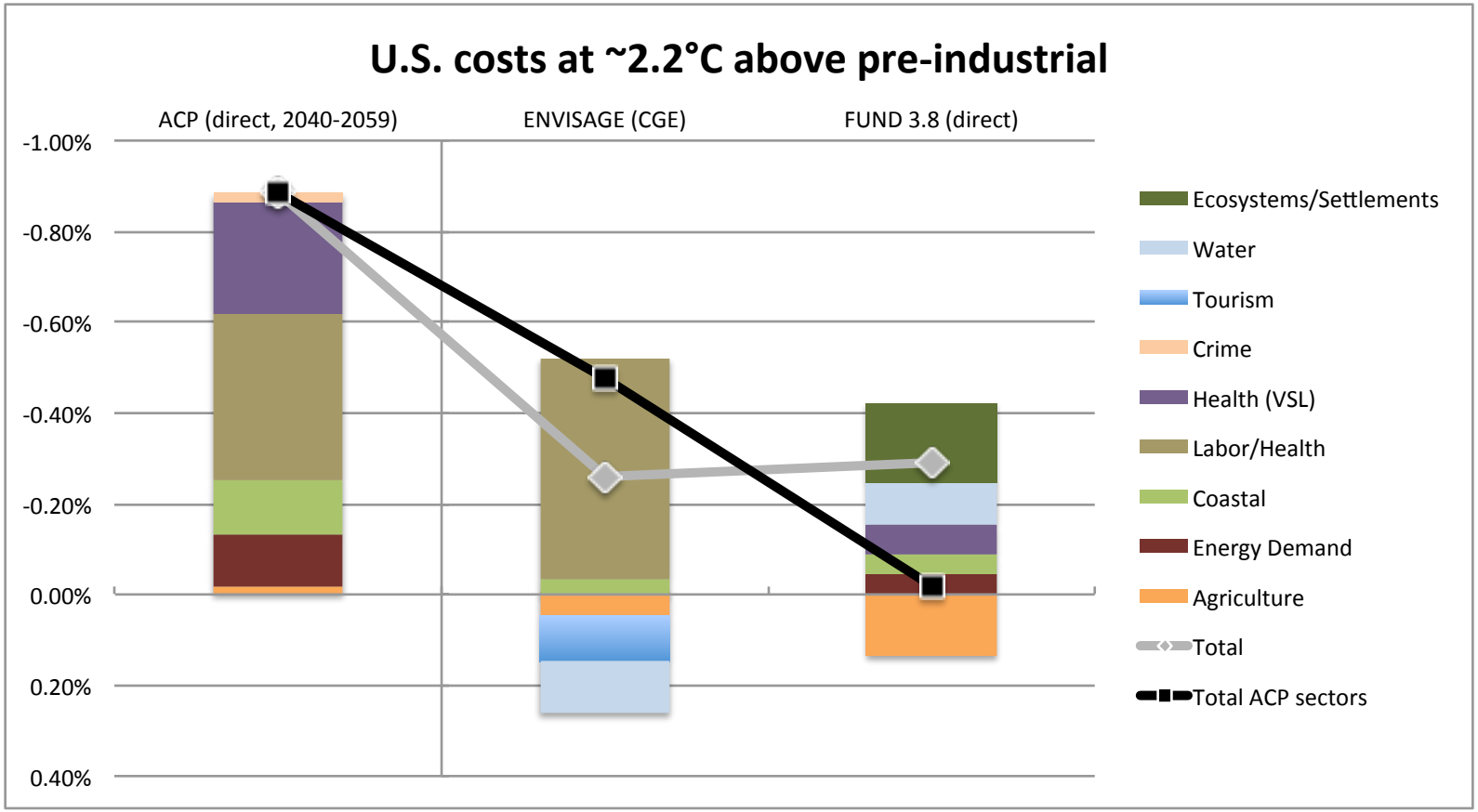


Direct costs and benefits

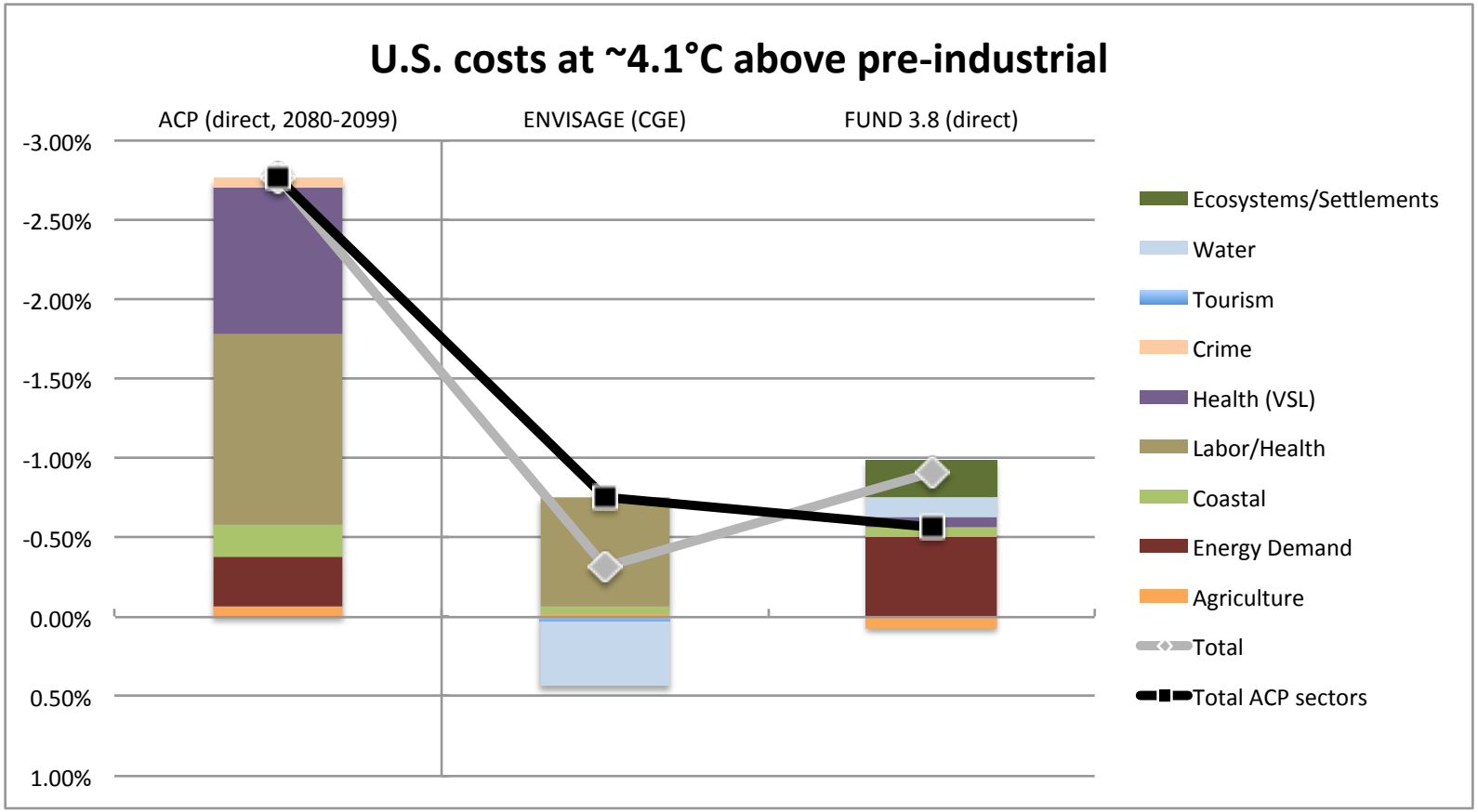
% of GDP, RCP 8.5, 2080-2099



Comparison to benefit-cost integrated assessment models



Comparison to benefit-cost integrated assessment models

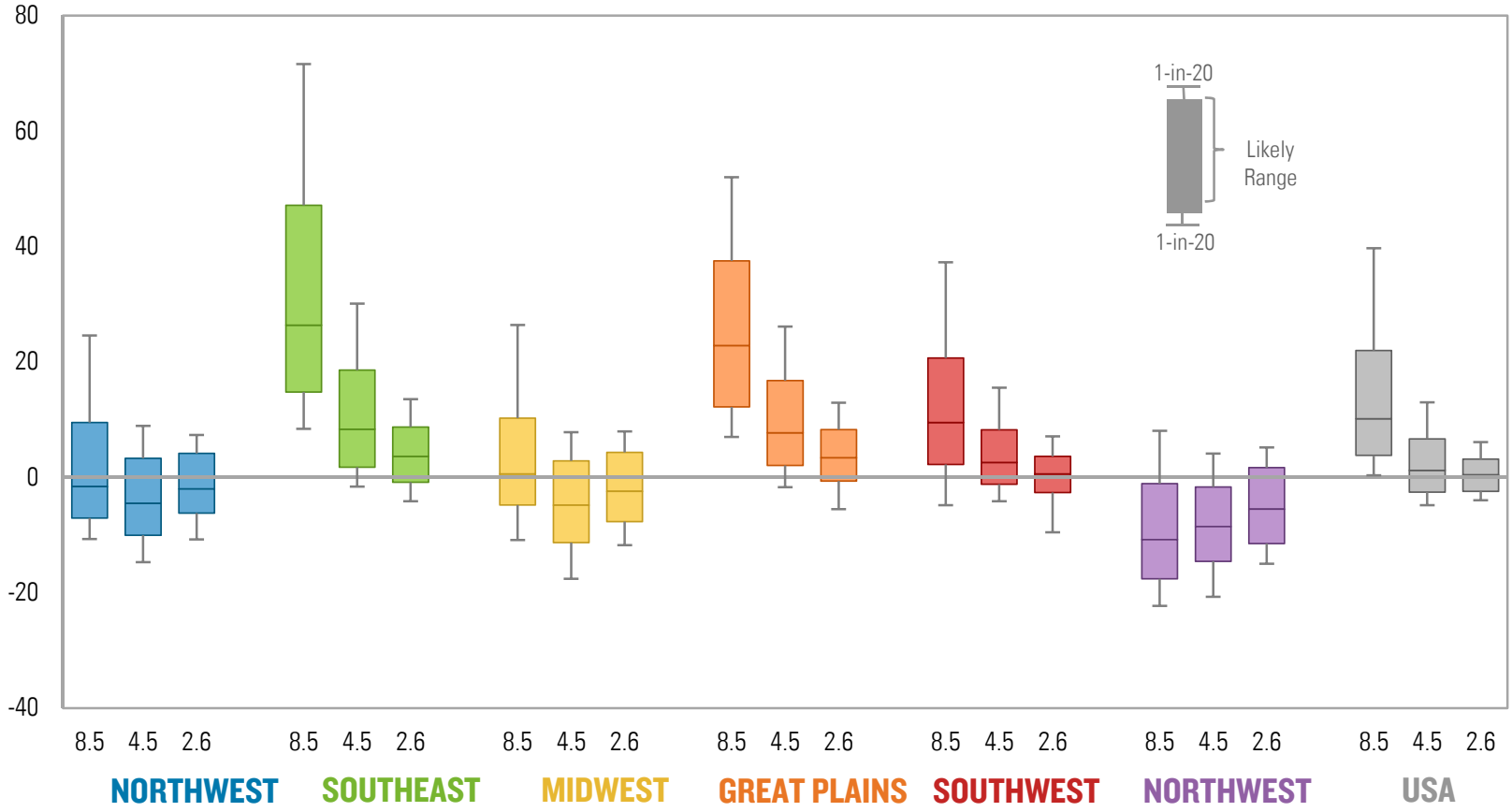


Considering mitigation and adaptation

Large mitigation benefit for mortality

Figure 21.5 Change in mortality rates 2080-2099

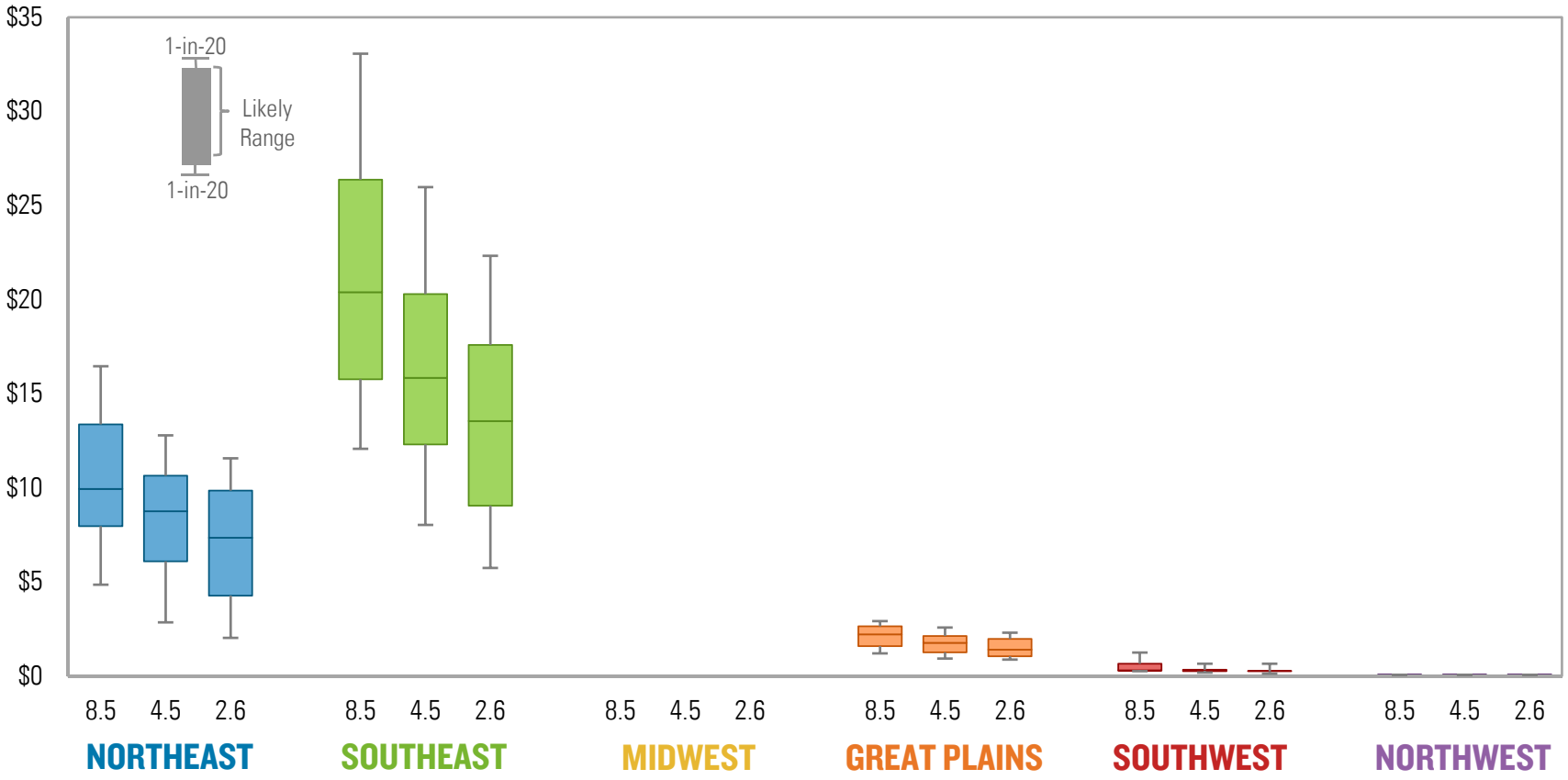
Deaths per 100,000, by NCA region and RCP



Smaller mitigation benefit for coastal impacts in 21st century

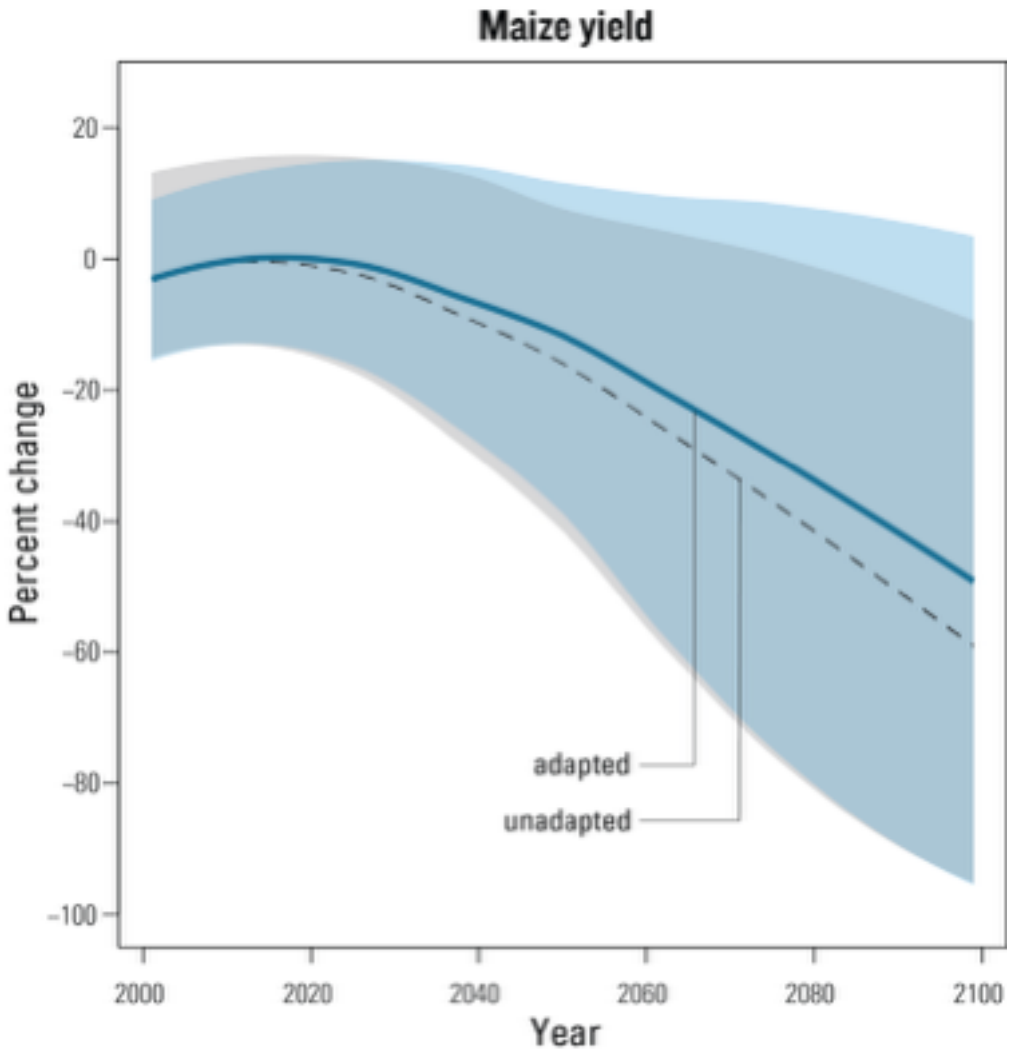
Figure 21.6: Change in average annual hurricane and inundation damage, 2080-2099

Billion 2011 USD

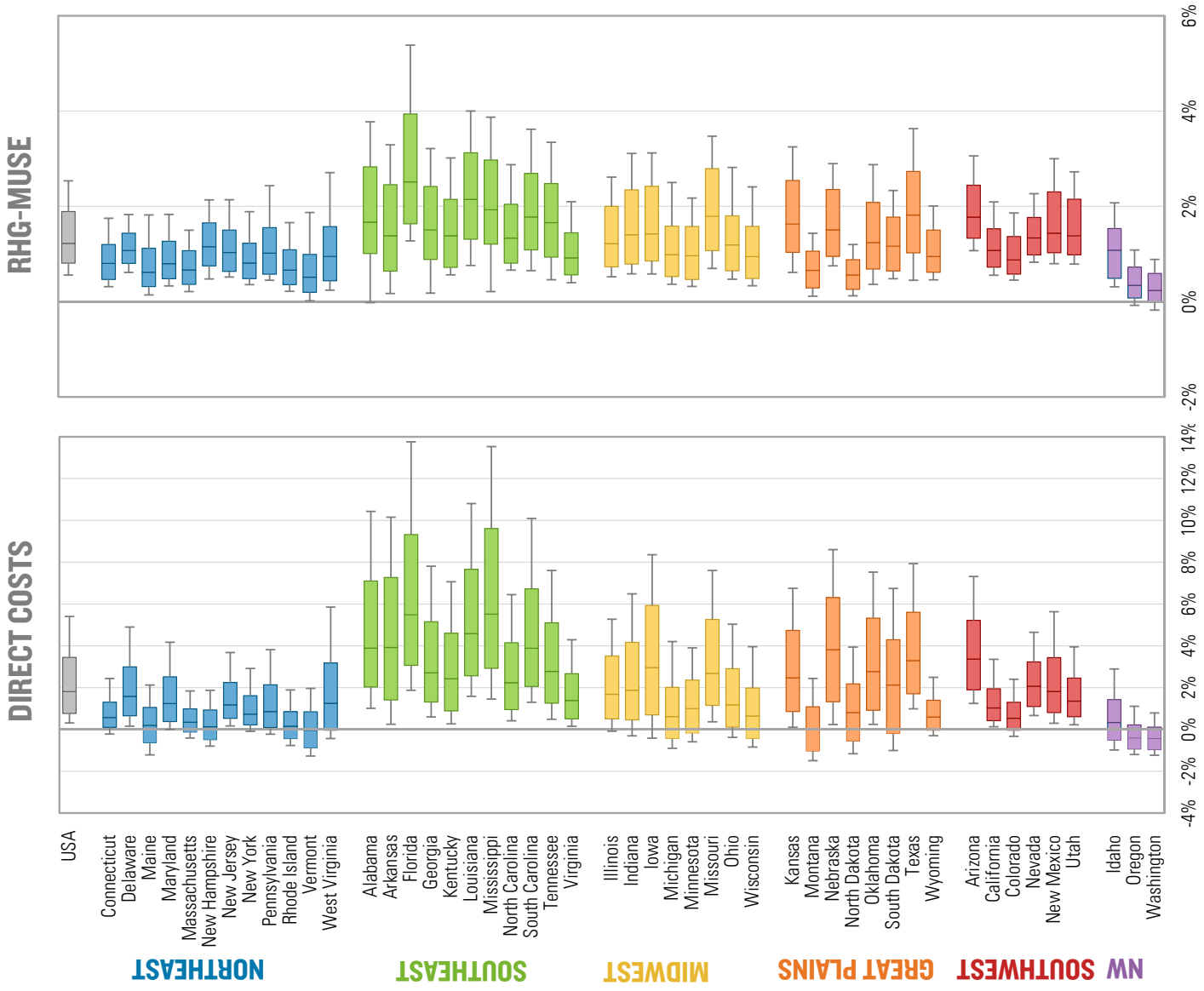


Thought experiment: benefits of adaptation

What if T/P-yield relationship in the East evolves toward that in the West?

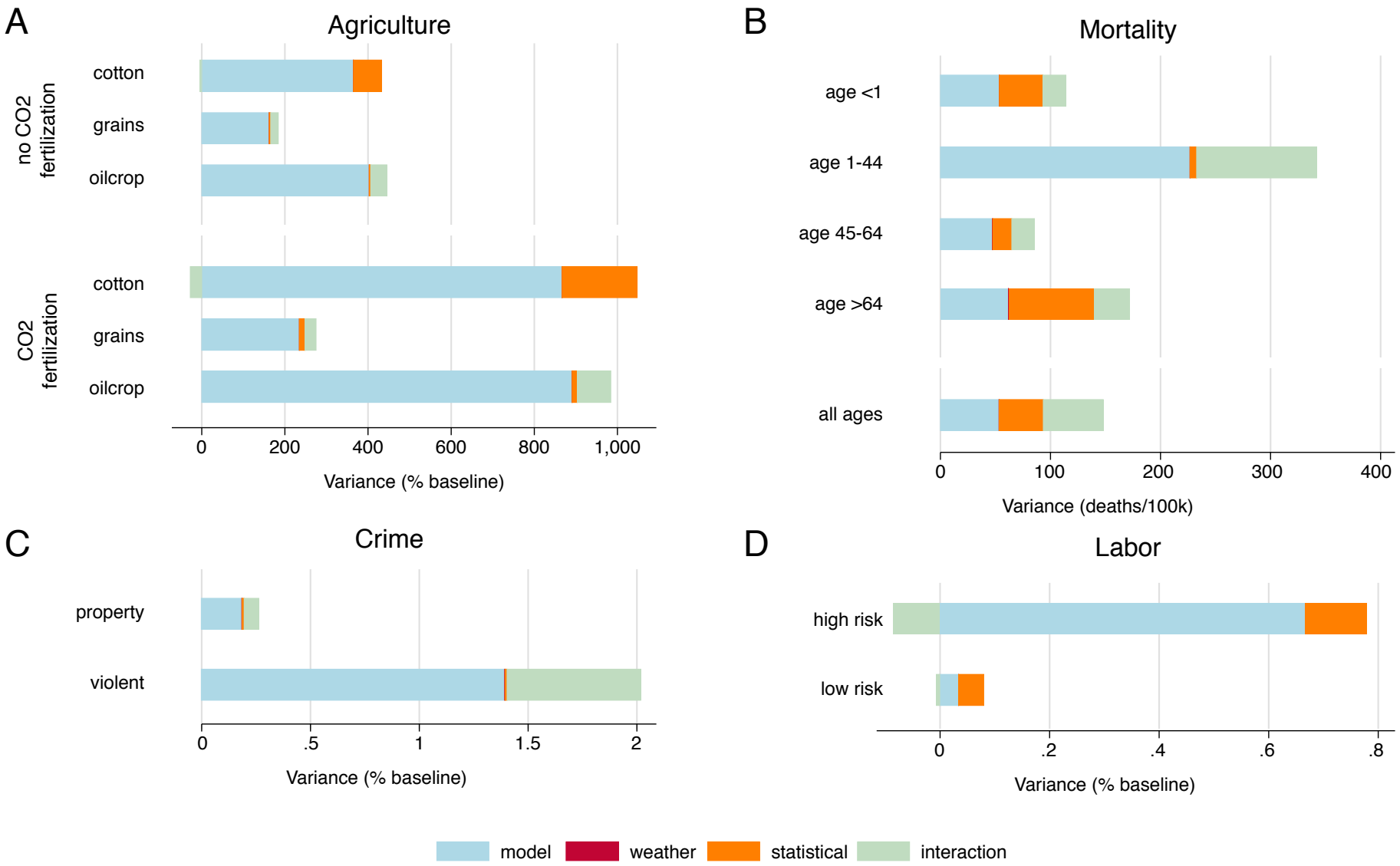


Market adaptation via general equilibrium effects



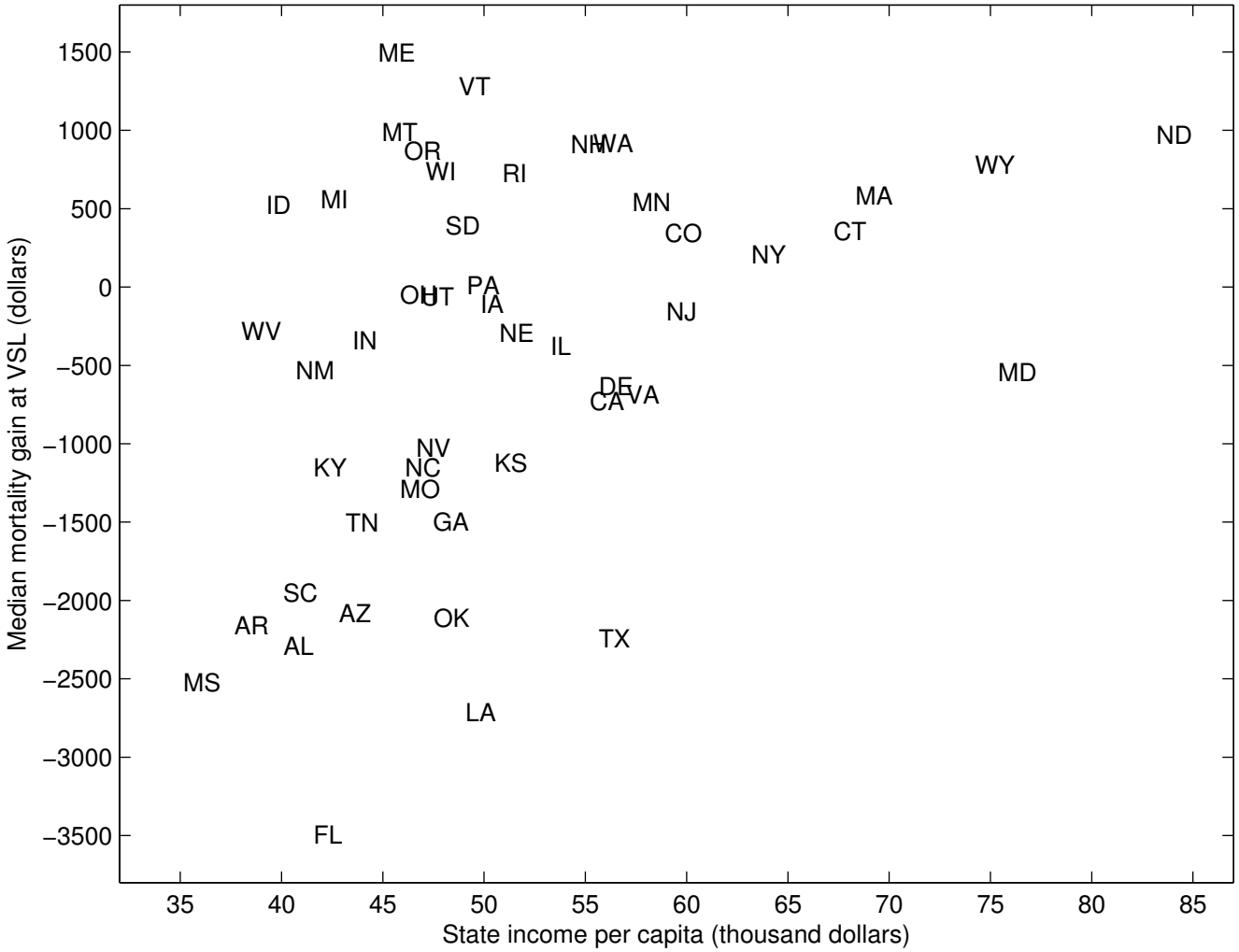
Uncertainty and inequality

Sources of uncertainty



Death is the most unequal impact

RCP 8.5 median, 2080-2099, valued at VSL



Average of 10 wealthiest states:
$75 gain/capita
(-1.1 deaths per 100,000)

Average of 10 poorest states:
$1900 loss/capita
(27 deaths per 100,000)

Valuing risk and inequality

certainty-equivalent consumption c_i* given by $$c_i^* = \left(\sum_j p_j c_{i,j}^{1-\eta} \right)^{1/(1-\eta)}.$$

inequality-neutral equivalent % loss f given by $$\sum_i N_i v(c_i^*) = \sum_i N_i v(c_i^0(1-f))$$

Table I5.1: Combined inequality-risk premiums for agricultural impacts, 2080-2099

RCP 8.5, Premium as percentage of expected losses for maize, wheat, cotton, and soy output

			RRA					
			<-- Low risk aversion					High risk aversion -->
			0	2	4	6	8	10
CIA	High inequality tolerance -->	0	0%	0%	1%	1%	2%	2%
		2	13%	13%	14%	14%	15%	15%
		4	21%	21%	22%	22%	23%	23%
		6	26%	27%	27%	28%	28%	29%
	<-- Low tolerance for inequality	8	32%	33%	33%	34%	34%	35%
		10	40%	41%	41%	42%	42%	42%

Table I5.2: Combined inequality-risk premiums for mortality impacts, 2080-2099

RCP 8.5, Premium as percentage of expected losses, applying value of a statistical life

			RRA					
			<-- Low risk aversion					High risk aversion -->
			0	2	4	6	8	10
CIA	High inequality tolerance -->	0	0%	3%	6%	10%	14%	18%
		2	28%	32%	36%	41%	46%	52%
		4	58%	64%	70%	76%	83%	91%
		6	90%	97%	104%	113%	121%	131%
	<-- Low tolerance for inequality	8	121%	129%	138%	148%	159%	170%
		10	150%	159%	170%	181%	193%	206%

Take-aways

- By 2020-2039, median projected average summer temperatures in DC match and the expected number of dangerously humid summer days exceed those of Mississippi today.
- By 2080-2099 under RCP 8.5, the NE, SE, and MW south of the Mason-Dixon lines have median projected summer T hotter than Louisiana today, and even north of M-D line have more expected dangerously humid days than Louisiana.
- Mortality & Labor are largest costs in the US; Energy & Coastal impacts sizable.
- Median projected increase in deaths under RCP 8.5, 2080-2099, is about 10 per 100,000, similar to current traffic death rate.
- Cost of Crime ≈ cost to Agriculture (small in $).

Take-aways

- Largest sources of uncertainty continues to be driven by physical climate.
- Nonlinear response functions → South and Midwest lose most in the sectors we quantified.
- Inequality impact on welfare is large (likely exceeds risk effect), with mortality the largest source of inequality (RCP 8.5 2080-2099 median, mortality in wealthiest 10 states falls ~1/100,000 and in poorest 10 states rises ~30/100,000).
- Mitigation benefits largest and most certain for labor, mortality, energy, and crime. Agriculture benefits less clear because of carbon fertilization; coastal because of slow response of the system.

Potentially generalizable innovations in SEAGLAS

- DMAS.berkeley.edu – broadly applicable to statistical analyses, lowers the cost of cross-disciplinary communication through automation.
- Framework for probabilizing GCM projections
- Approach to micro-founding damage functions
- Coupling of downscaled GCMs and impact functions in a coherent probabilistic framework to quantify risk and inequality

Prepared for the Risky Business Project

American Climate Prospectus

Economic Risks in the United States

Trevor Houser
Rhodium Group

Robert Kopp
Rutgers University

Solomon Hsiang
UC Berkeley

Roger Muir-Wood
RMS

Kate Larsen
Rhodium Group

DJ Rasmussen
Rhodium Group

Amir Jina
Columbia University

Paul Wilson
RMS

Michael Delgado
Rhodium Group

Michael Mastrandrea
Stanford University

James Rising
Columbia University

Shashank Mohan
Rhodium Group

Climate Change Impacts/Integrated Assessment | Snowmass, CO | July 22, 2014

www.climateprospectus.org

Extra slides

Challenges

1. Global temperatures do not describe local conditions
2. Individual GCMs represent group's 'best estimates,' not probability distributions, and are not at county-level resolution
3. Most IAMs assume a small number of representative agents, but impacts occur at the person-by-hour level
4. No framework exists for integrating empirical results, no database exists of trusted empirical findings, and no system exists for updating the database of findings
5. Prices will adjust and populations will adapt
6. Finish in 12 months

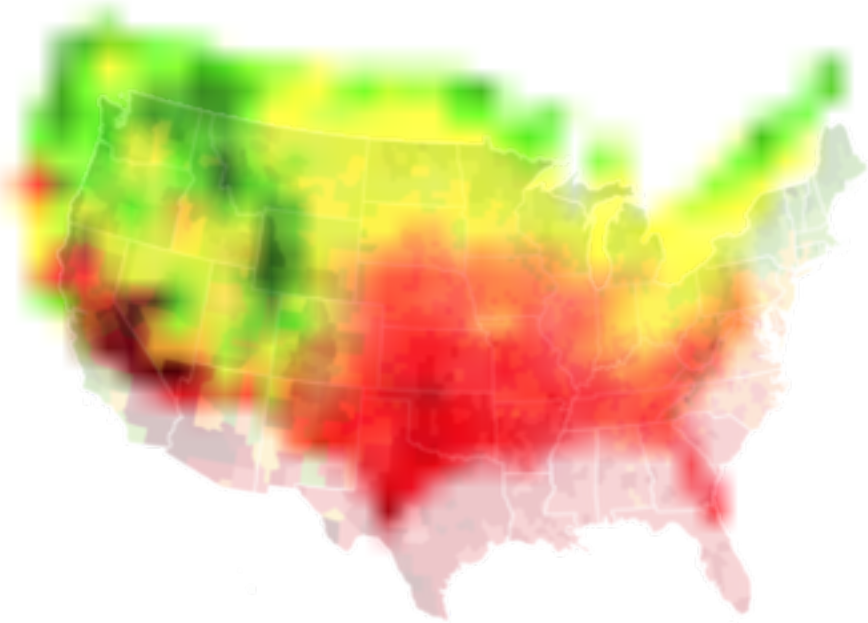
To do that, we don't just need good "best" estimates. We also need good "1%" estimates.

"If there's a 1% chance [of extreme climate change impacts], we have to treat it as a certainty in terms of our response."

(Actually, he was talking about Pakistani assistance for an al-Qaeda nuclear weapon.)

And we need spatial resolution.

Because, as Tip O'Neill said of politics, all climate change is local – no one lives at the global mean.



(We use Bureau of Reclamation Bias-Corrected, Spatially-Disaggregated (BCSD) downscaled projections)

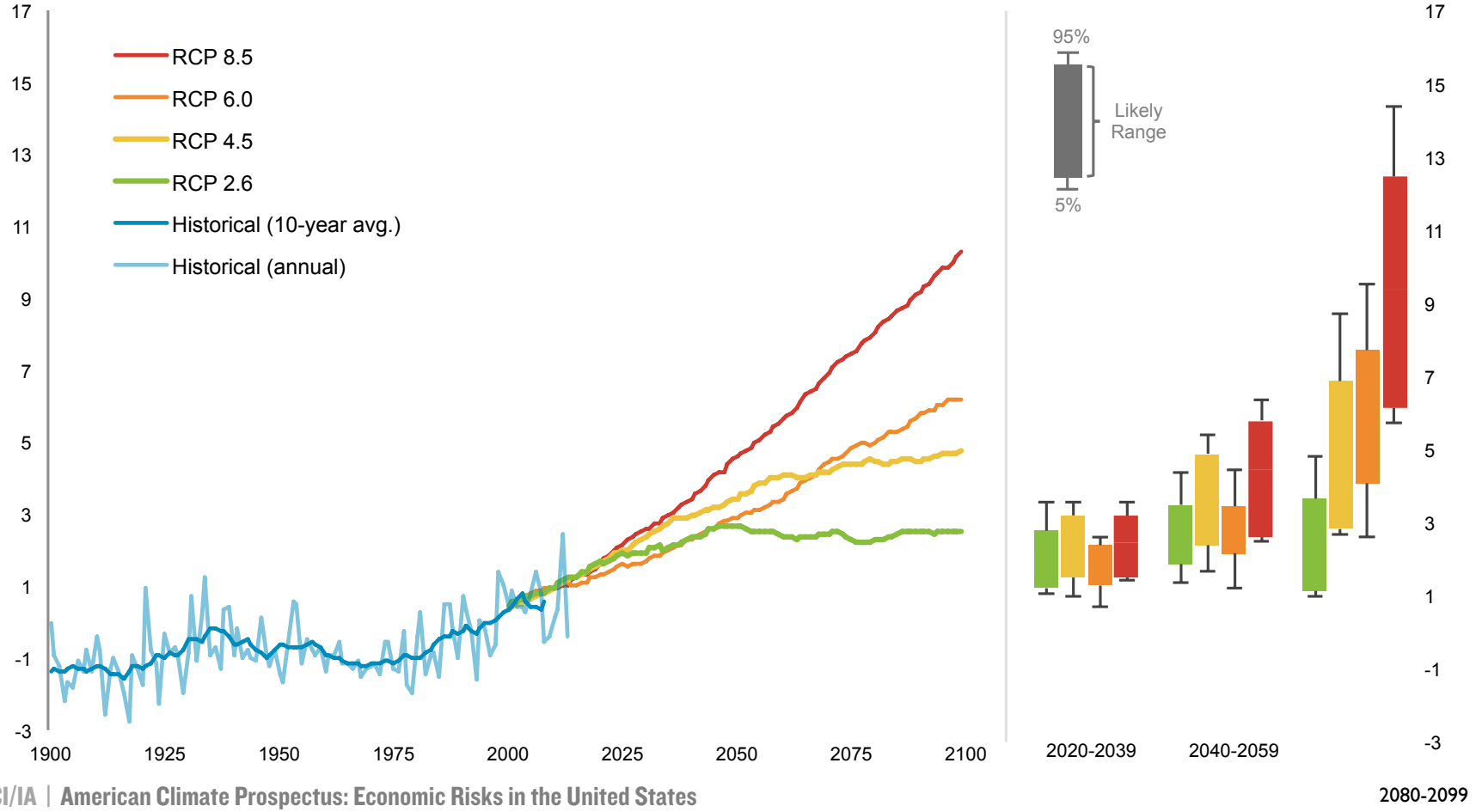
And we can't just think about changes in mean climate – we have to think about how changes in the mean interact with natural variability (such as the weather).

which gives rise to uncertain projections of temperature change…

Sources of uncertainty

- Socio-economic/Emissions
- Global climate response
- Regional climate response
- Natural variability
- Tipping points & the unknown

Contiguous US average annual temperature (°F), median and ranges



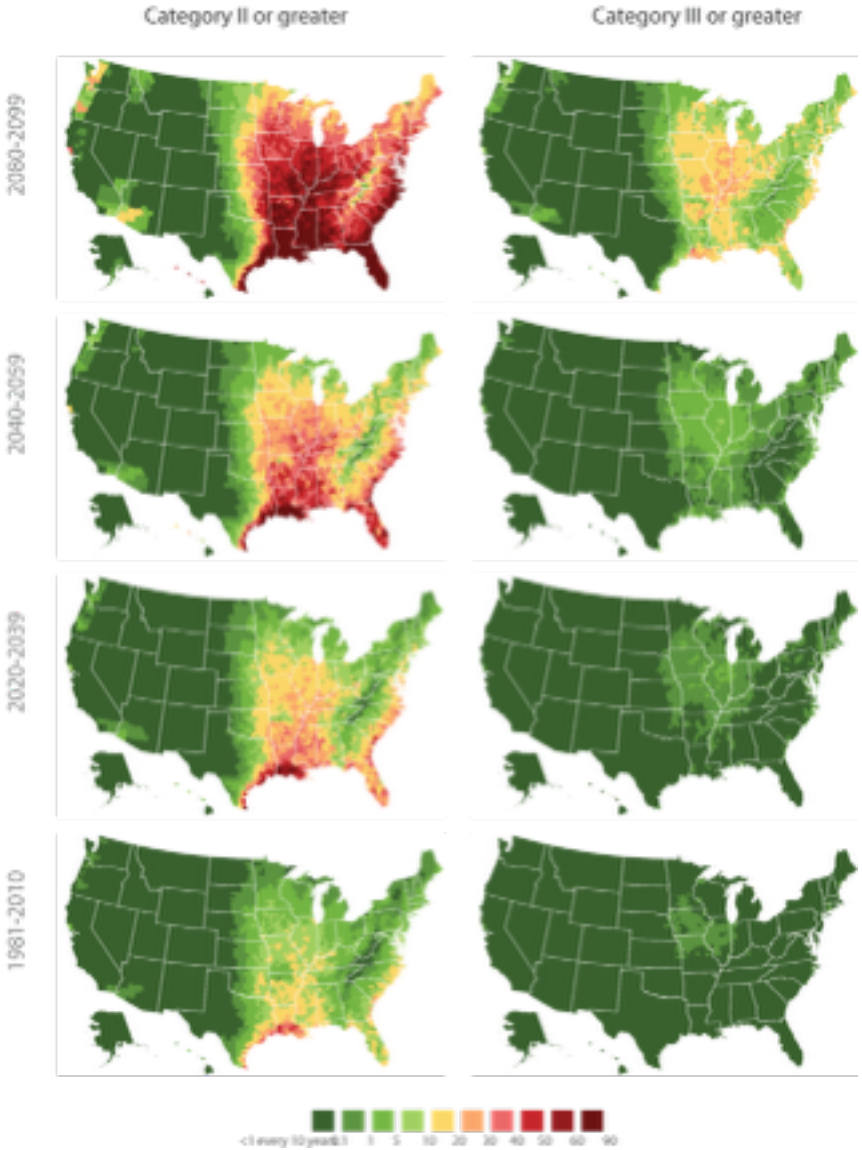
American Climate Prospectus Humid Heat Stroke Index

"It's not just the heat, it's the humidity."

ACP HHSI	Peak Wet Bulb Temperature	Description (hottest part of day)
I	74°F-80°F	Uncomfortable. Typical of much of summer in the Southeast.
II	80°F-86°F	Dangerous. Typical of most humid parts of Texas and Louisiana in hottest summer month, and most humid summer days in Washington and Chicago.
III	86°F-92°F	Extremely dangerous. Comparable to Midwest during peak days of 1995 heat wave.
IV	>92°F	Extraordinarily dangerous. Exceeds all U.S. historical records. Heat stroke likely for fit individuals after less than one hour of moderate activity in the shade.

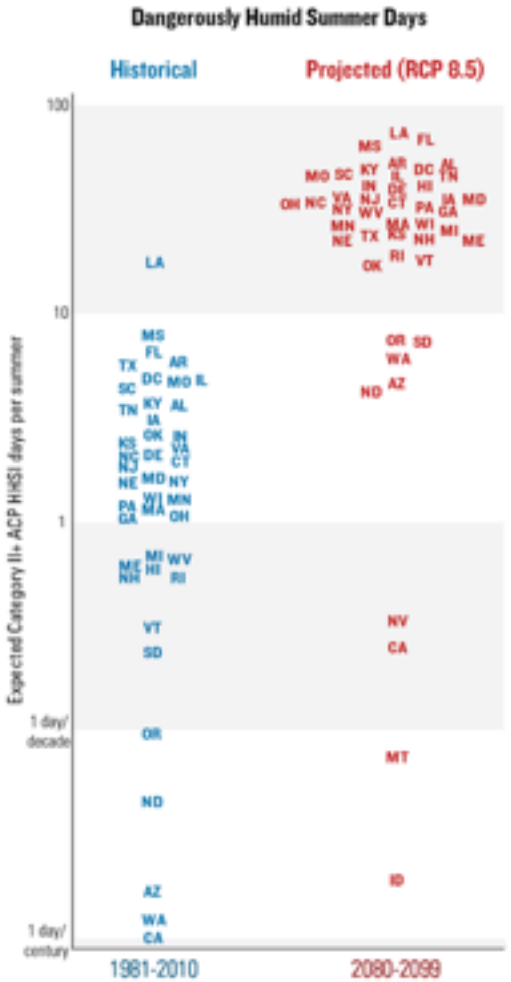
Changes in the mean interact with weather variability to change the frequency of extremes.

Expected number of Category 2+ (dangerous) and Category 3+ (extremely dangerous) in a typical year under RCP 8.5 (high-emissions).



Sources of uncertainty

- Socio-economic/Emissions
- Global climate response
- Regional climate response
- Natural variability
- Tipping points & the unknown

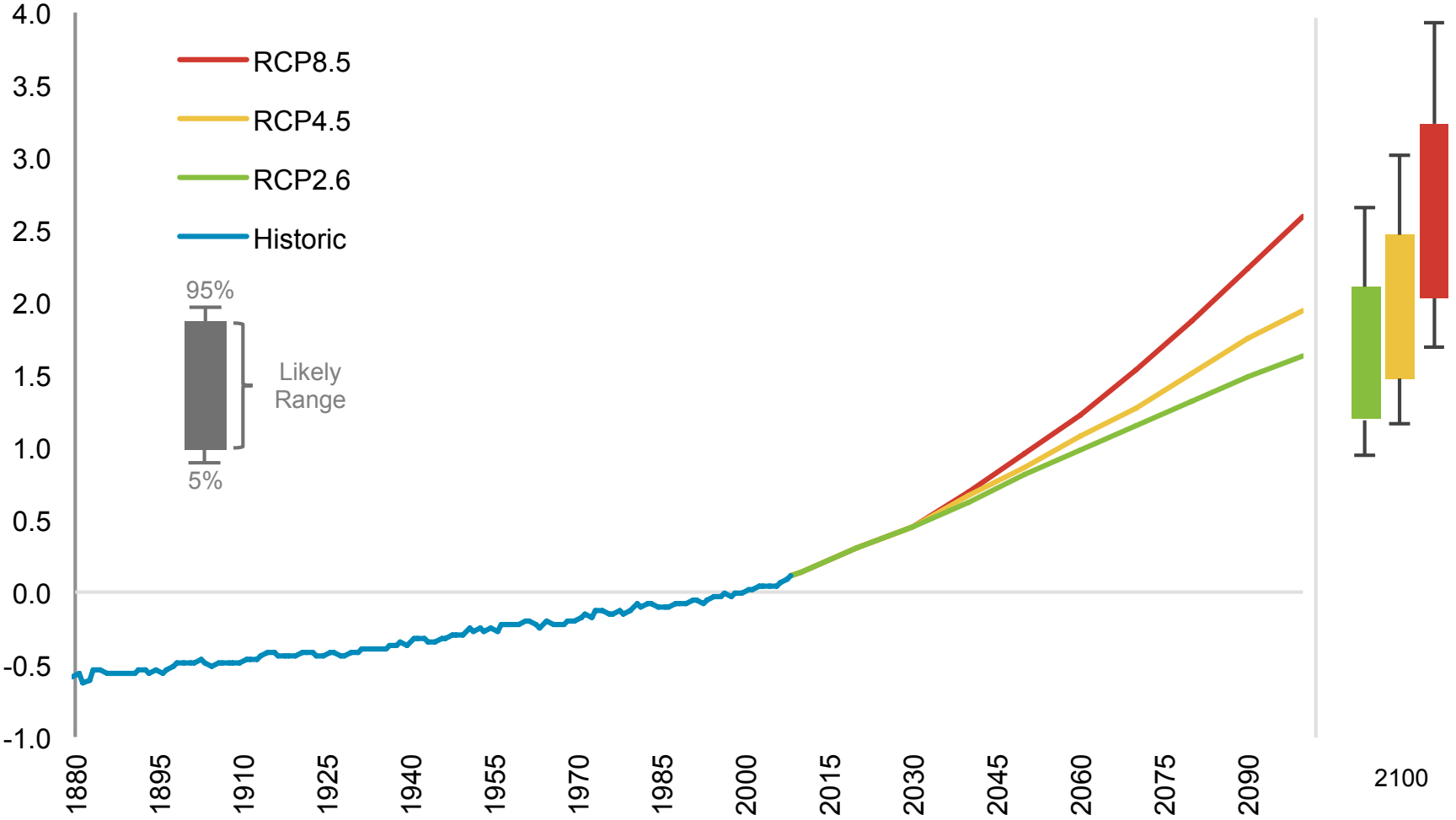


The global sea-level response is similarly uncertain.

Sources of uncertainty

- Socio-economic/Emissions
- Global climate response
- Regional climate response
- Natural variability
- Tipping points & the unknown

Feet global mean sea-level rise above year 2000 levels

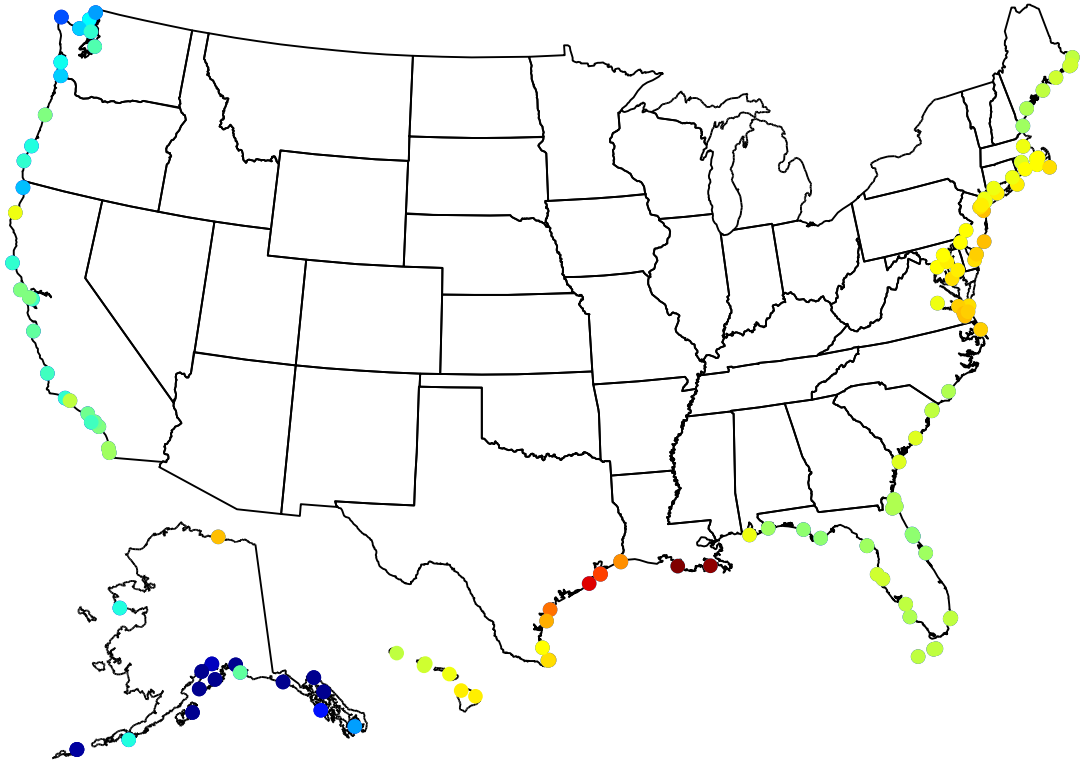


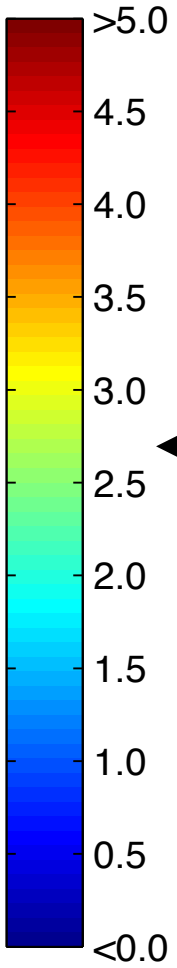
The varying local sea-level response will lead to damages both from inundation and greater storm flooding.

Sources of uncertainty

- Socio-economic/Emissions
- Global climate response
- Regional climate response
- Natural variability
- Tipping points & the unknown

Median projected local sea-level rise, year 2100 under RCP 8.5 (high emissions)



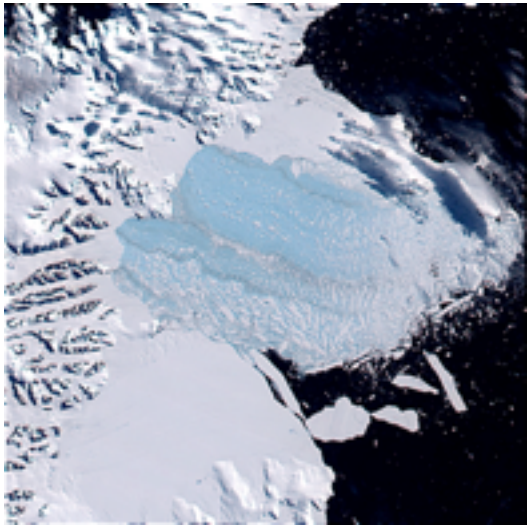


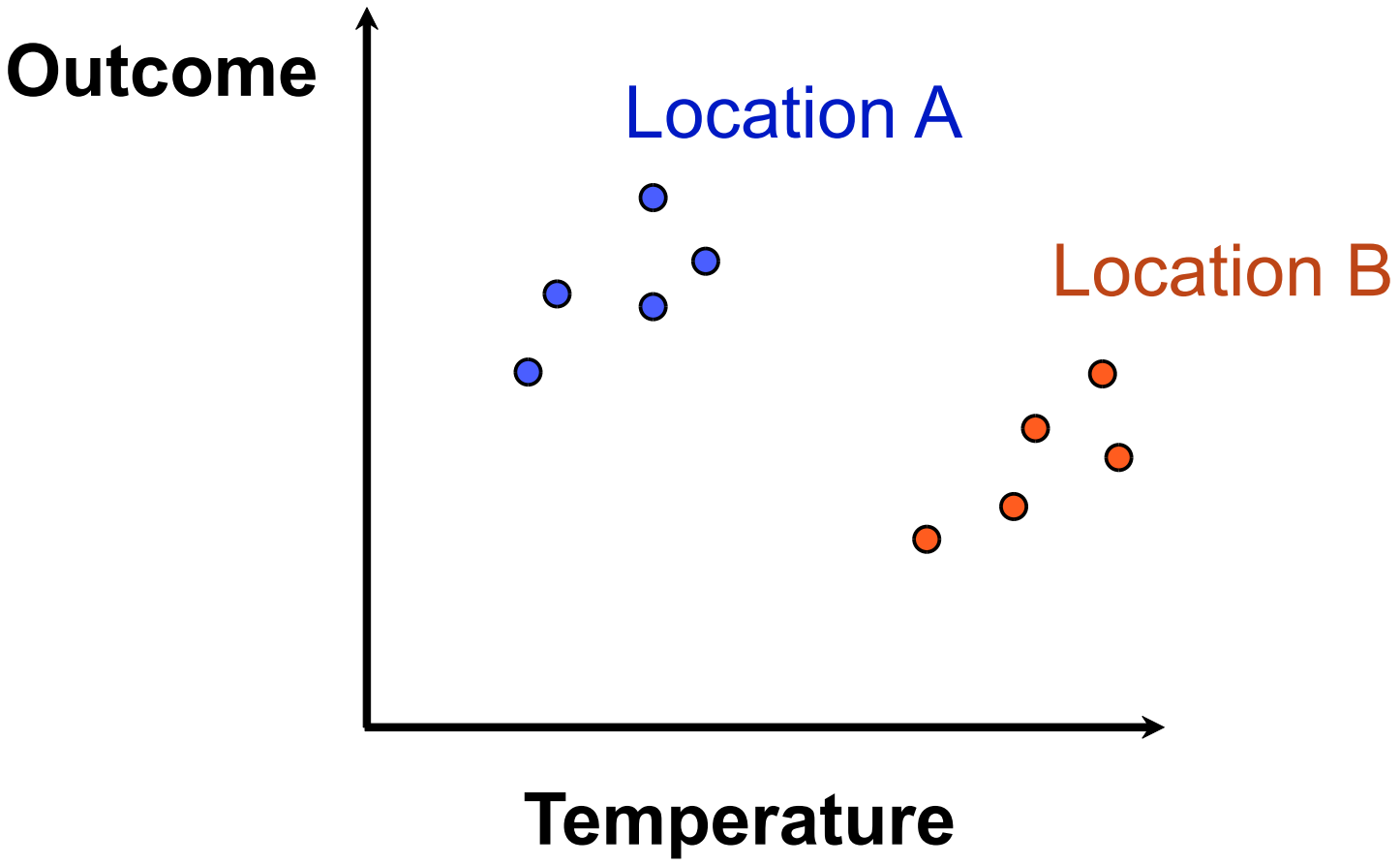
Median global mean sea-level rise = 2.6 ft

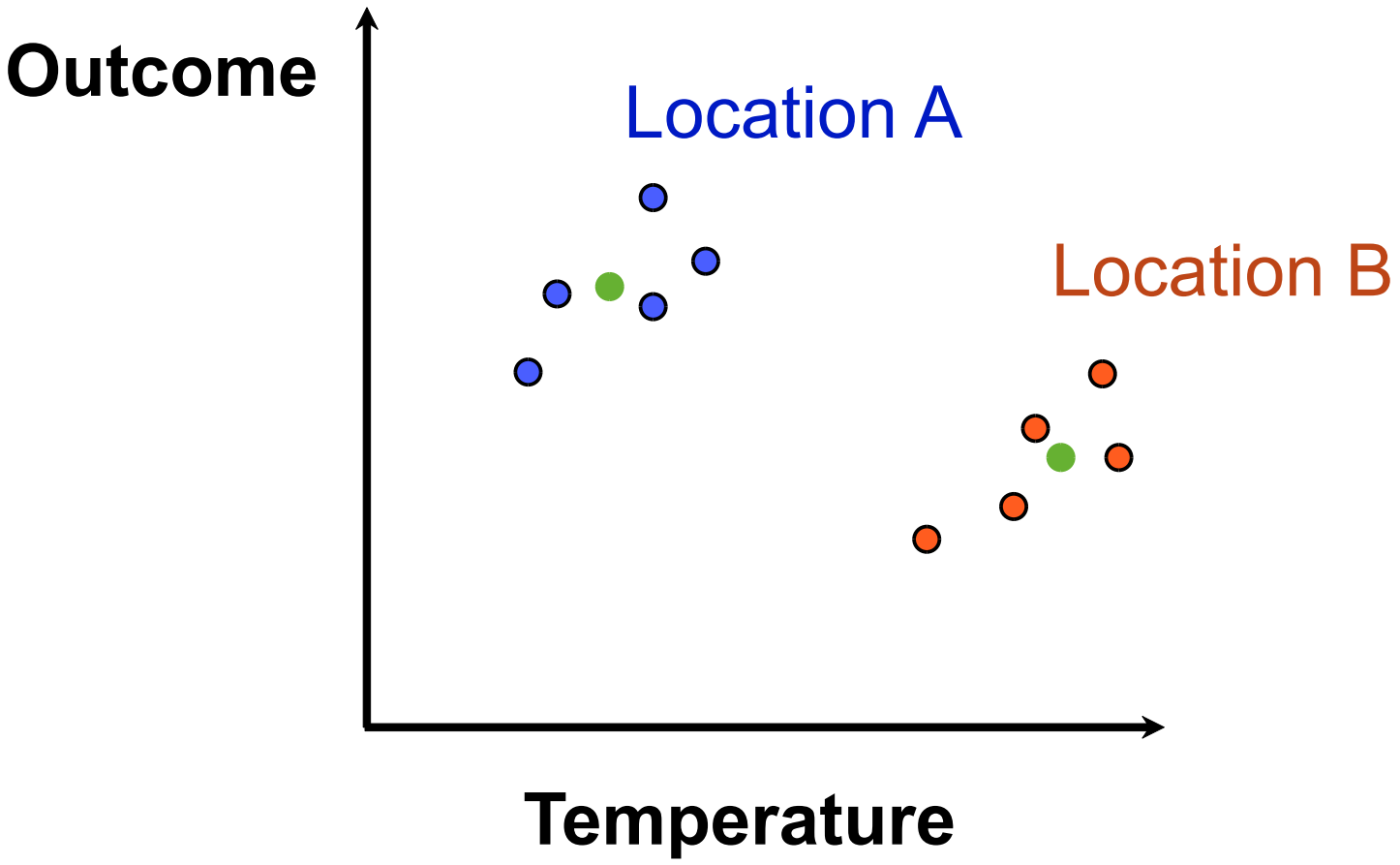
But partially unquantified uncertainty arising from potential tipping points and 'unknown unknowns' remains.

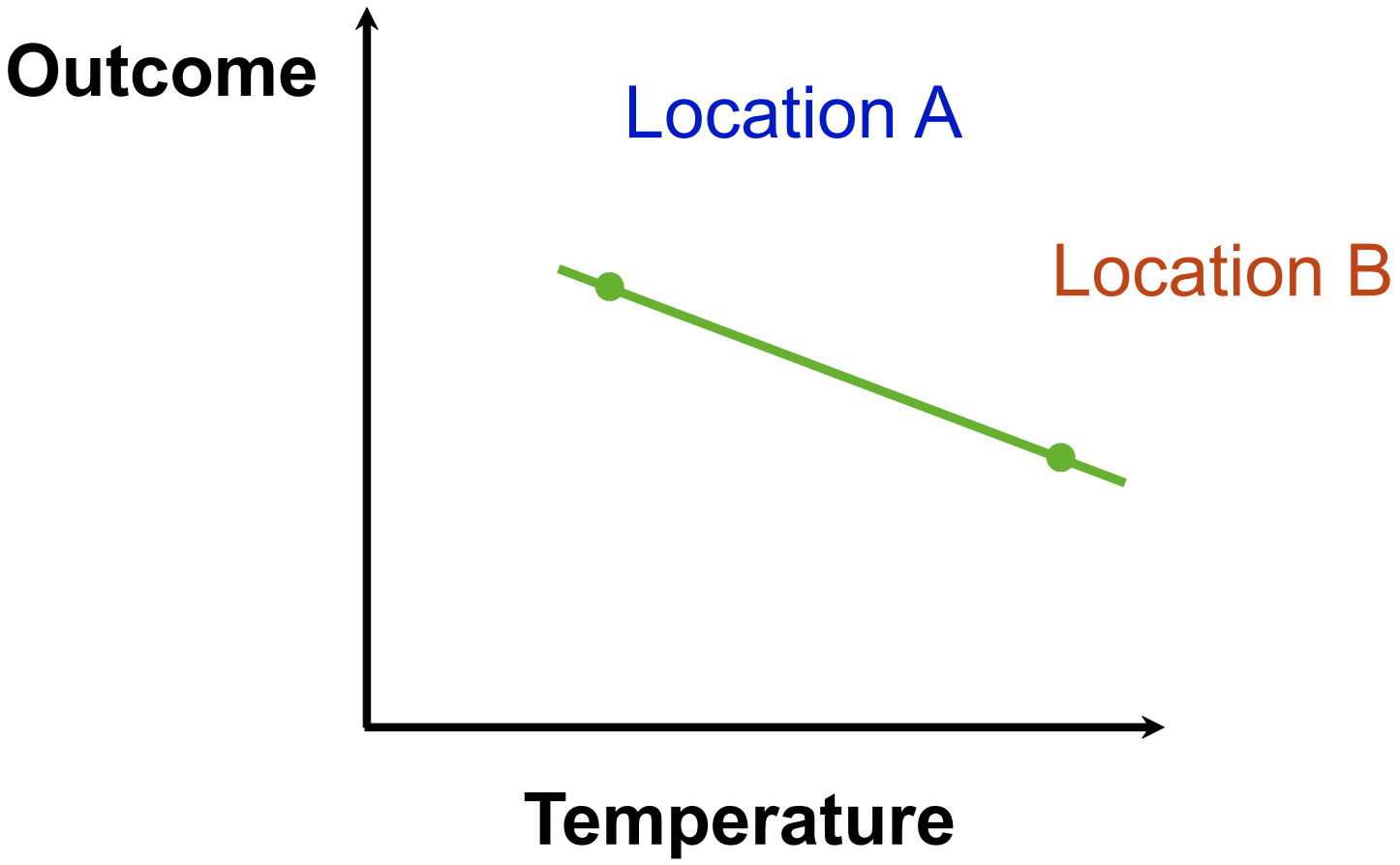
Sources of uncertainty

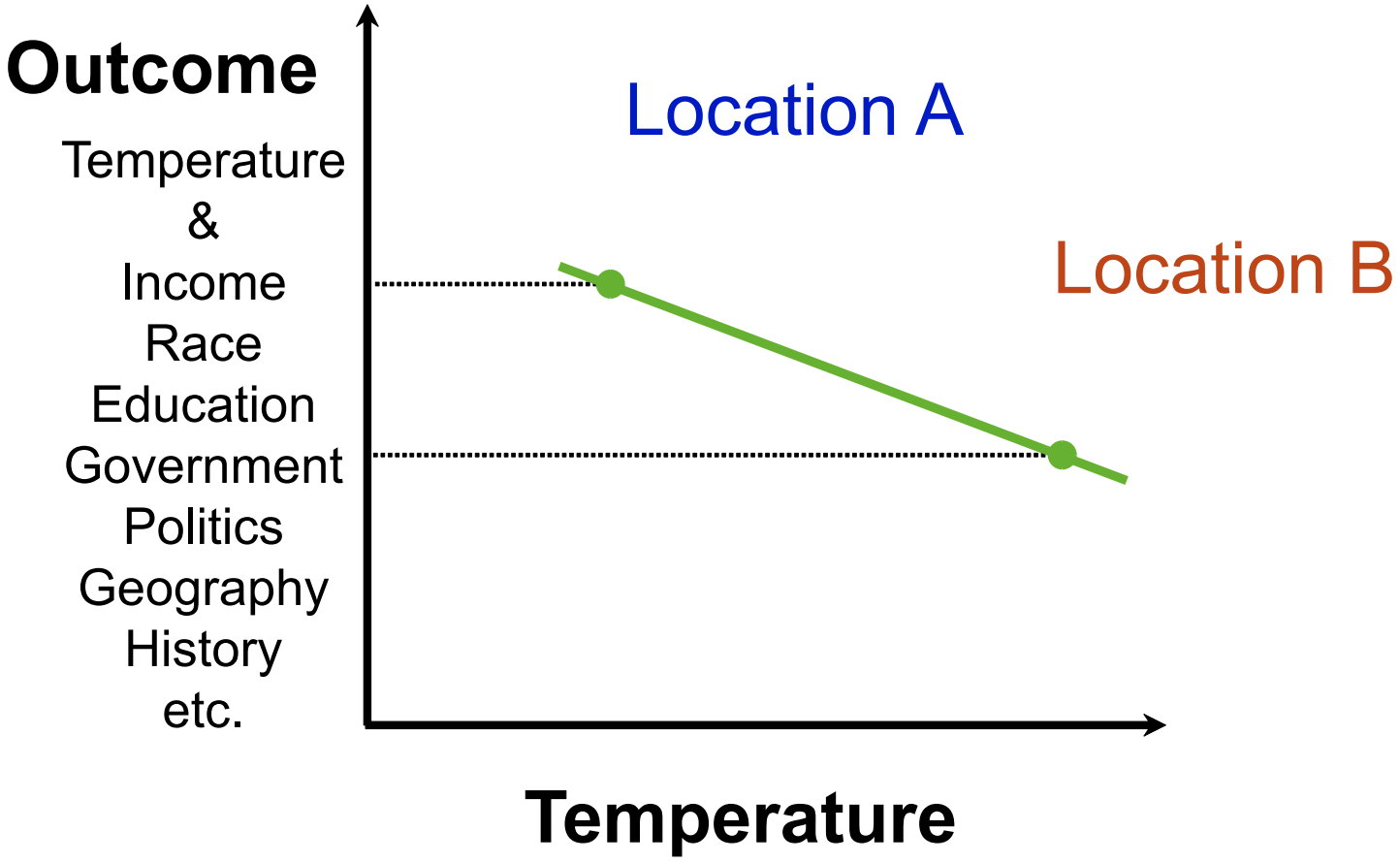
- Socio-economic/Emissions
- Global climate response
- Regional climate response
- Natural variability
- Tipping points & the unknown

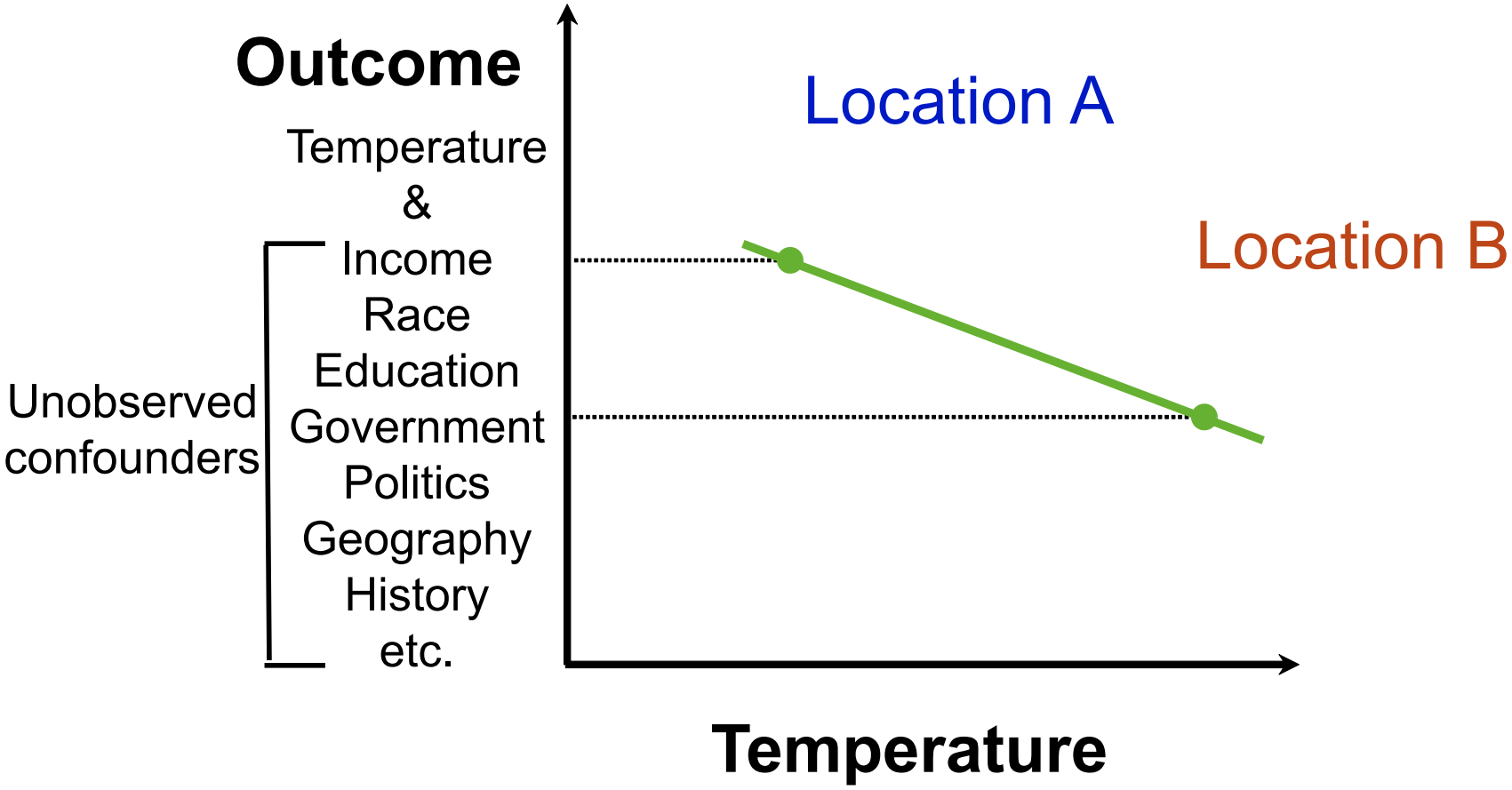


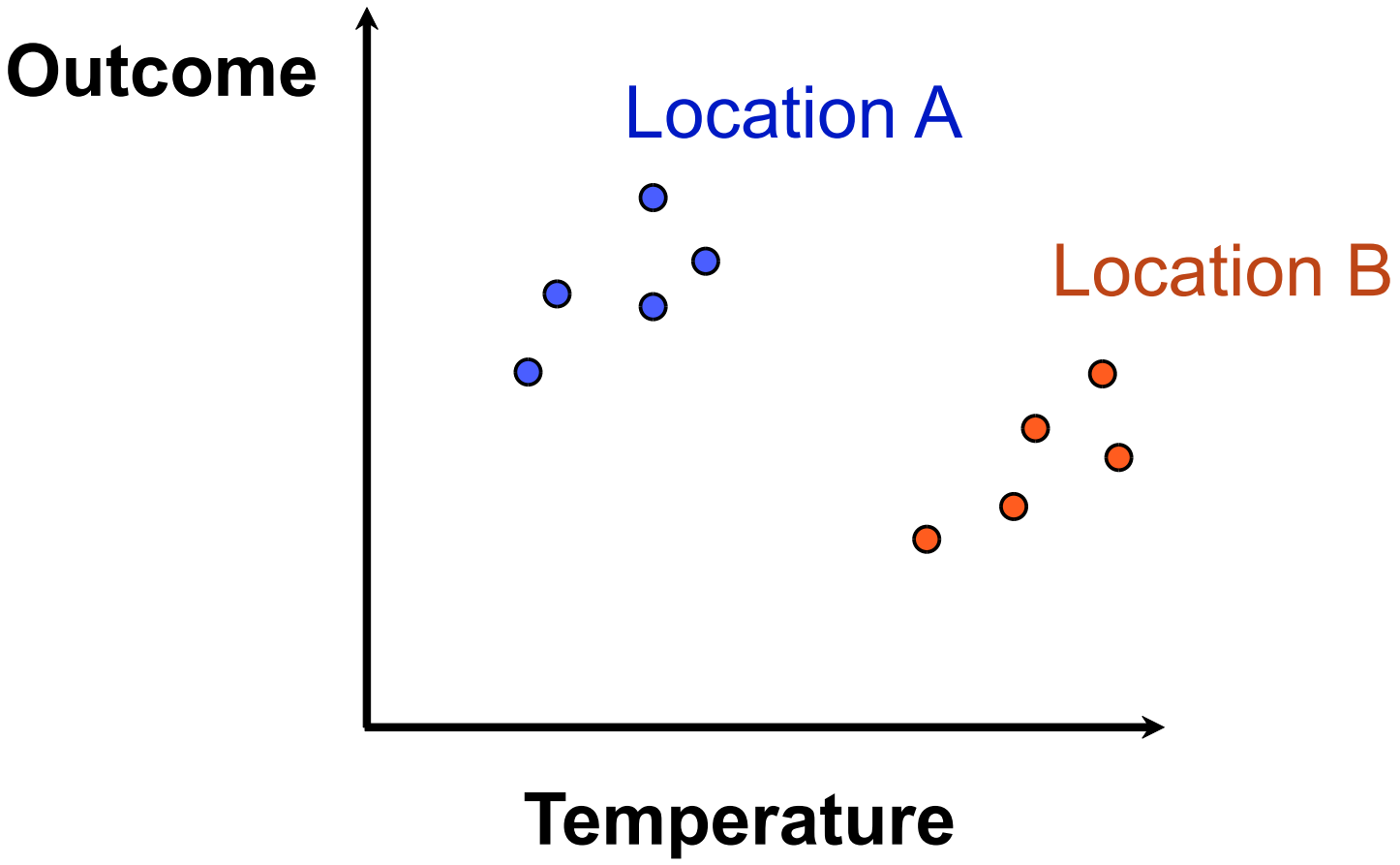

Outcome
Location A
Location B
Temperature

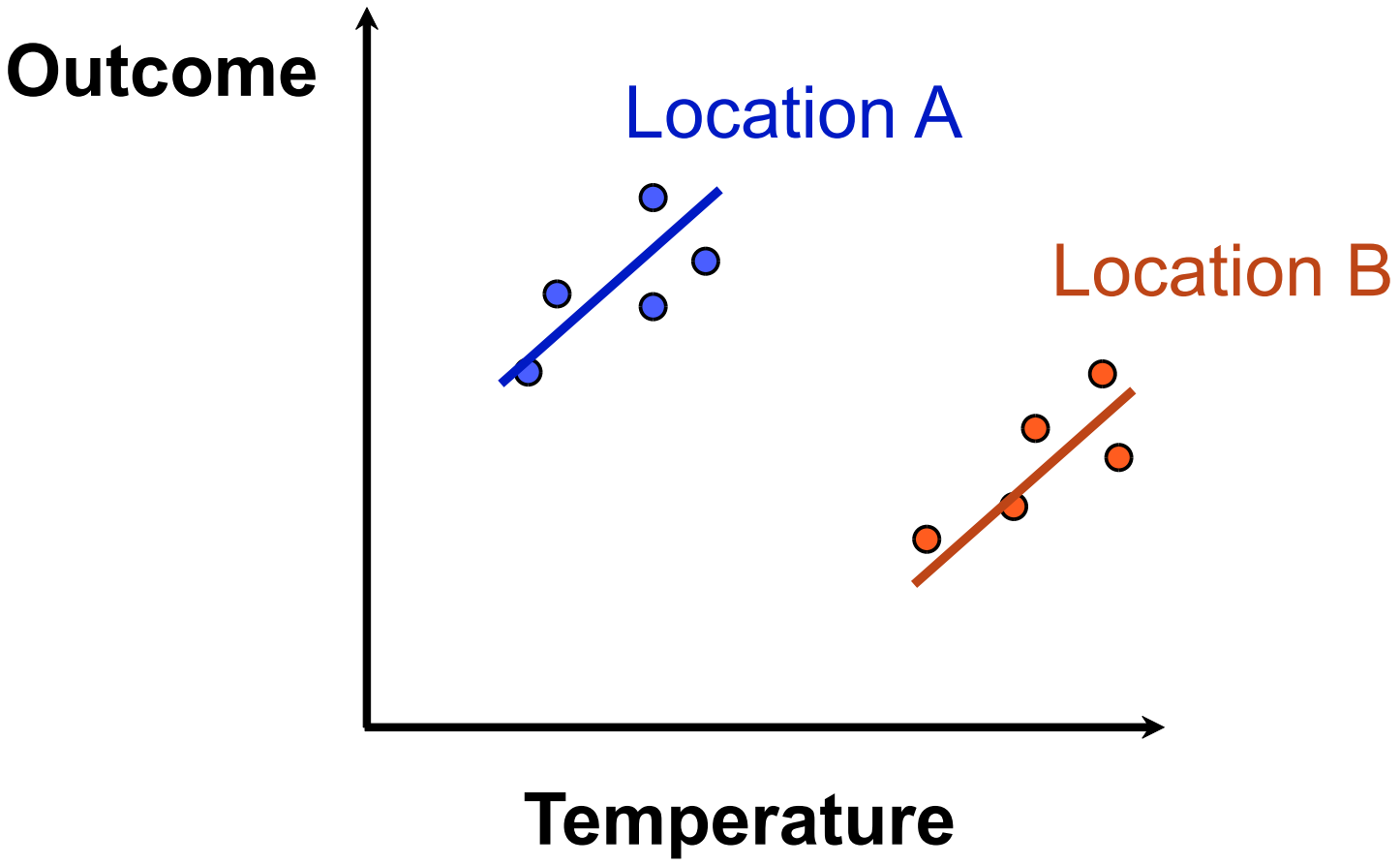

Outcome
Location A
Location B
Temperature

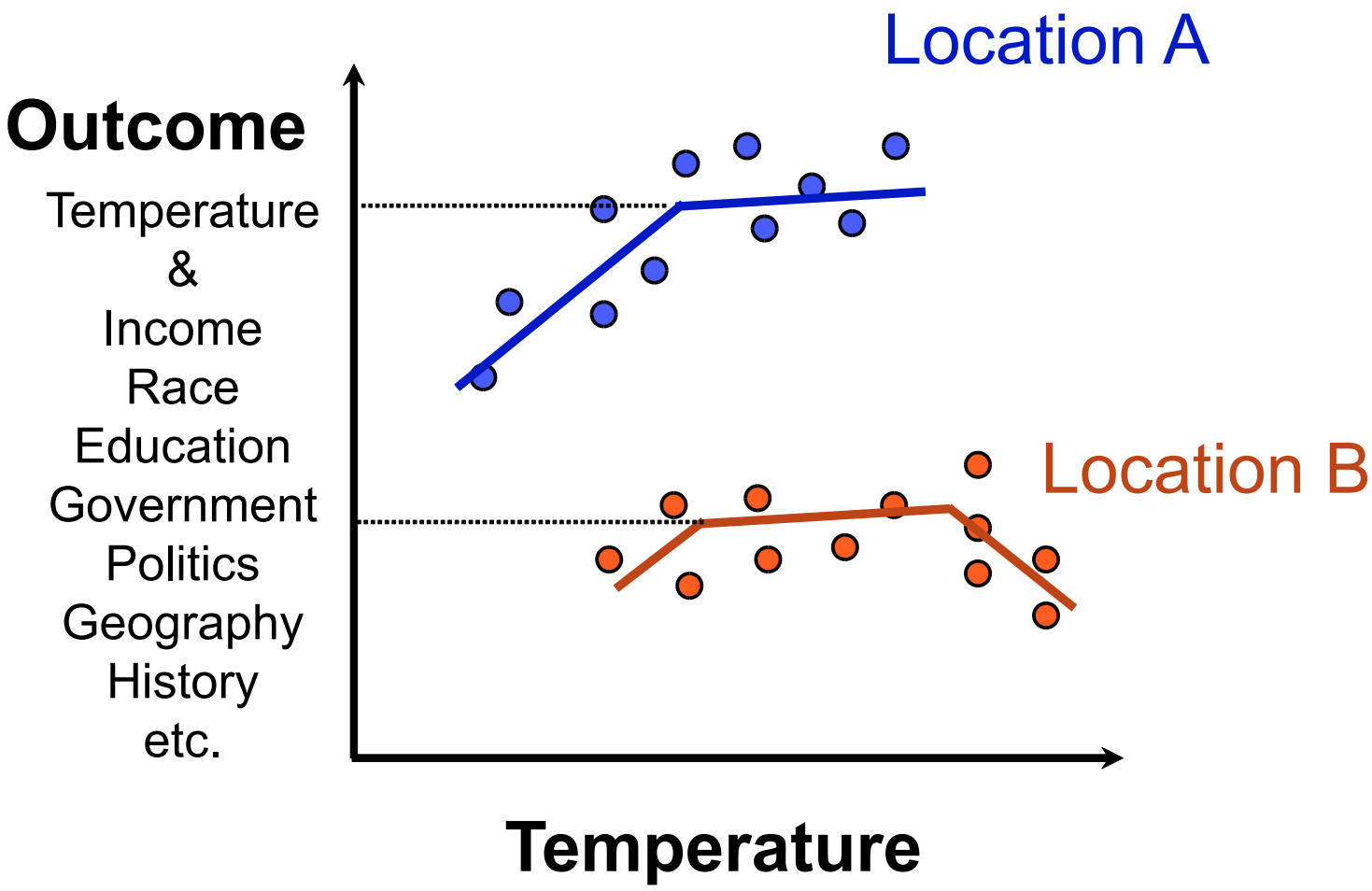

Outcome
Location A
Location B
Temperature


Outcome
Temperature
&
Income
Race
Education
Government
Politics
Geography
History
etc.
Location A
Location B
Temperature


Outcome
Temperature
&
Income
Race
Education
Government
Politics
Geography
History
etc.
Unobserved
confounders
Location A
Location B
Temperature


Outcome
Location A
Location B
Temperature

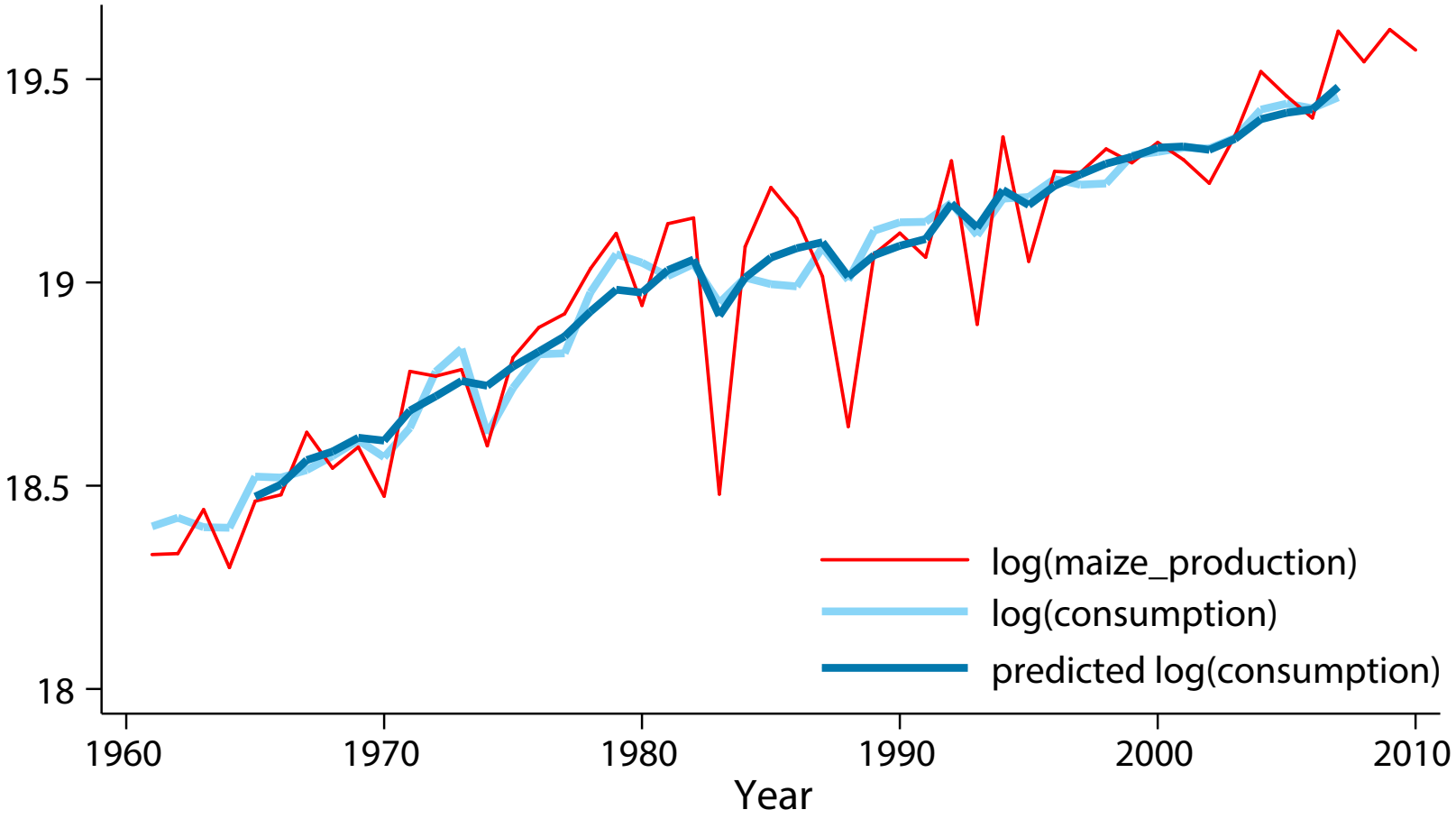

Outcome
Location A
Location B
Temperature


Location A
Outcome
Temperature
&
Income
Race
Education
Government
Politics
Geography
History
etc.
Location B
Temperature

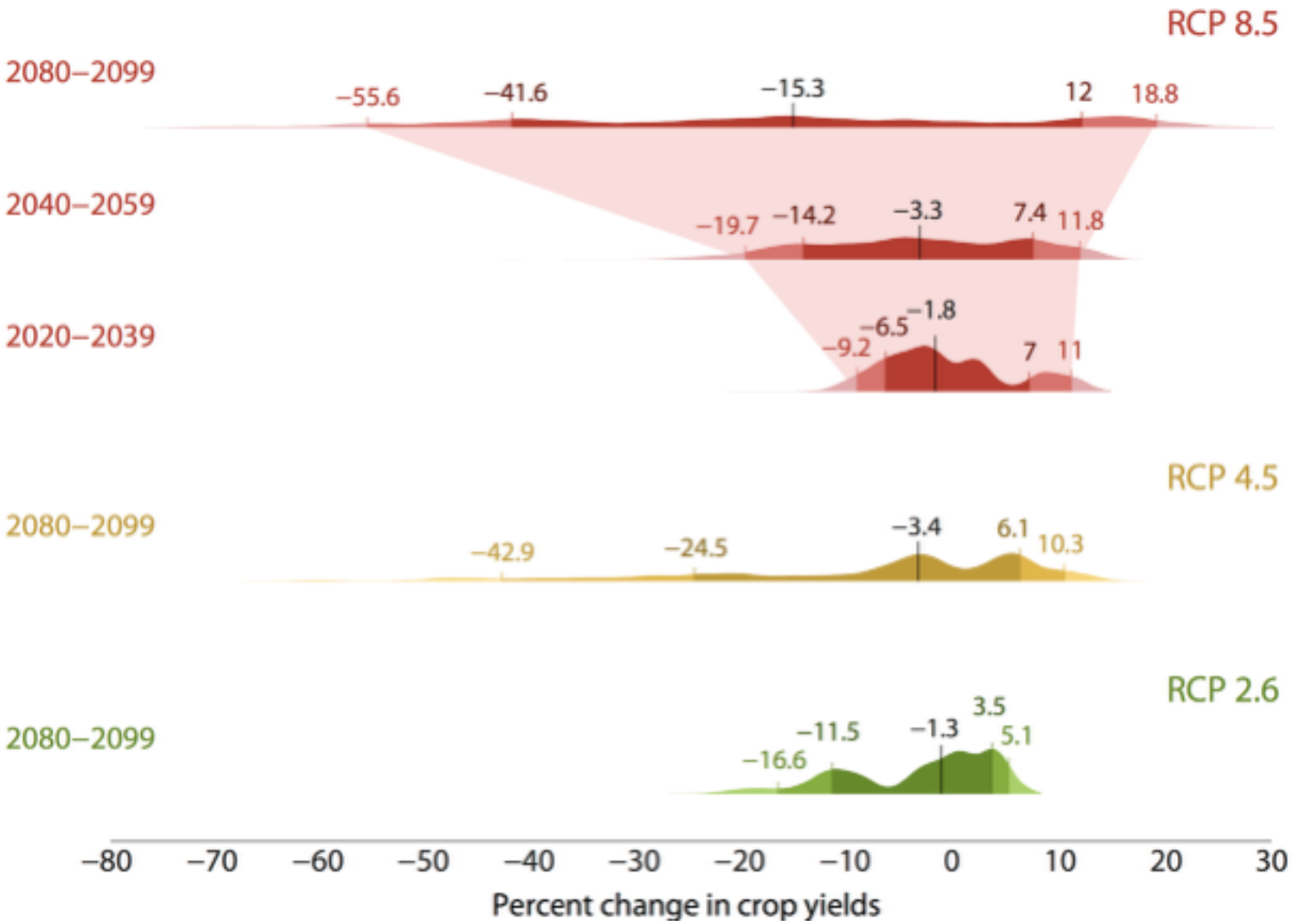
Advances

- **Distributed Meta-Analysis System**
- **Identifying criteria studies**
- **Estimate benefits & costs using real-world behavior/data**
- **Full treatment of temporal displacement, non-linearity**
- **Standardized, spatially-resolved, multi-model projections**
- **Full treatment of model and statistical uncertainty**
- **Incorporates daily weather variability**
- **Linkages to economy-wide model**
- **Empirically-based approach to modeling adaptation**

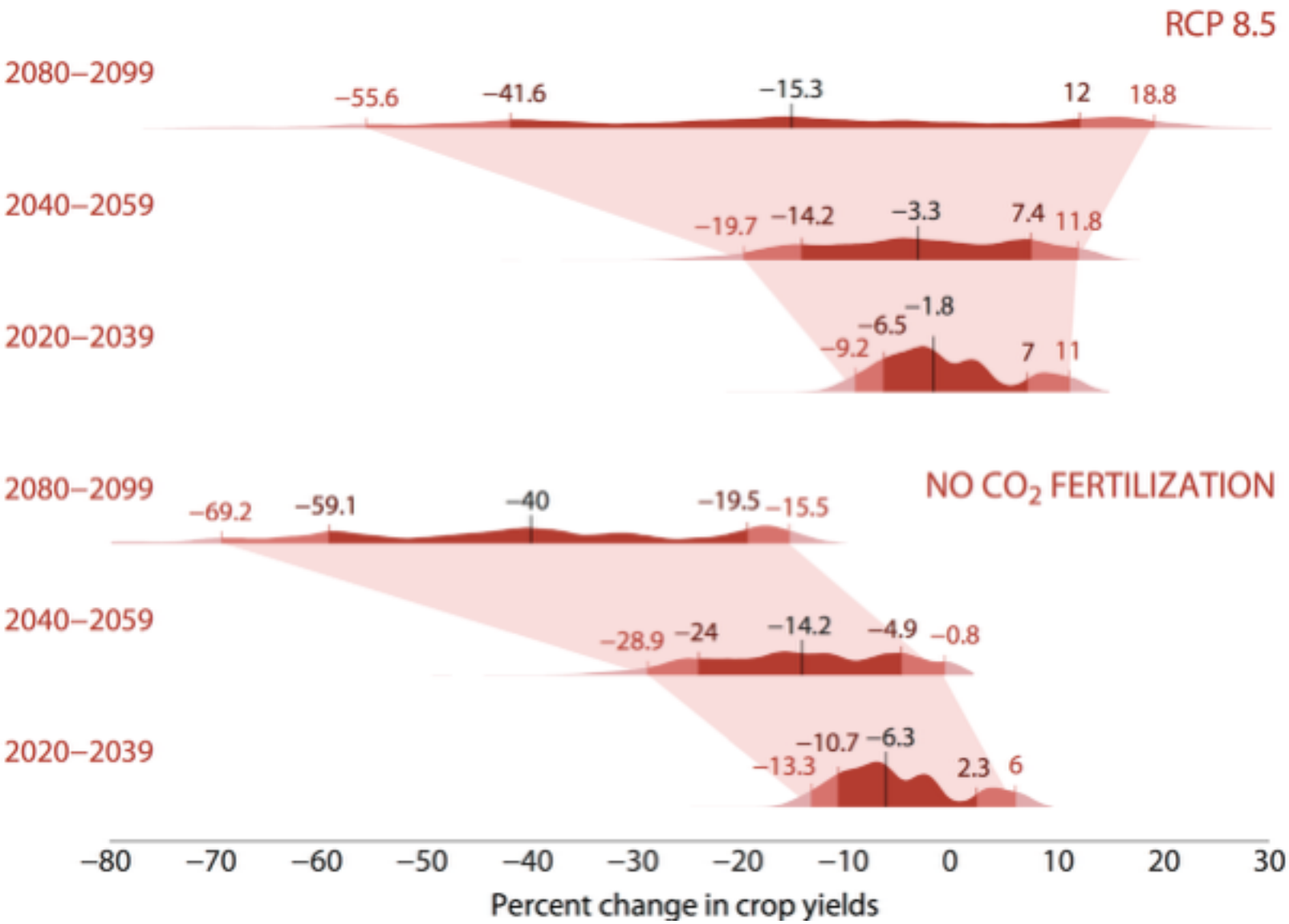
Agriculture example: Temporal displacement



Agriculture example: National risk



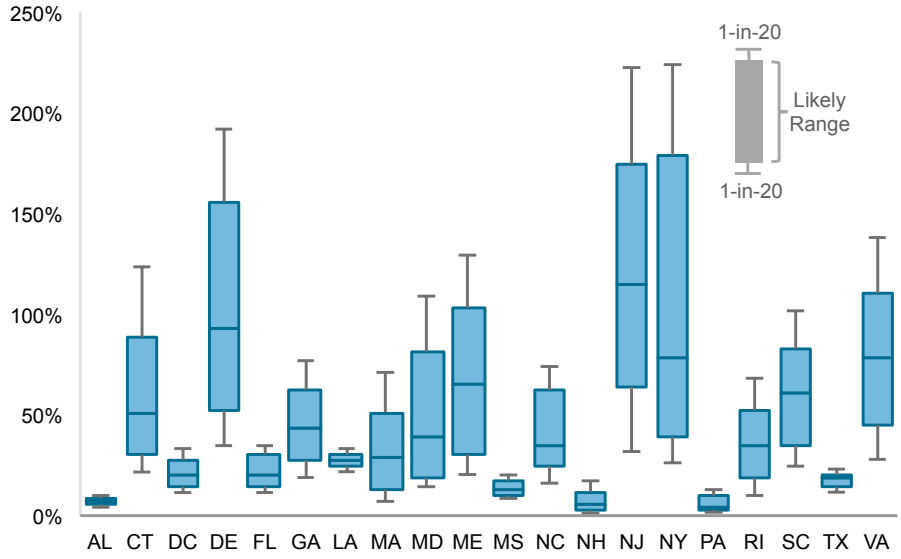
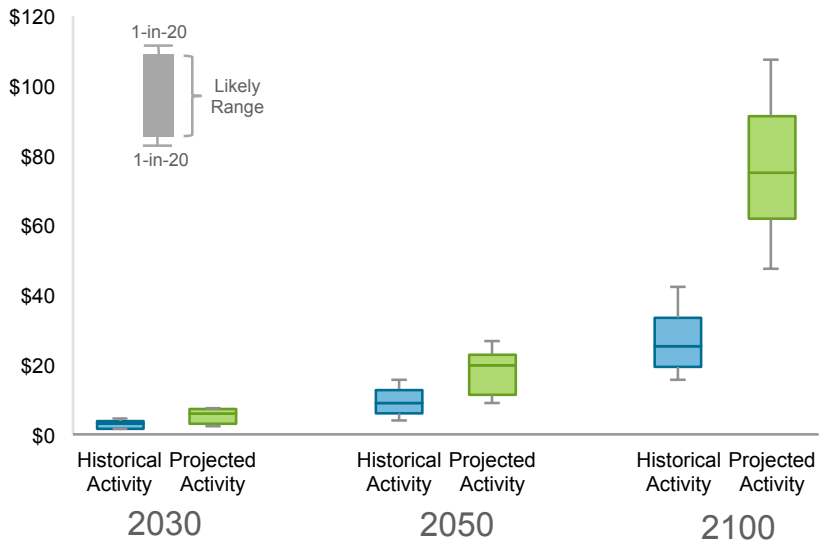
Agriculture example: Assumption sensitivity



Average annual coastal flood damage

Property + business interruption due to coastal flooding, RCP 8.5 2050

State-level %age increase historical storm activity



National billion USD increase