Treatment of uncertainty in climate change risk assessments

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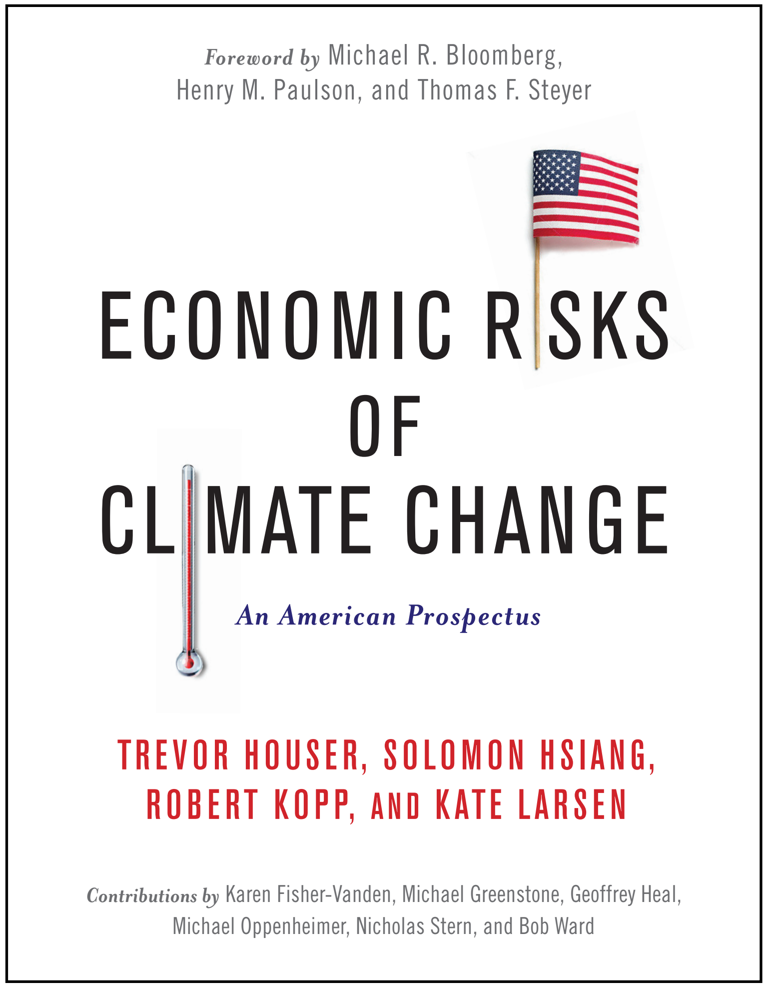
Methods for Characterizing Risk in Climate Change Assessments
NAS workshop, March 23, 2016

Key points

- It's important to be cognizant of both forced and unforced changes, and about the interaction between physical and socio-economic uncertainty.
- Simple, probabilistic climate models provide a useful complement to large-scale Earth system models, which represent modeling groups' best estimates.
- An increasing number of socio-economic impacts can be quantified using state-of-the-art econometric and process models.
- We need tools and frameworks for translating probabilistic information into actionable information. But these involve decision-specific values such as time horizon and risk tolerance – they can't be decided by scientists acting in isolation.
- Many potential impacts – such as 'tipping points' – remain (and will likely continue for a long while to remain) unquantified.
- Although 'tipping point' probability may be hard to assess, and the 'tipping points' concept itself has promoted confusion, it is important to be cognizant of (deeply uncertain) thresholds in both physical *and social* systems.
- More value issues: In physical systems, many of the consequences of 'tipping points' may play out on timescales well beyond those of conventional decision-making, but with important effects on our civilizational legacy.

Economic Risks of Climate Change

An American Prospectus



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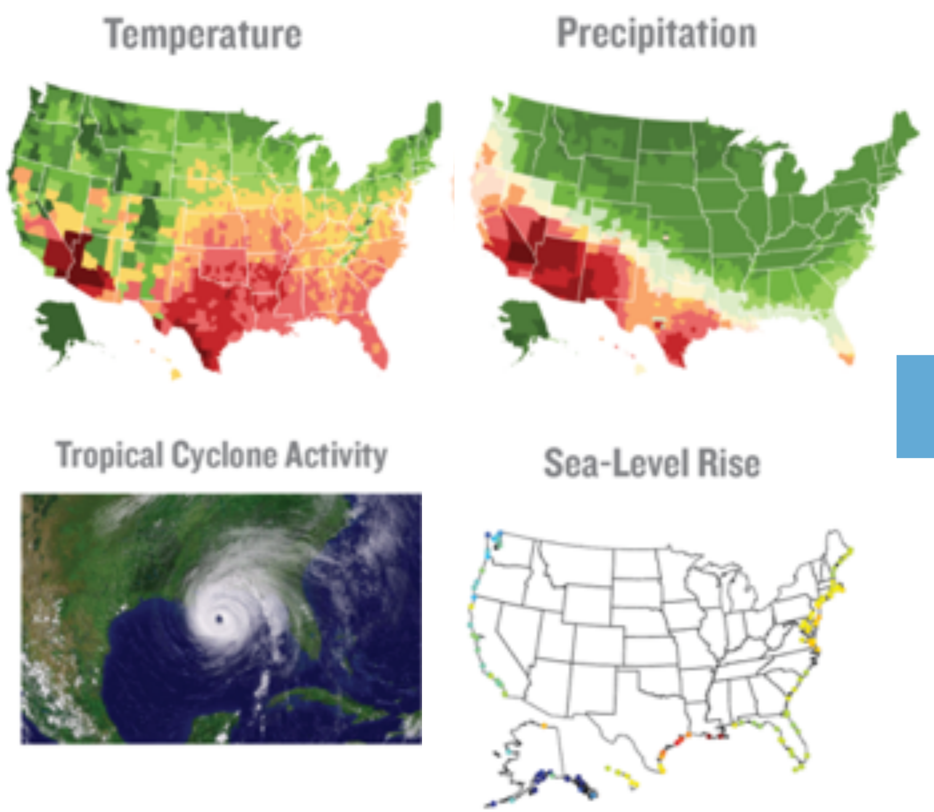
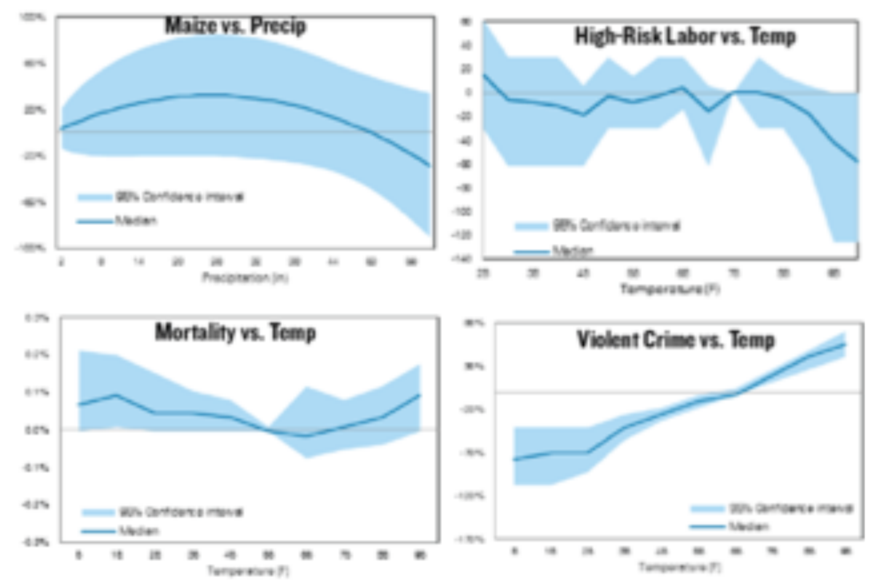
www.climateprospectus.org

Working with our collaborators at Berkeley, UChicago, and Rhodium Group, we are working to leverage 'big data' and the recent explosion of empirical research to assess the associated climate risks.

Statistically downscaled, probabilistic physical climate projections



Impact estimates based on meta-analysis of econometric research



complemented by detailed sectoral models

Local and global information for benefit-cost and risk analysis

Targeting sectors where an adequate empirical basis for analysis exists:

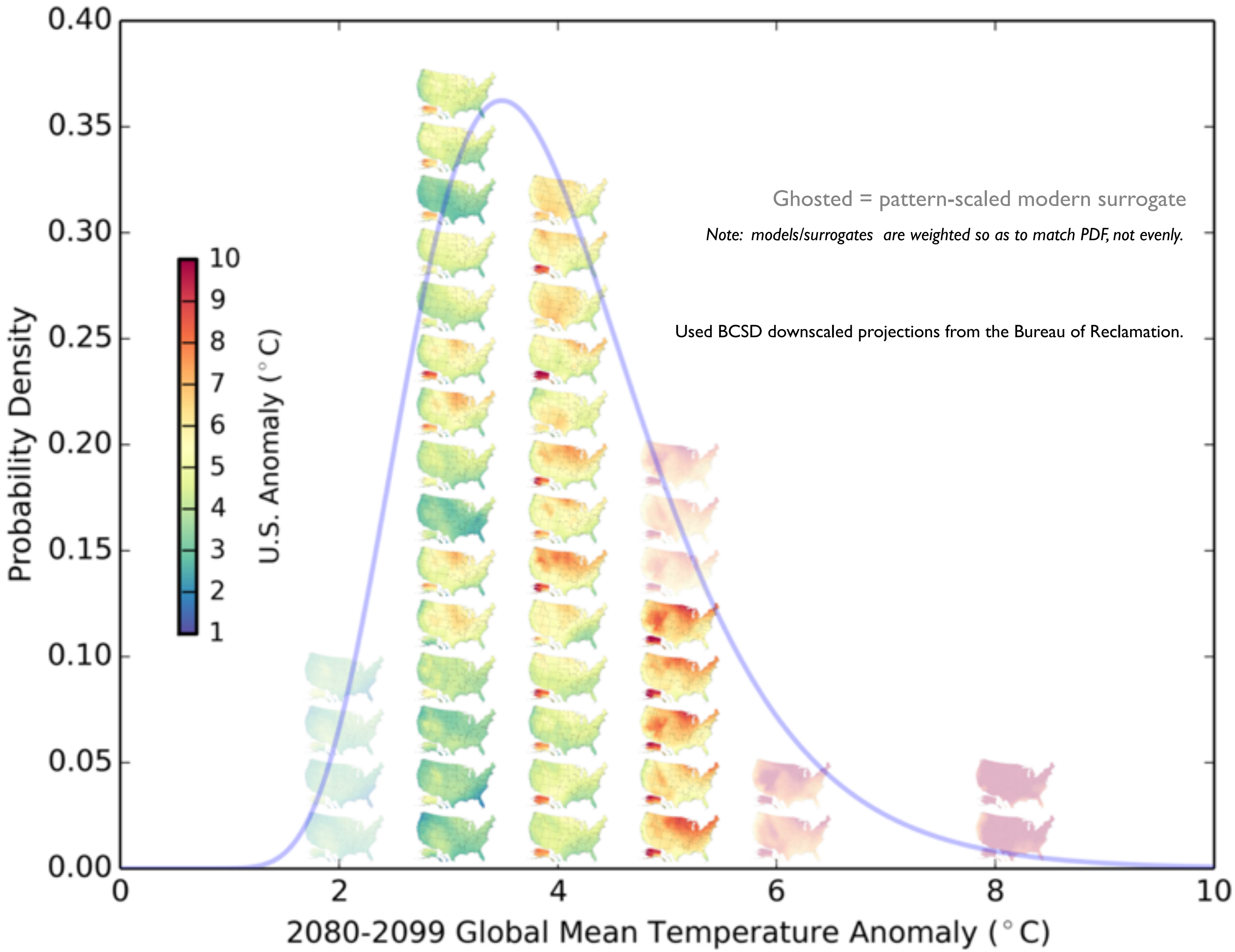
- **Agricultural production**
- **Health**
- **Labor productivity**
- Energy supply and **energy demand**
- **Coastal buildings and infrastructure**
- **Crime** and conflict
- Migration

Bold: included in US analysis

Key sources of uncertainty considered

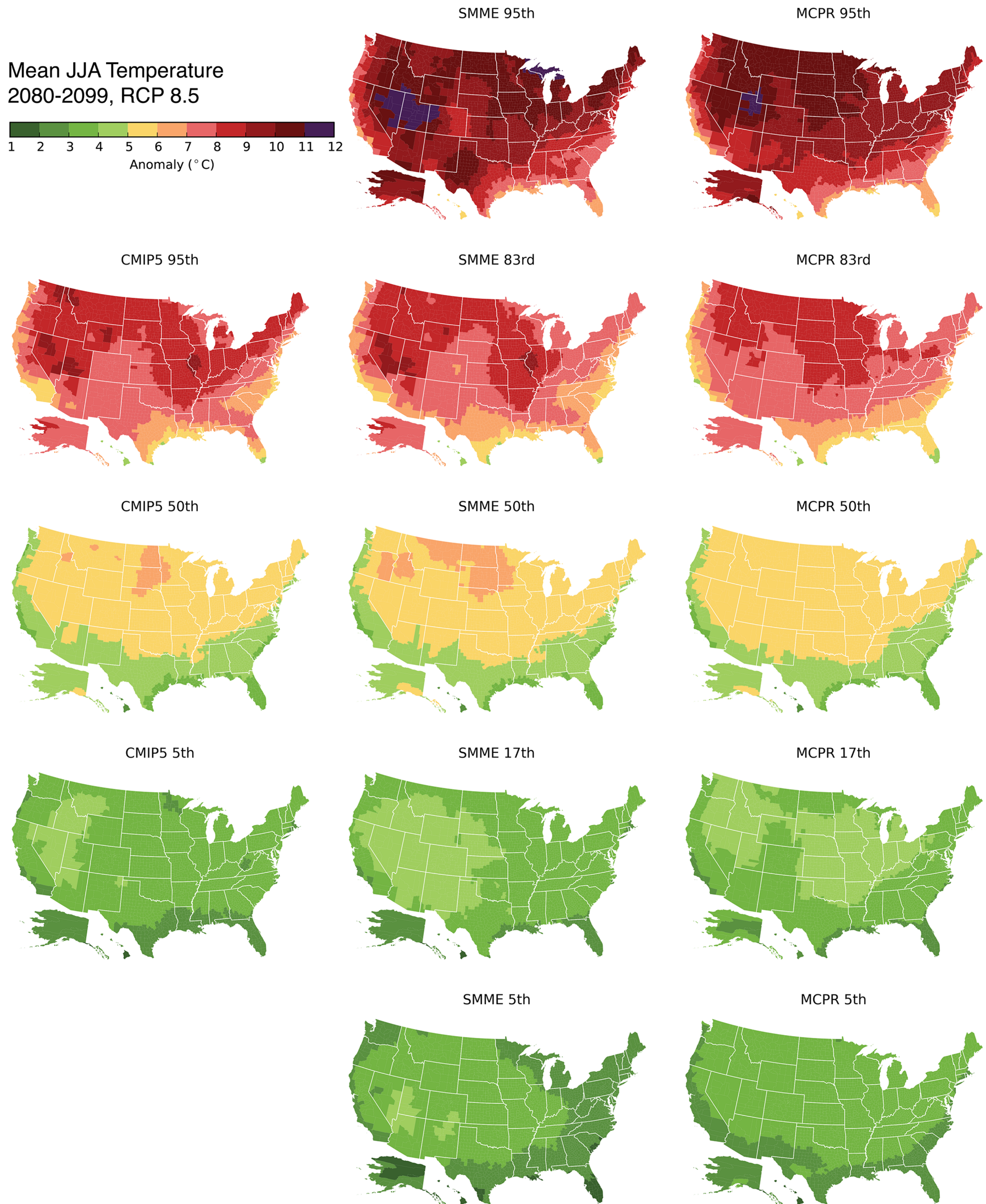
- Emissions (via RCPs)
- *Socio-economic baseline (via SSPs) [not considered for ACP]*
- Global temperature response (from probabilistic simple climate model), conditional upon emissions
- Forced regional climate response, conditional upon global temperature response (derived from GCM)
- Unforced regional climate variability (derived from GCM)
- Socio-economic response, conditional upon local, daily weather (and socio-economic baseline)
- Structural uncertainty/omitted factors (tipping points, etc.)

Goal is to get distribution of local changes consistent with global mean temperature projection



Probability distribution developed from simple climate model and downscaled global climate model projections with the surrogate/model mixed ensemble method of Rasmussen et al. (in rev.; available on Arxiv)

Rasmussen et al. (in rev.)



95%

83%

50%

17%

5%

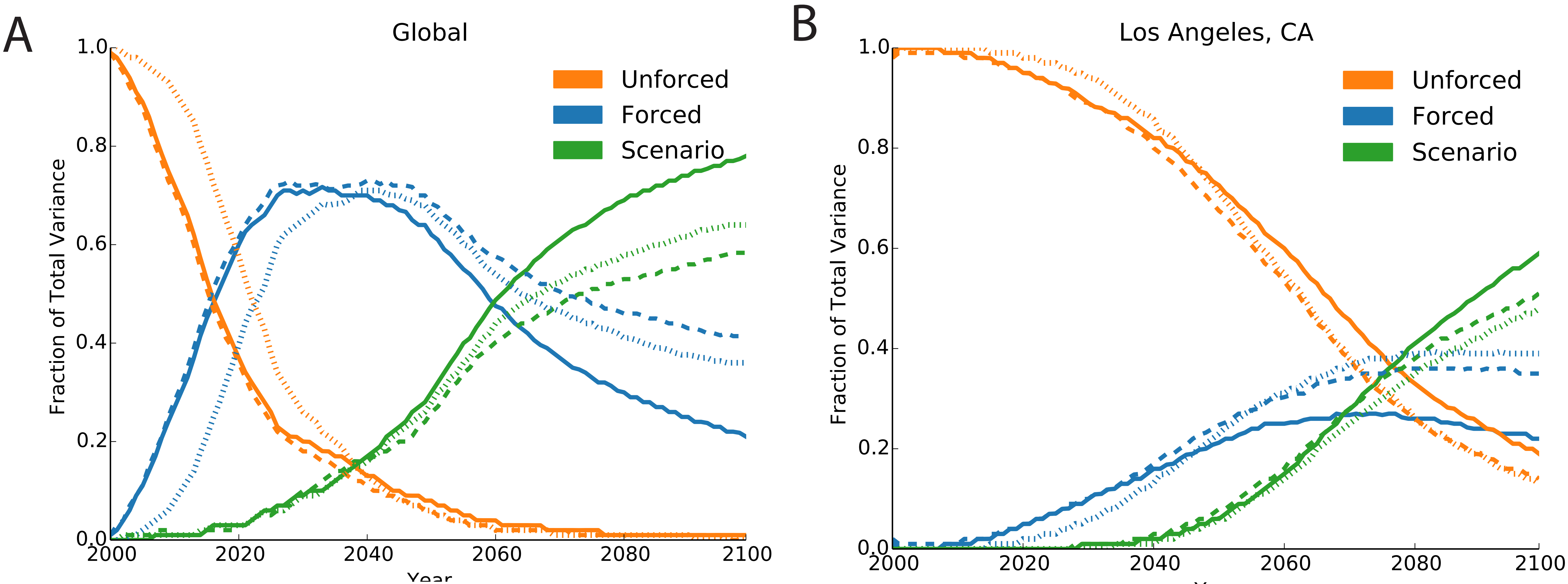
Recall that IPCC AR5 interprets the 5th-95th percentile of CMIP5 temperature projections as a 'likely' (67% probability) range

Rasmussen et al. (in rev.)

Contributors to annual temperature variance

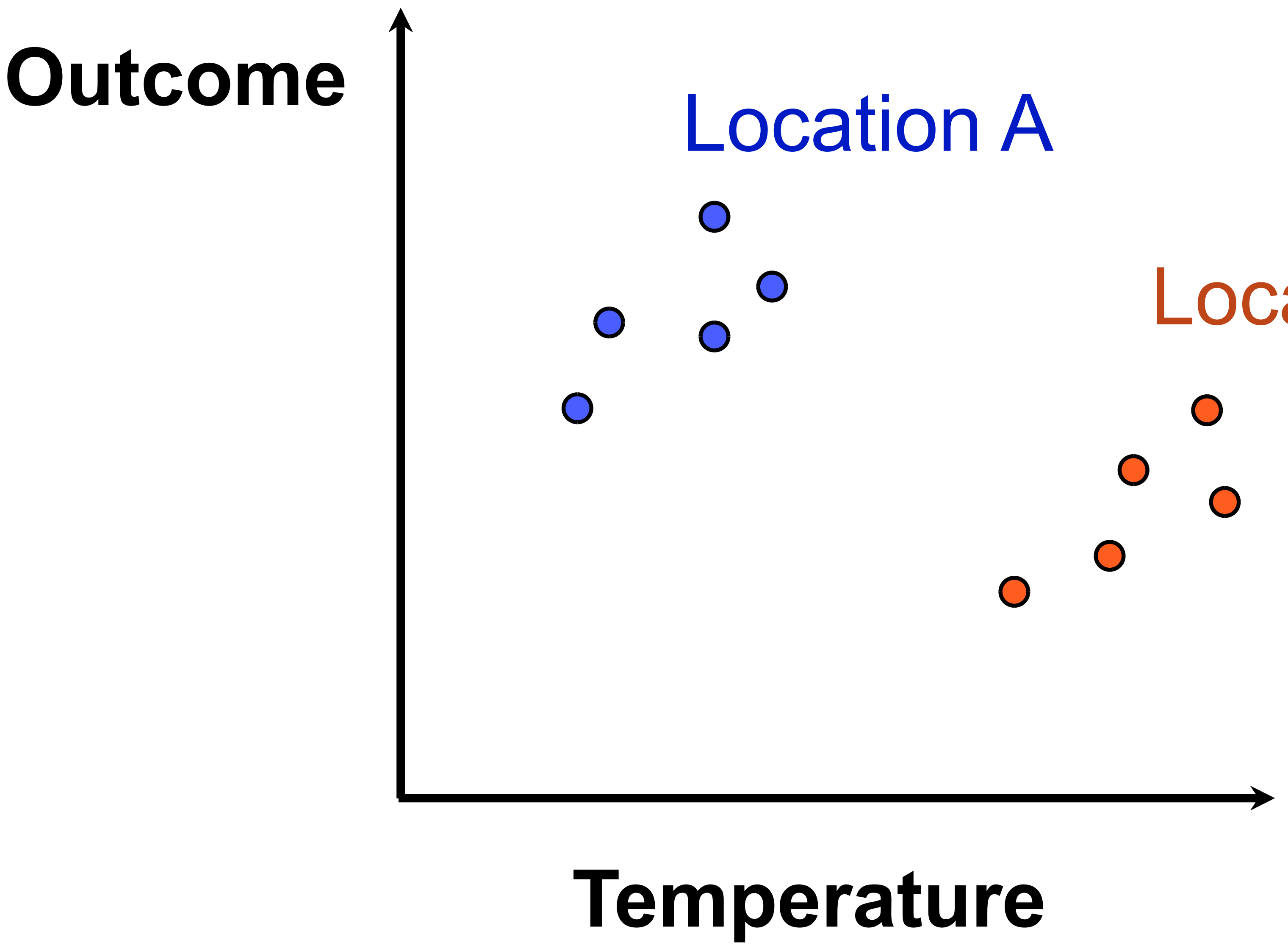
(solid = CMIP5, dashed=SMME, dotted=MCPR)

note that ratio of unforced/(forced + scenario) decreases over longer averaging intervals



Rasmussen et al. (in rev.)

Econometric impact analyses based on identifying historical responses to short-/medium-run climatic variability/change.



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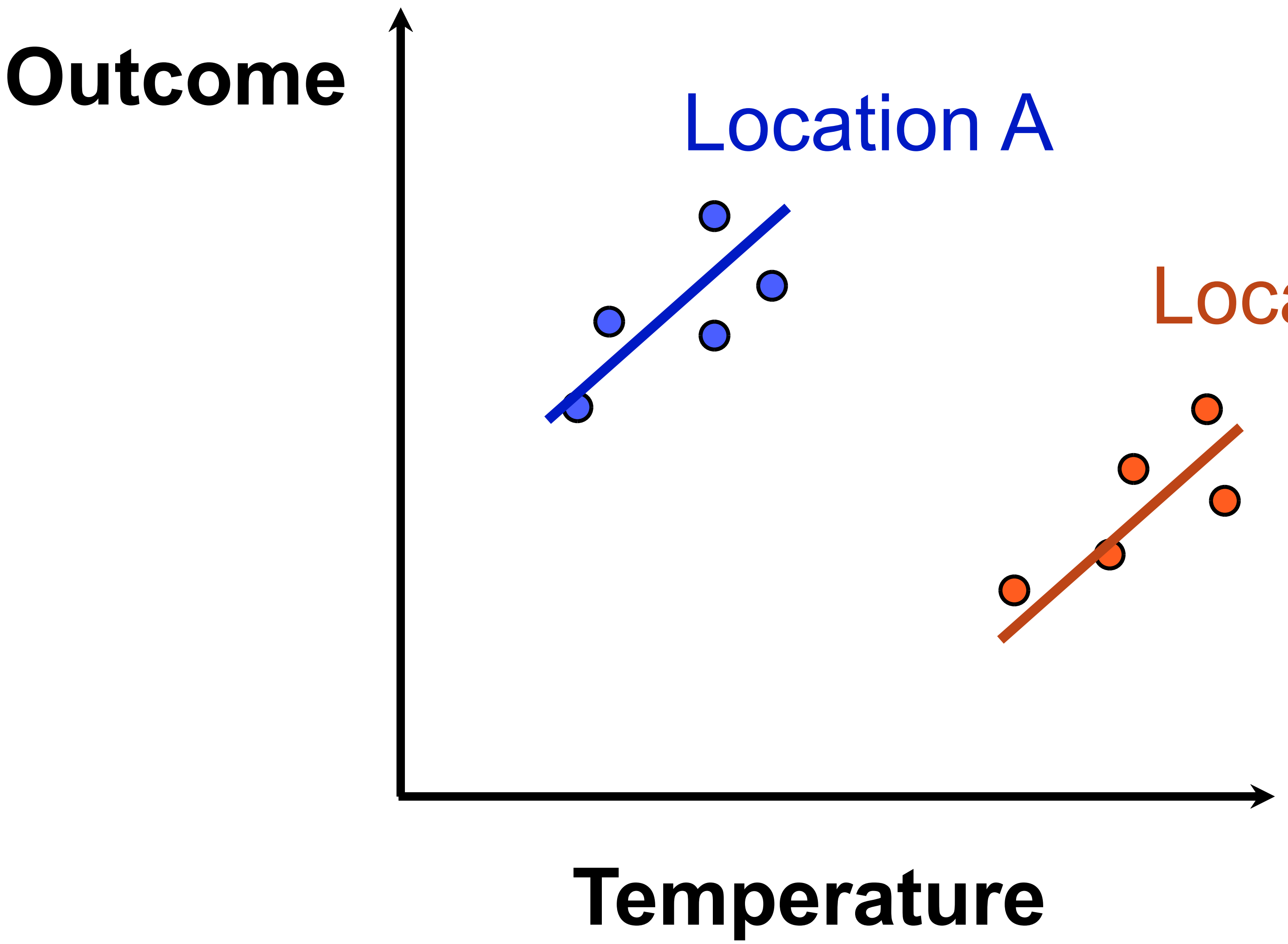

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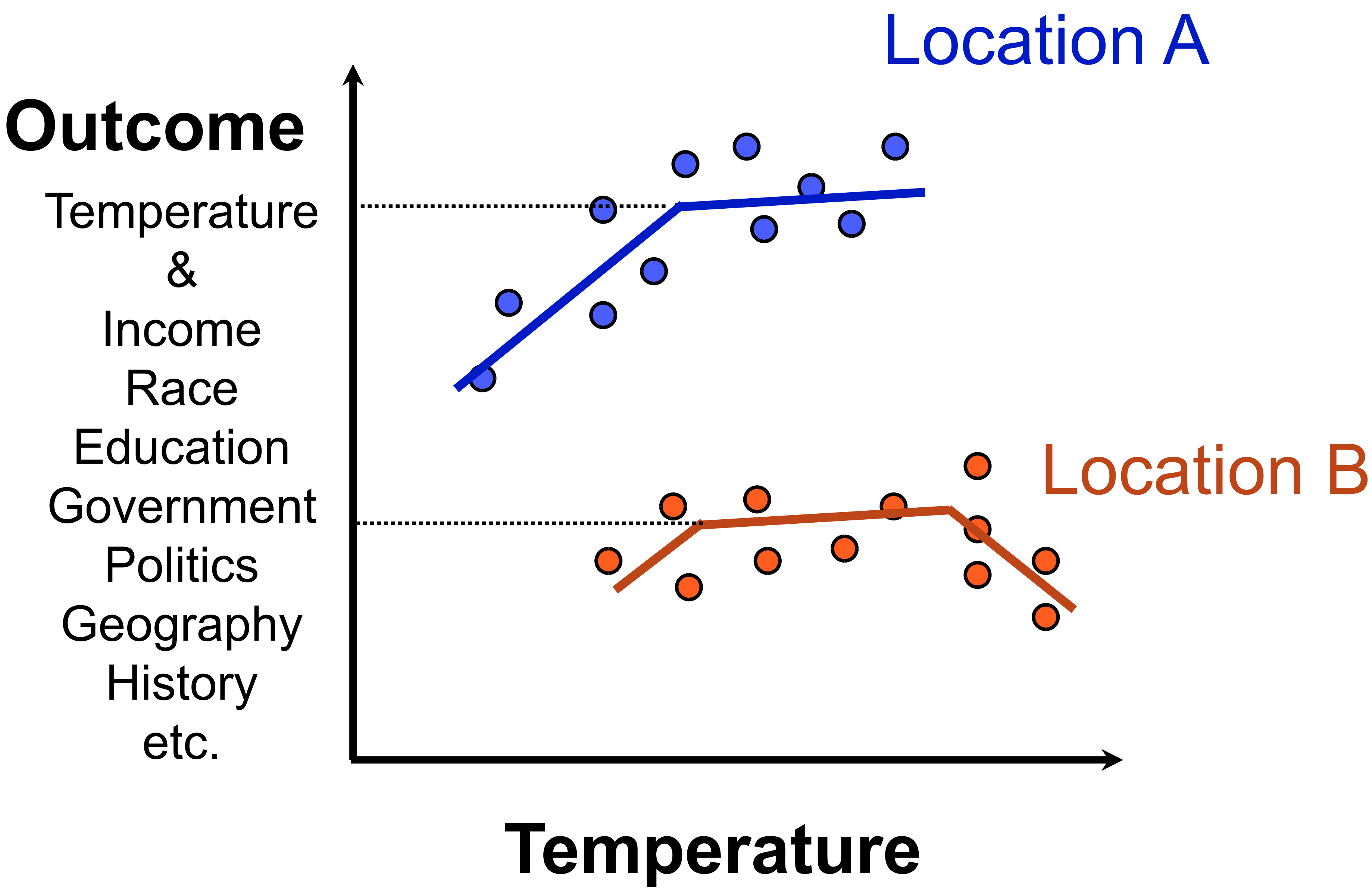
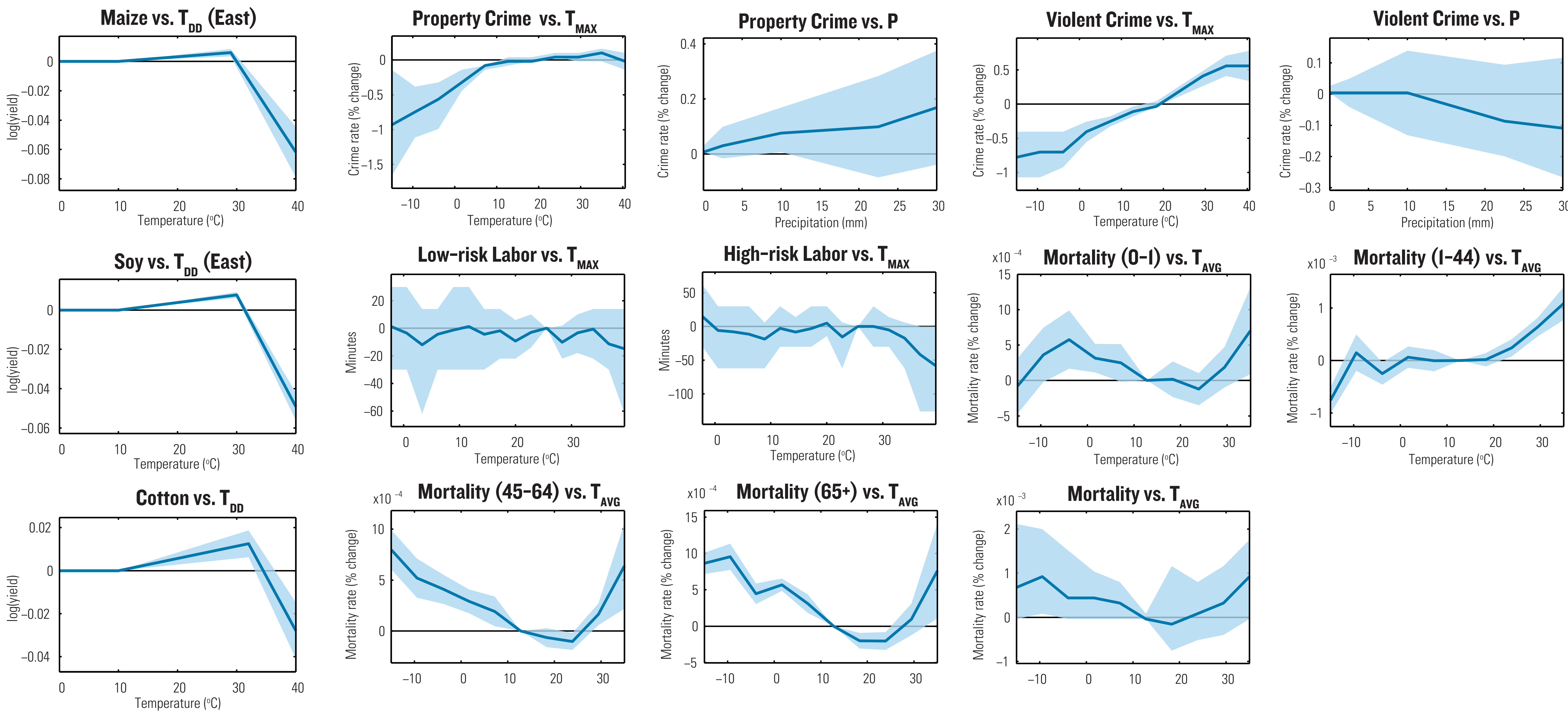
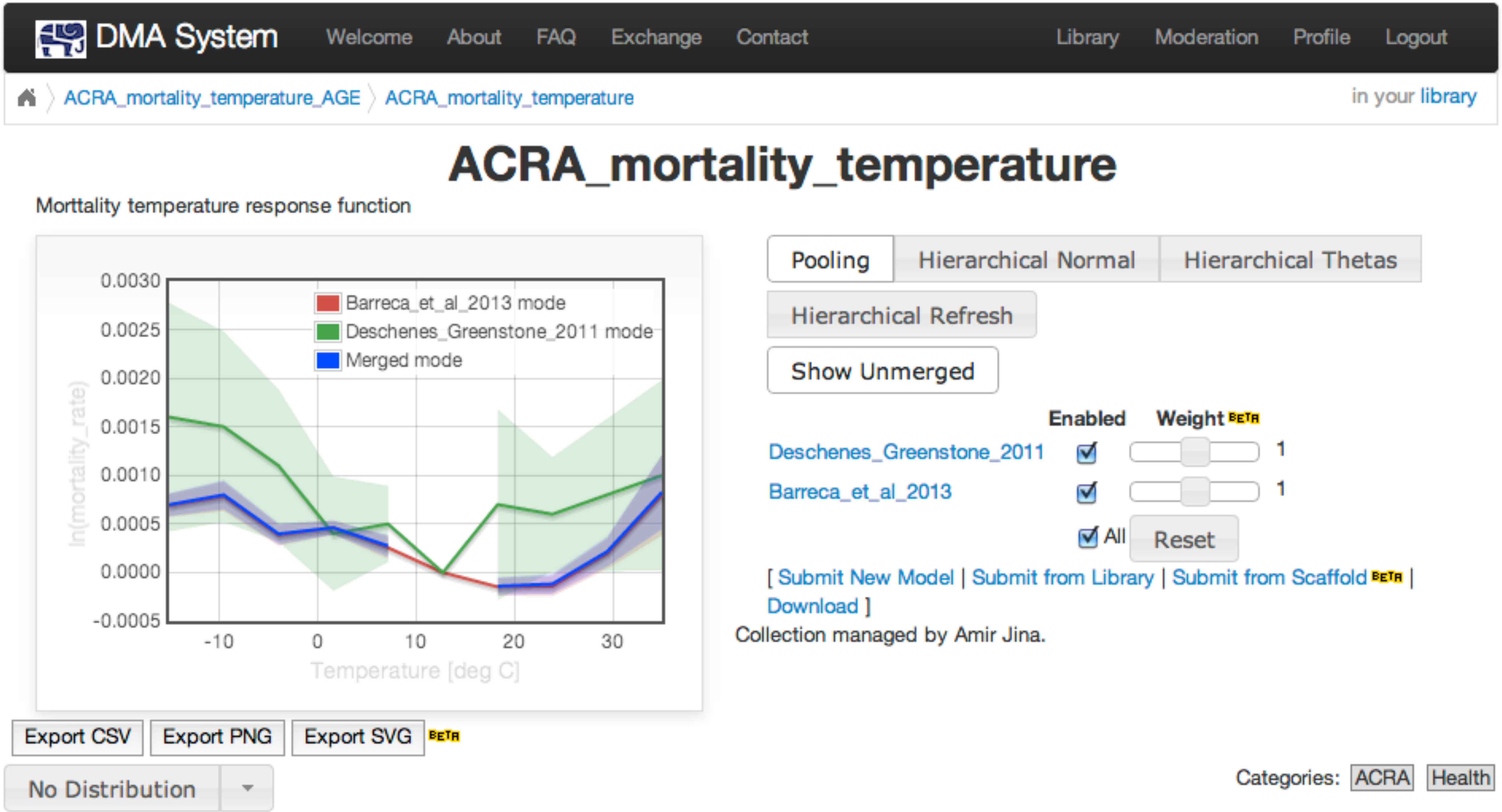


Econometric analysis of historical data allows us to relate historical climate ‘doses’ to economically-relevant responses.

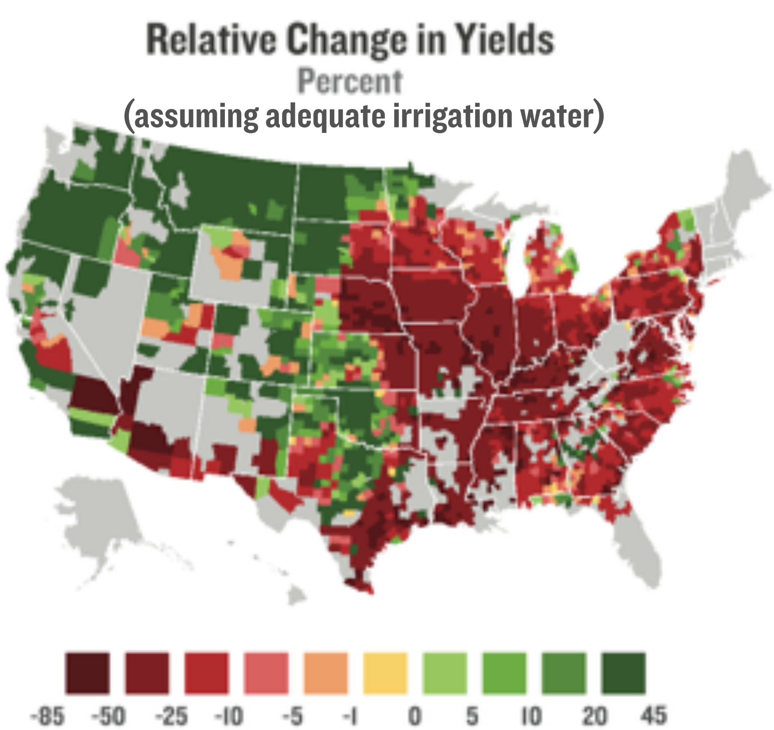


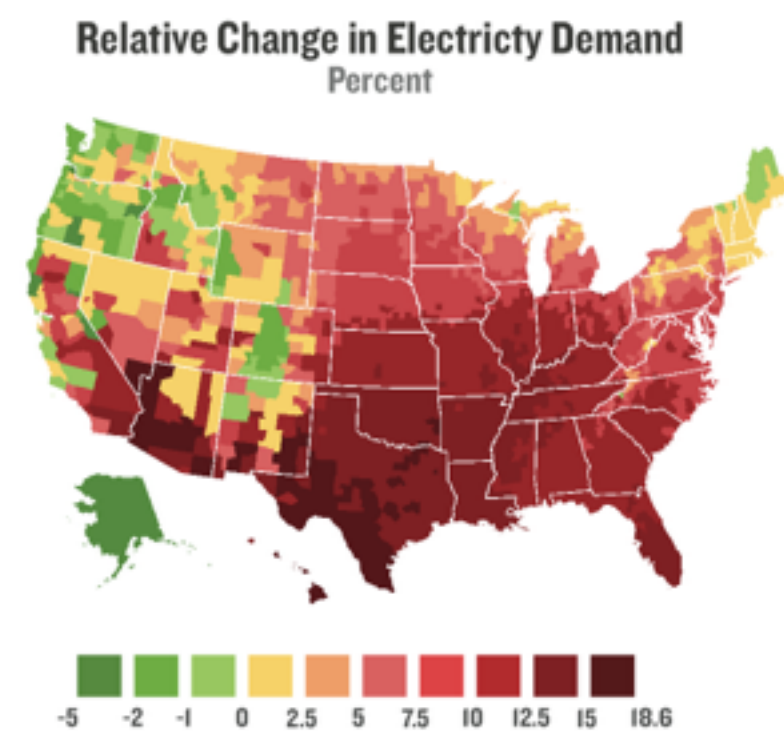
We've developing an open platform (the Distributed Meta-Analysis System) for aggregating and meta-analyzing climate impact functions

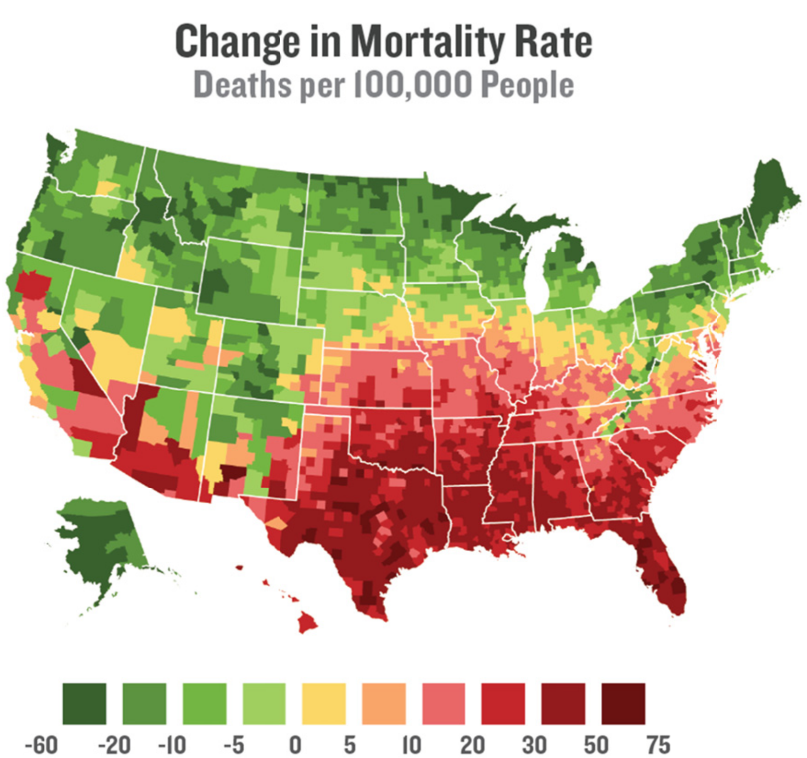


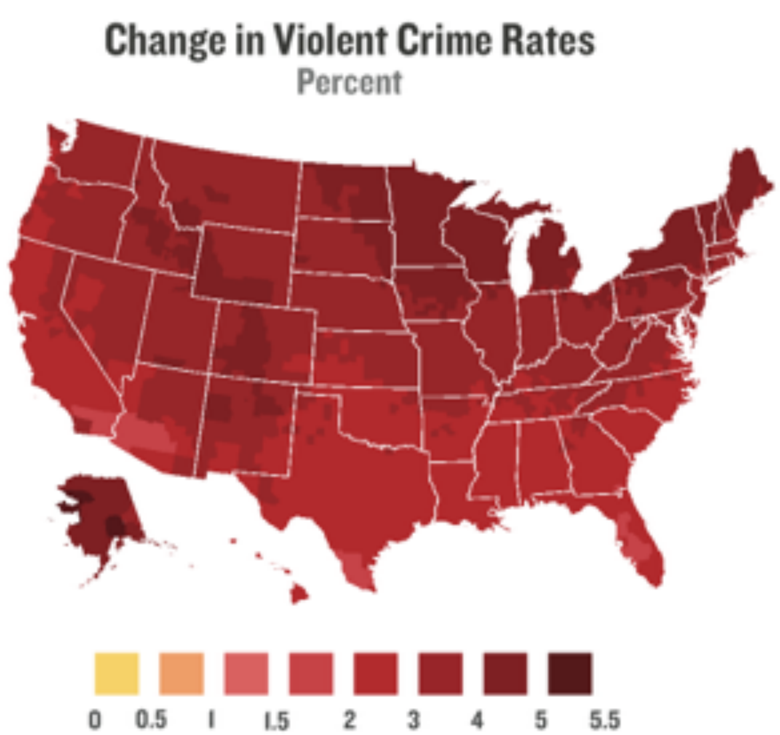
Climate change will have unevenly distributed economic impacts.

RCP 8.5, 2080-2099 average impact, median projections

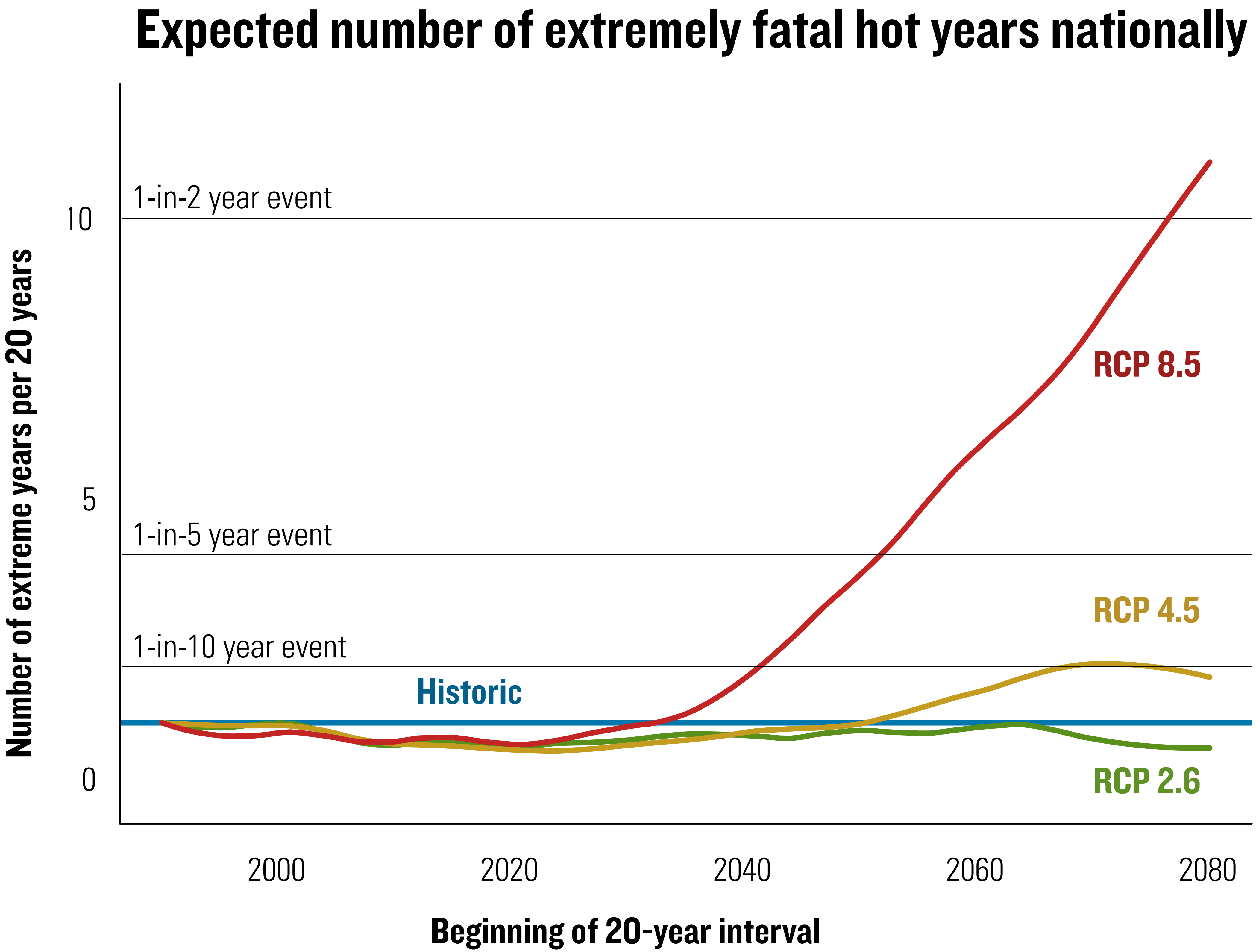








Climate change will make socio-economic extremes more common.



Both Bayesian uncertainty about future states of the world and response functions, and also frequentist uncertainty about climate variability, come into play here.

This plot answers: Given what we know now, how many economic extremes do we expect in a given future year?

1-in-20 year event in current population: 25,000 deaths

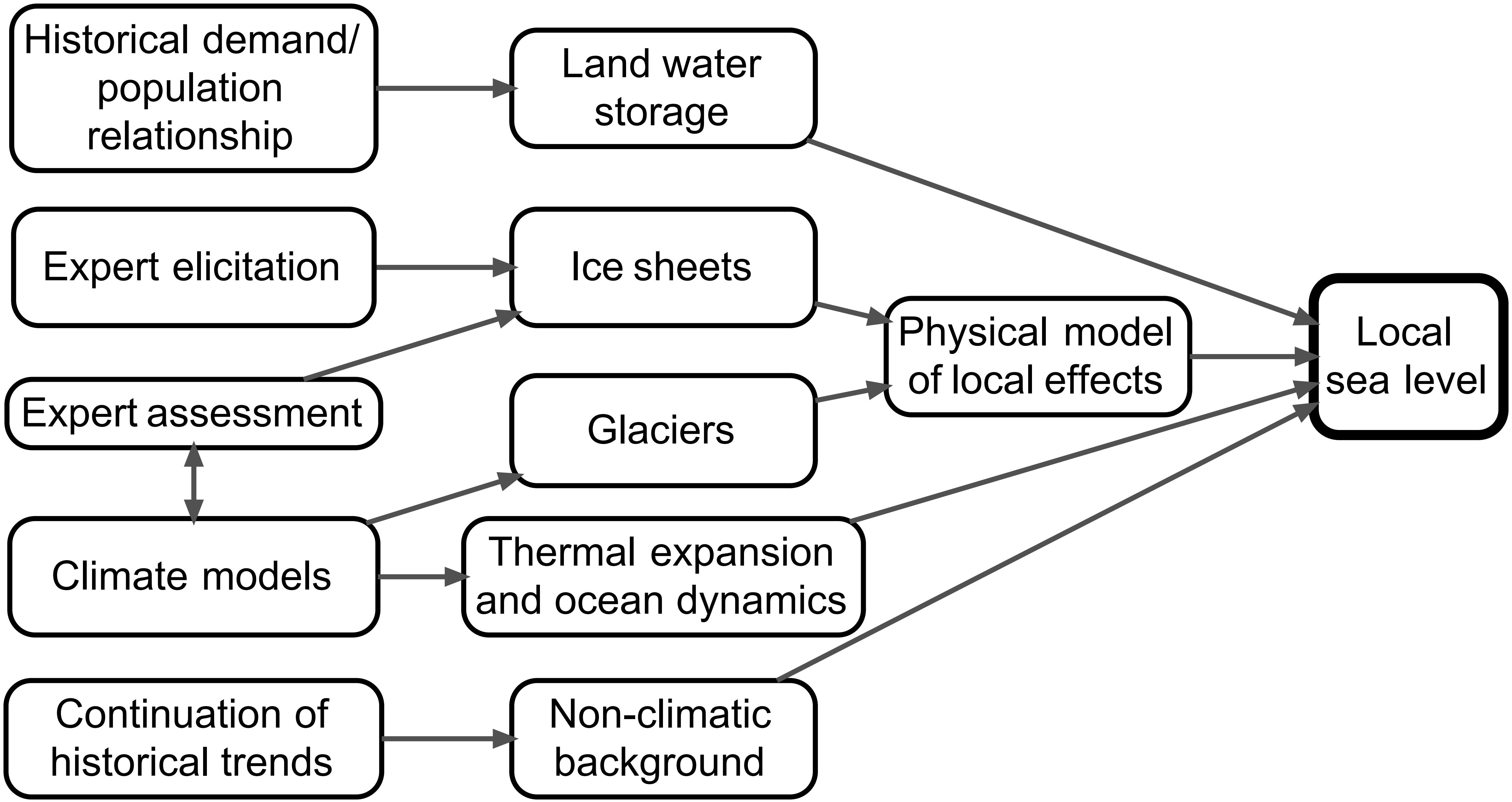
Translating uncertain projections to inform decision-making: An example of sea-level rise

For more, see:

Kopp et al. (2014), Earth's Future, doi:10.1002/2014EF000239

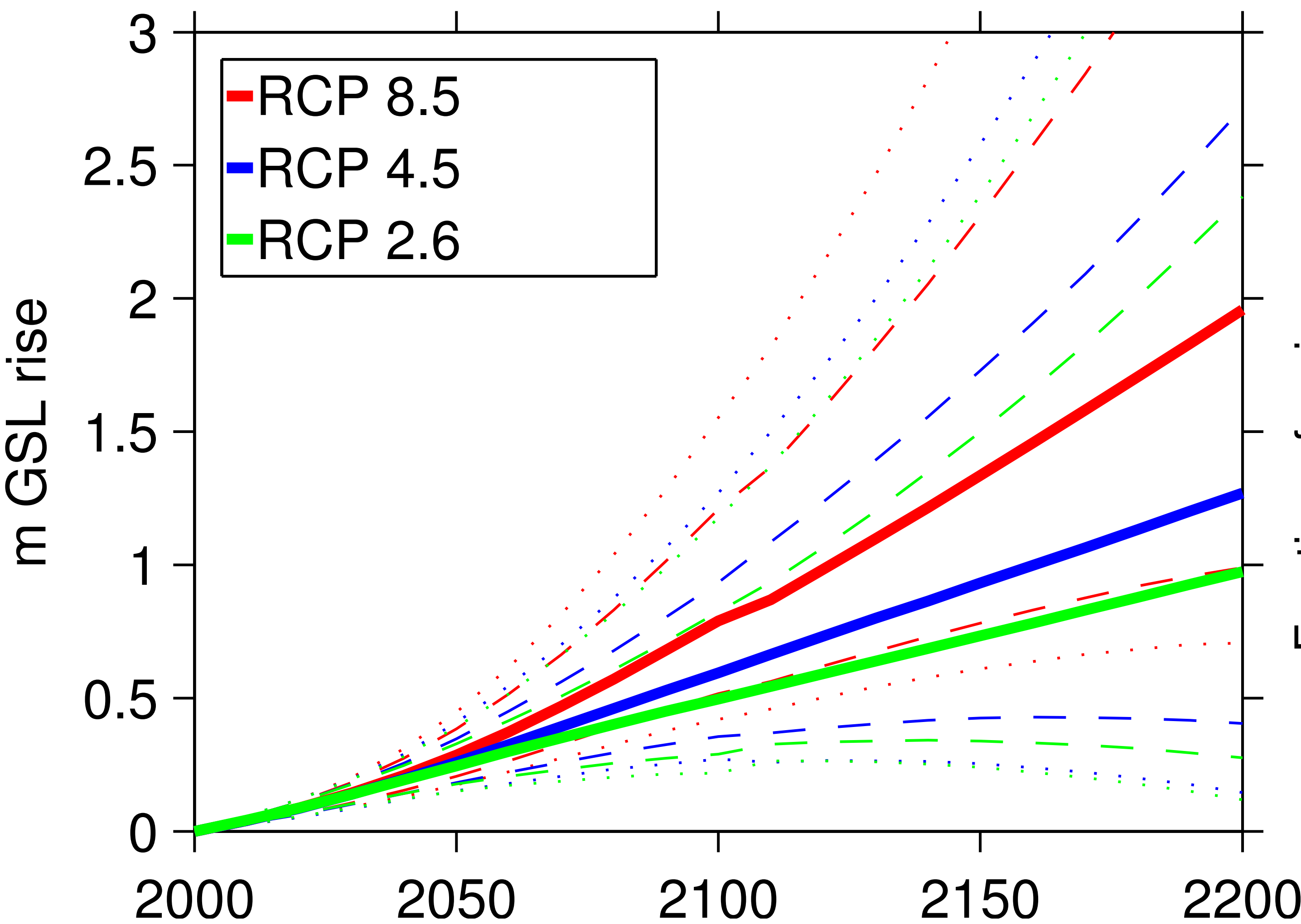
Buchanan et al. (in rev.), arxiv:1510.08550.

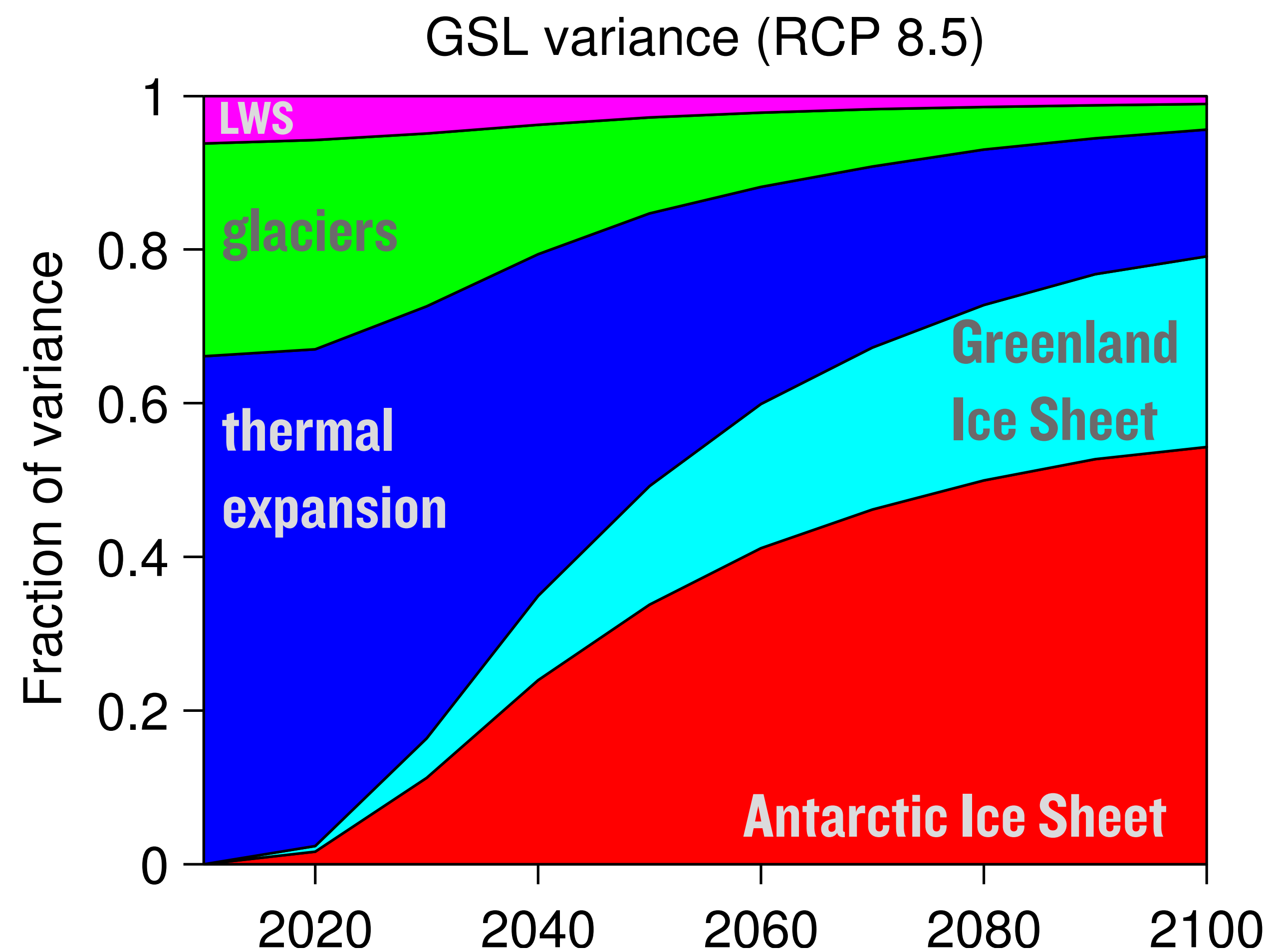
Sea-level rise projections based on bottom-up, probabilistic assessment



Kopp et al. 2014

Projected GMSL rise and sources of uncertainty

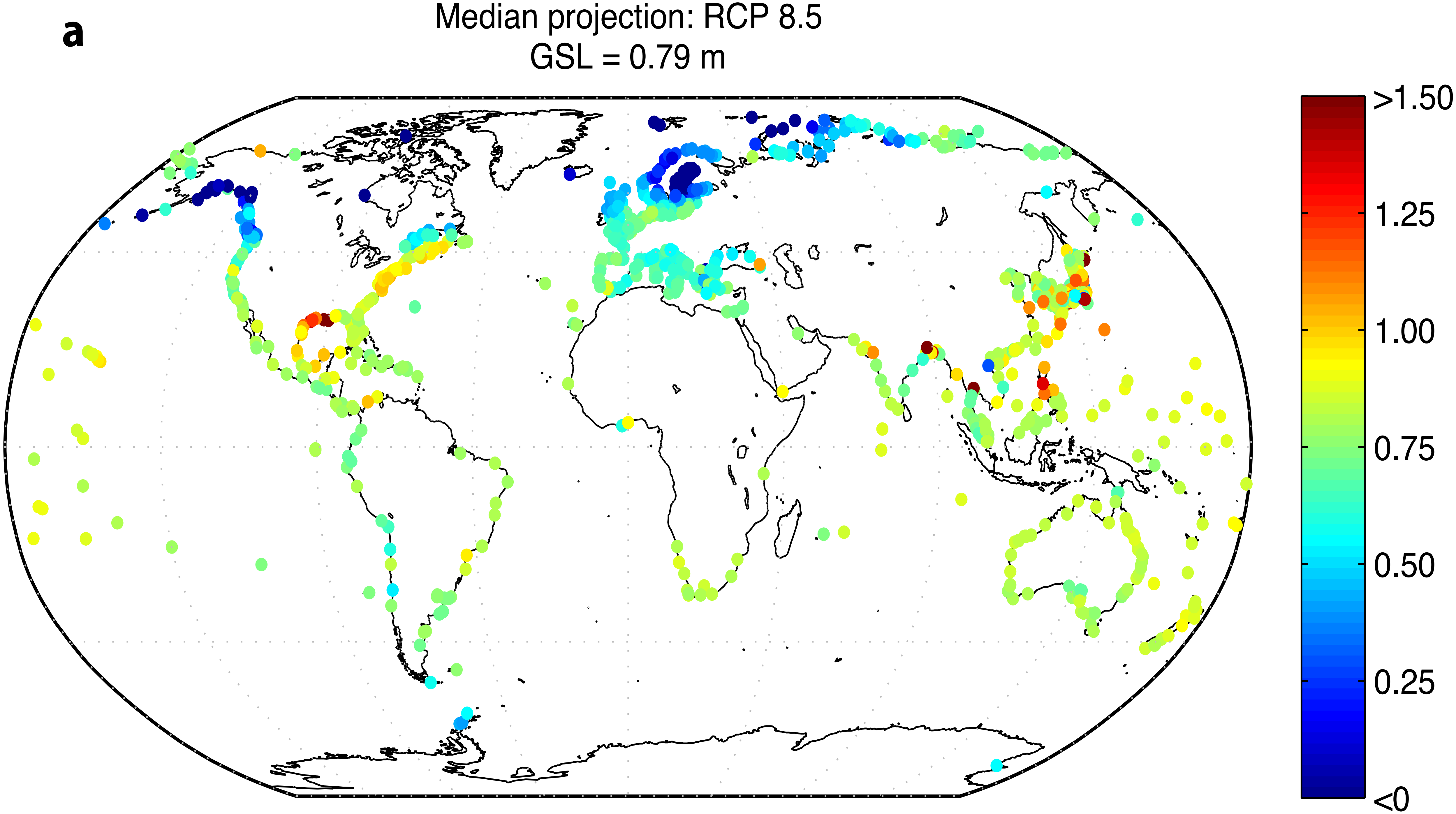




GMSL rise from 2000 to:	Likely (17-83%)	1-in-20 (95%)	1-in-200 (99.5%)	Max. poss. (99.9%)
2100, RCP 8.5 (high emissions)	24"-39" (62-100 cm)	47" (121 cm)	69" (176 cm)	96" (245 cm)
2100, RCP 2.6 (low emissions)	14"-26" (37-65 cm)	32" (82 cm)	56" (141 cm)	83" (210 cm)

Kopp et al. 2014

Local sea-level rise projections show significant spatial variability



Kopp et al. 2014

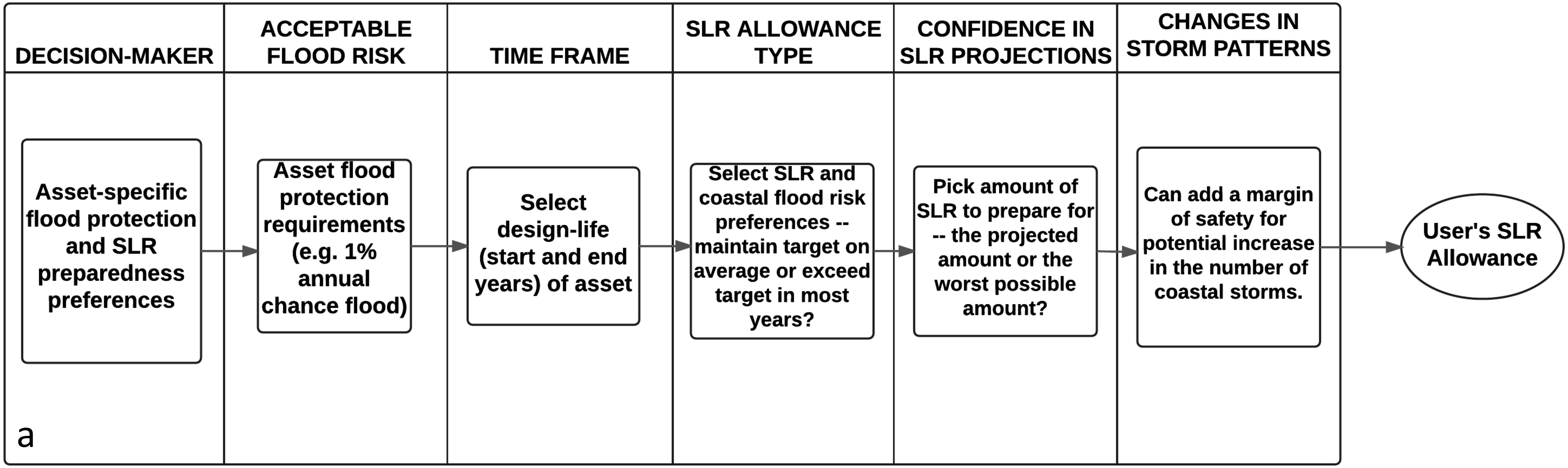
Users of our sea-level rise projection framework (in part or whole)

- NOAA nuisance flooding analysis
- California Energy Commission
- Southeast Florida Water Management District
- City of Boston
- New Jersey Climate Adaptation Alliance
- State of Delaware
- Structures of Coastal Resilience

- similar approach (which inspired ours) adopted by New York City Panel on Climate Change

How do we translate probabilistic projections into actionable information?

The sea-level rise allowance framework provides one illustrative approach.

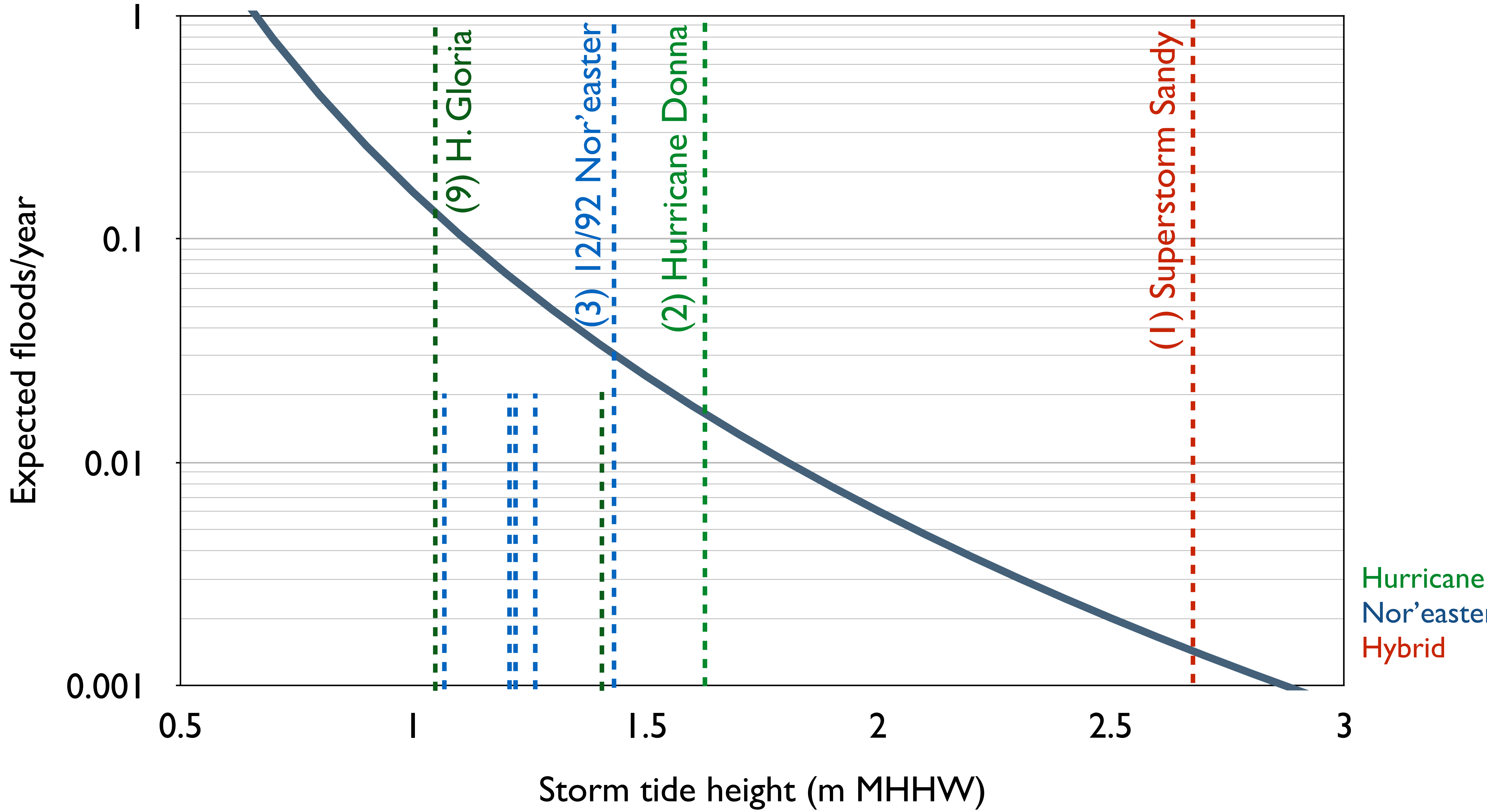


Buchanan et al., in rev.

Extreme value statistics

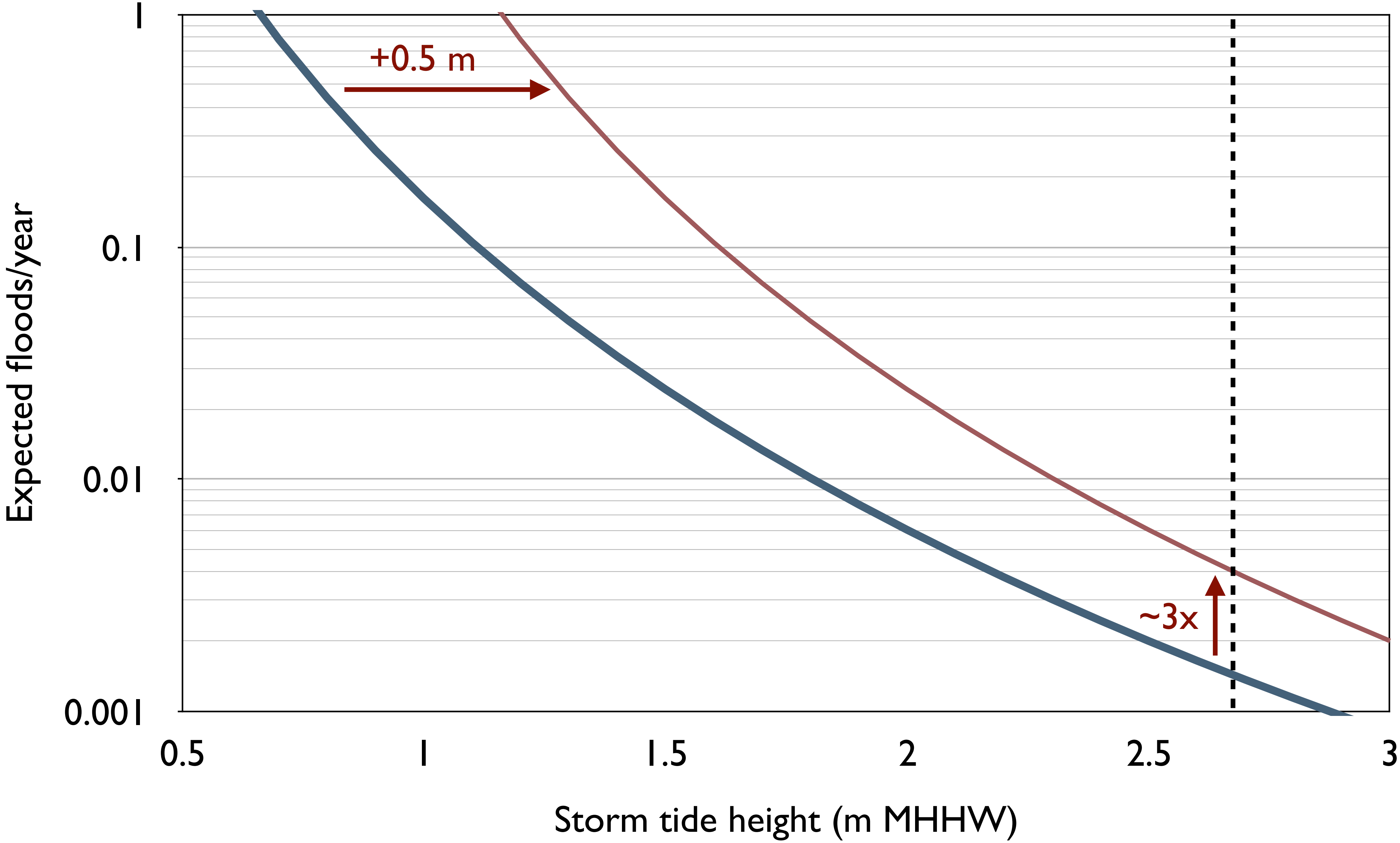
Expected number of floods per year at the Battery, New York City (1920-2013)

based on maximum-likelihood Generalized Pareto Distribution fit to observed extremes



Expected number of flood events changes significantly with SLR

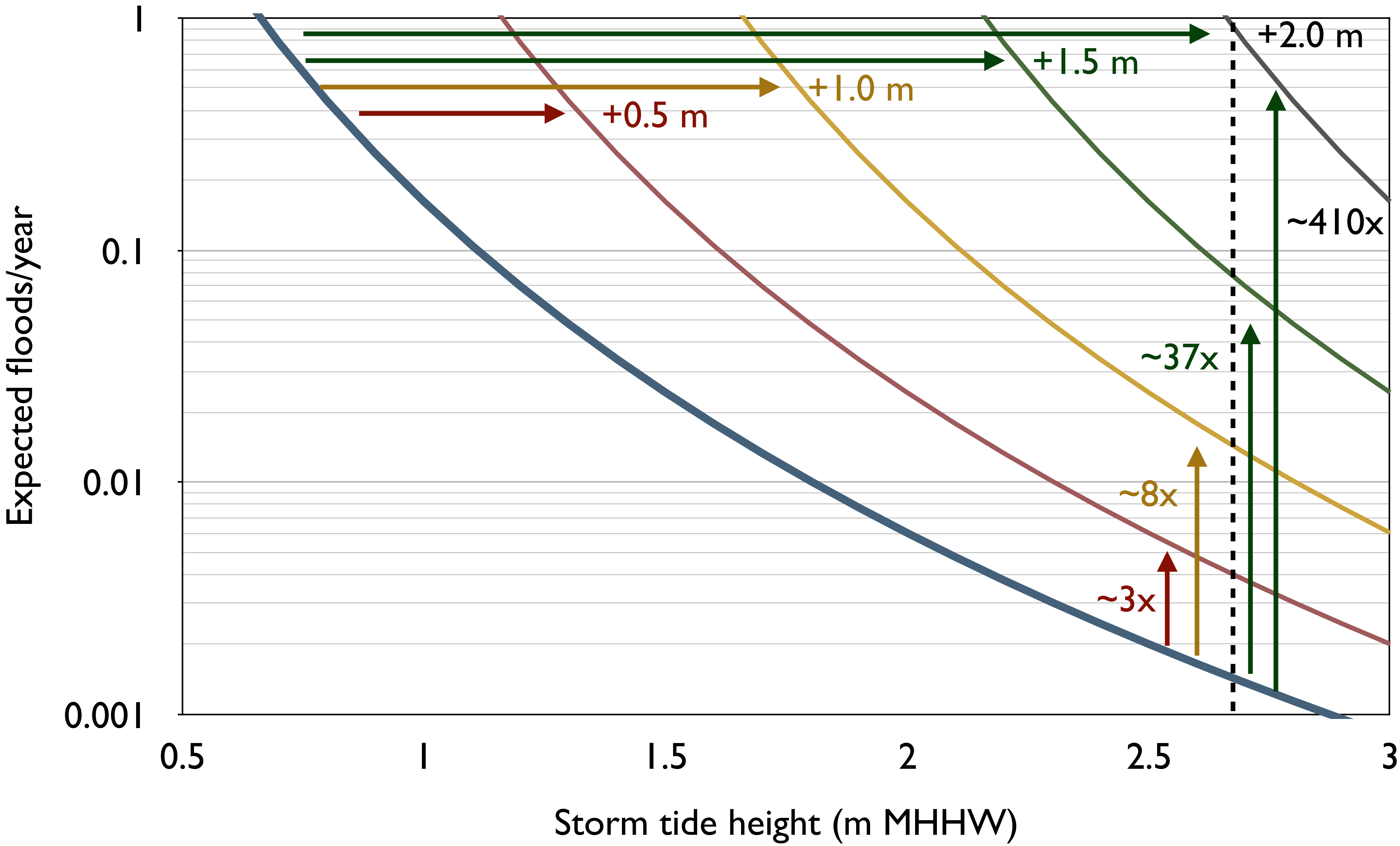
Expected number of floods per year at the Battery, New York City



Frequency increases labeled are for Sandy flood height.

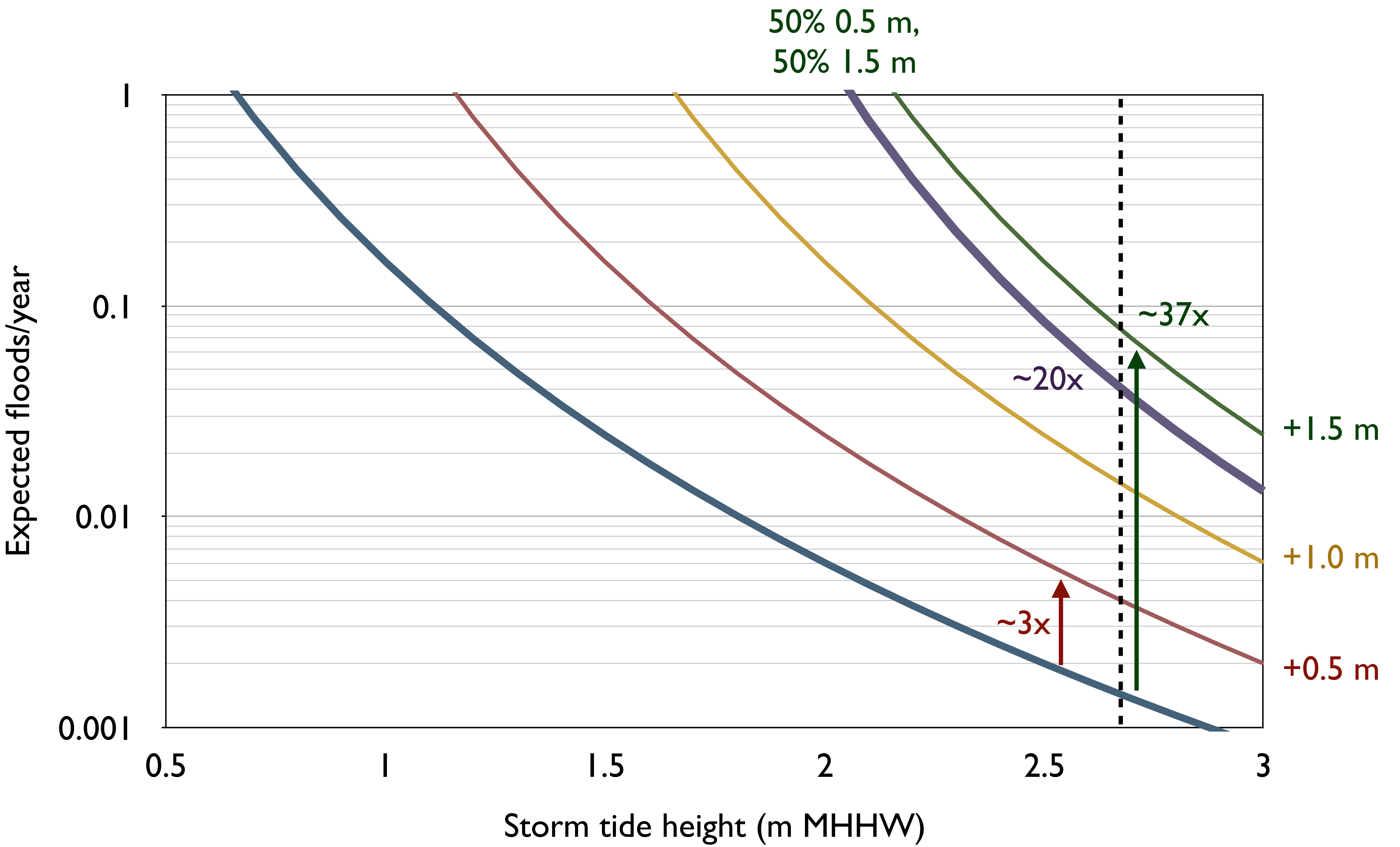
Expected number of flood events changes significantly

Expected number of floods per year at the Battery, New York City



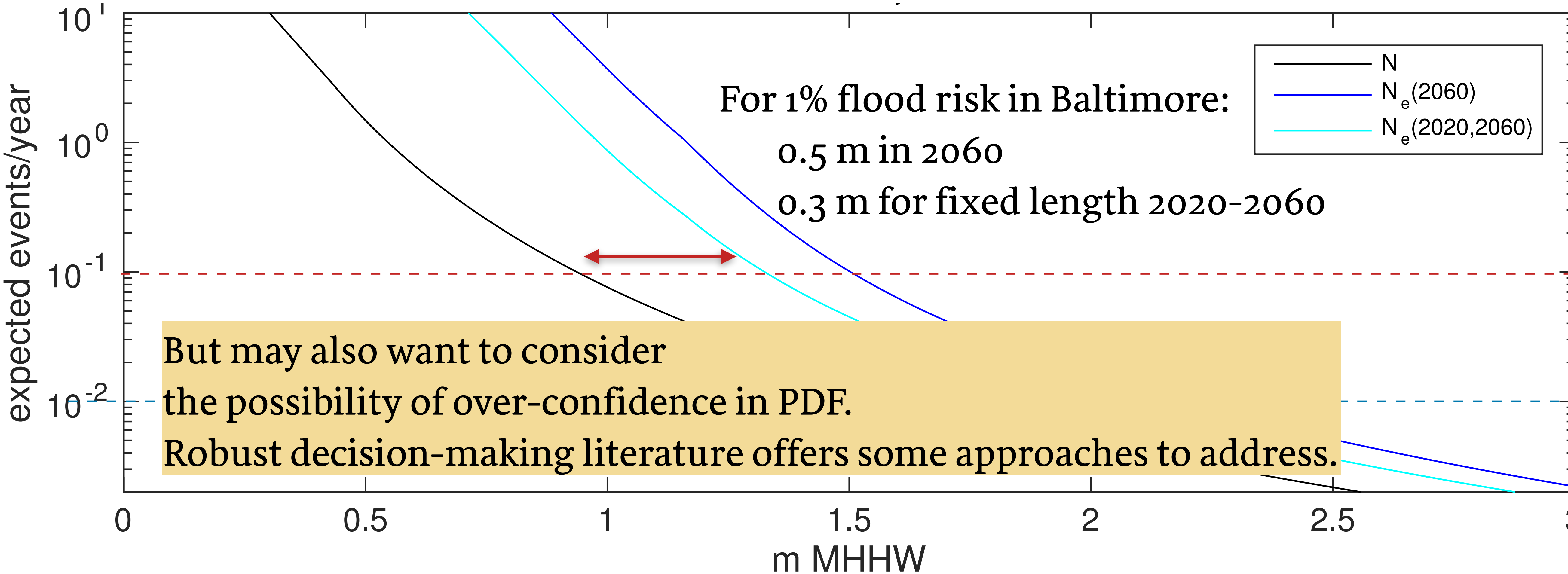
Frequency increases labeled are for Sandy flood height.

Under uncertainty, expectation heavily skews toward high end – even if SLR projection is symmetric



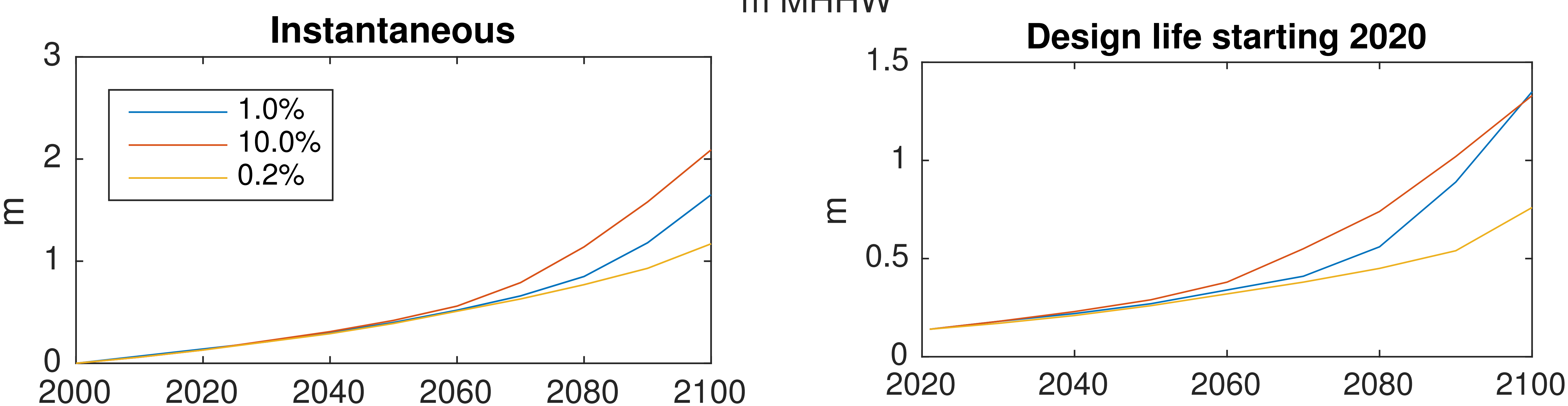
Frequency increases labeled are for Sandy flood height.

Allowances provide a framework for thinking about the interaction of extremes and changes in the mean



For 1% flood risk in Baltimore:
- 0.5 m in 2060
- 0.3 m for fixed length 2020-2060

But may also want to consider the possibility of over-confidence in PDF.
Robust decision-making literature offers some approaches to address.

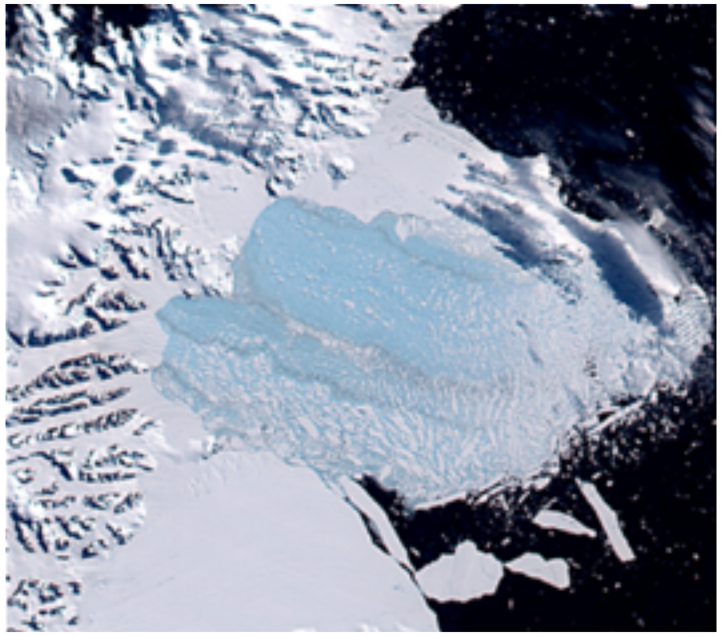


Buchanan et al., in rev.

We can't forget about those risks we don't have good ways to assess probabilities of right now – they may in the end prove to be the most important.

Example:

'Tipping elements', 'tipping points', and 'economic catastrophes'

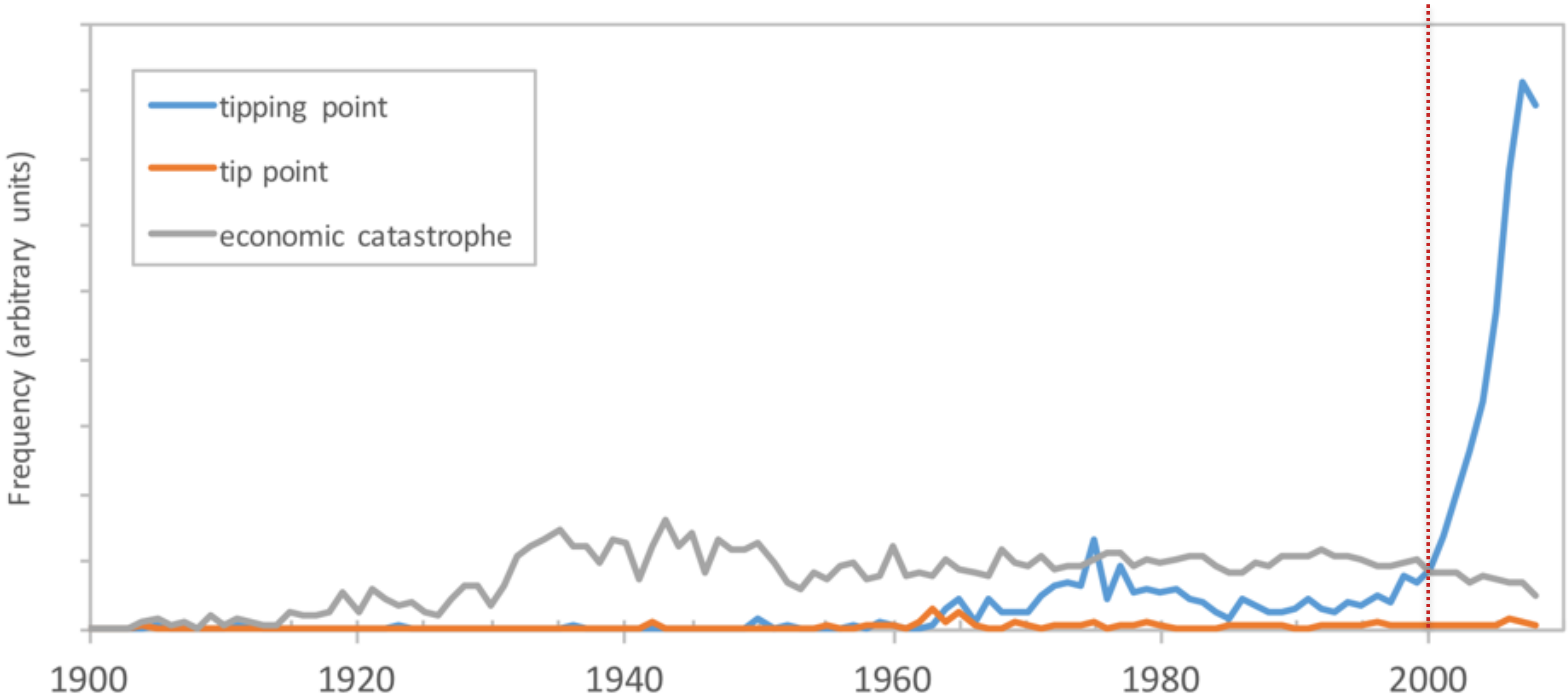


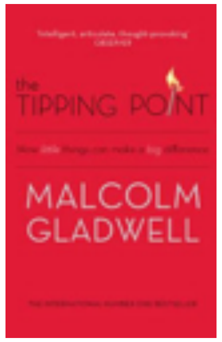
Research supported by: Linden Trust *for* Conservation

Working paper: arxiv:1603.00850

A tipping point in "tipping points"

Google N-Gram Frequency





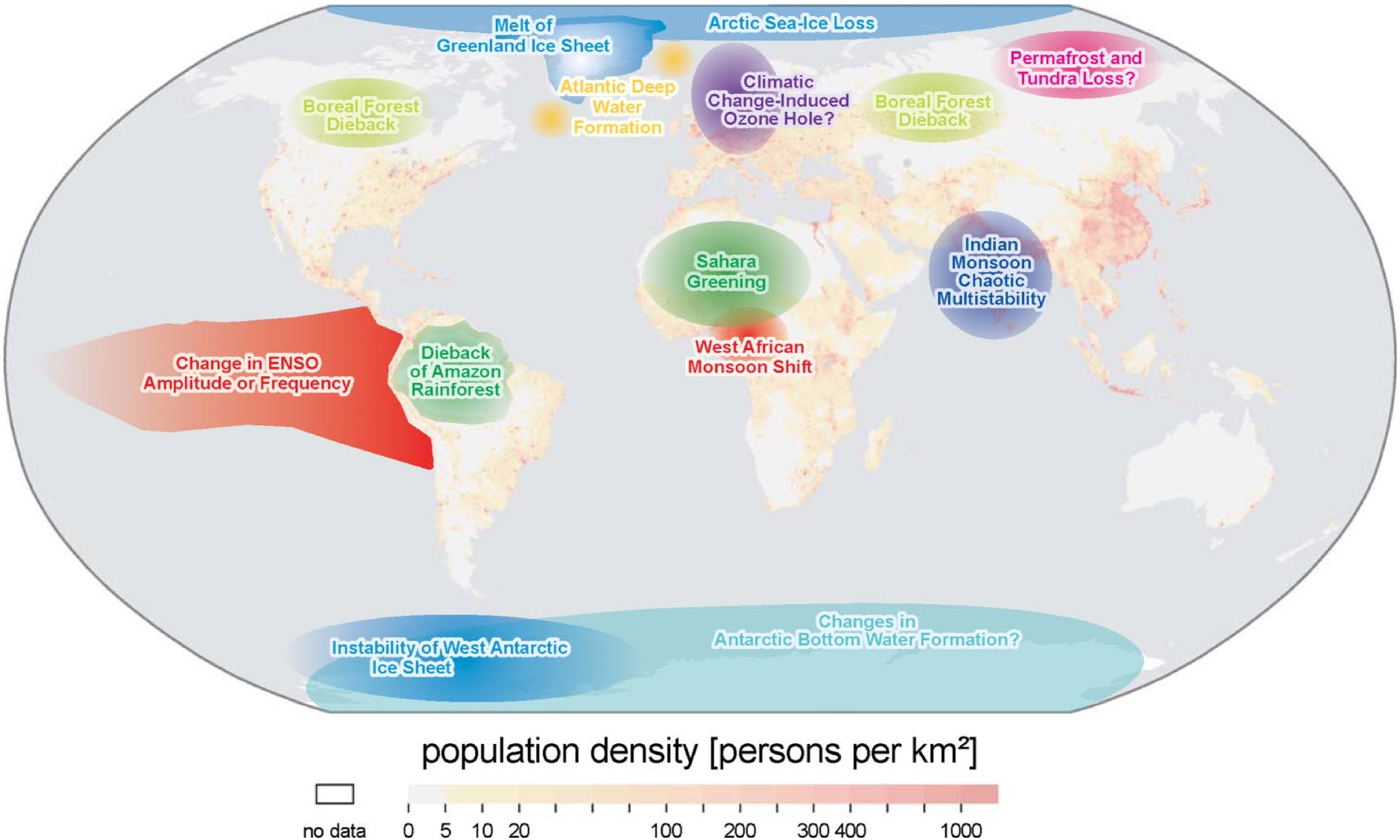
Gladwellian tipping points are: (1) contagious and involve a large change that (2) results from small changes and (3) occurs quickly.

Many climatic 'tipping elements' don't fit the third criterion.

Kopp et al. (in rev.)

Tipping elements in the Earth's climate system

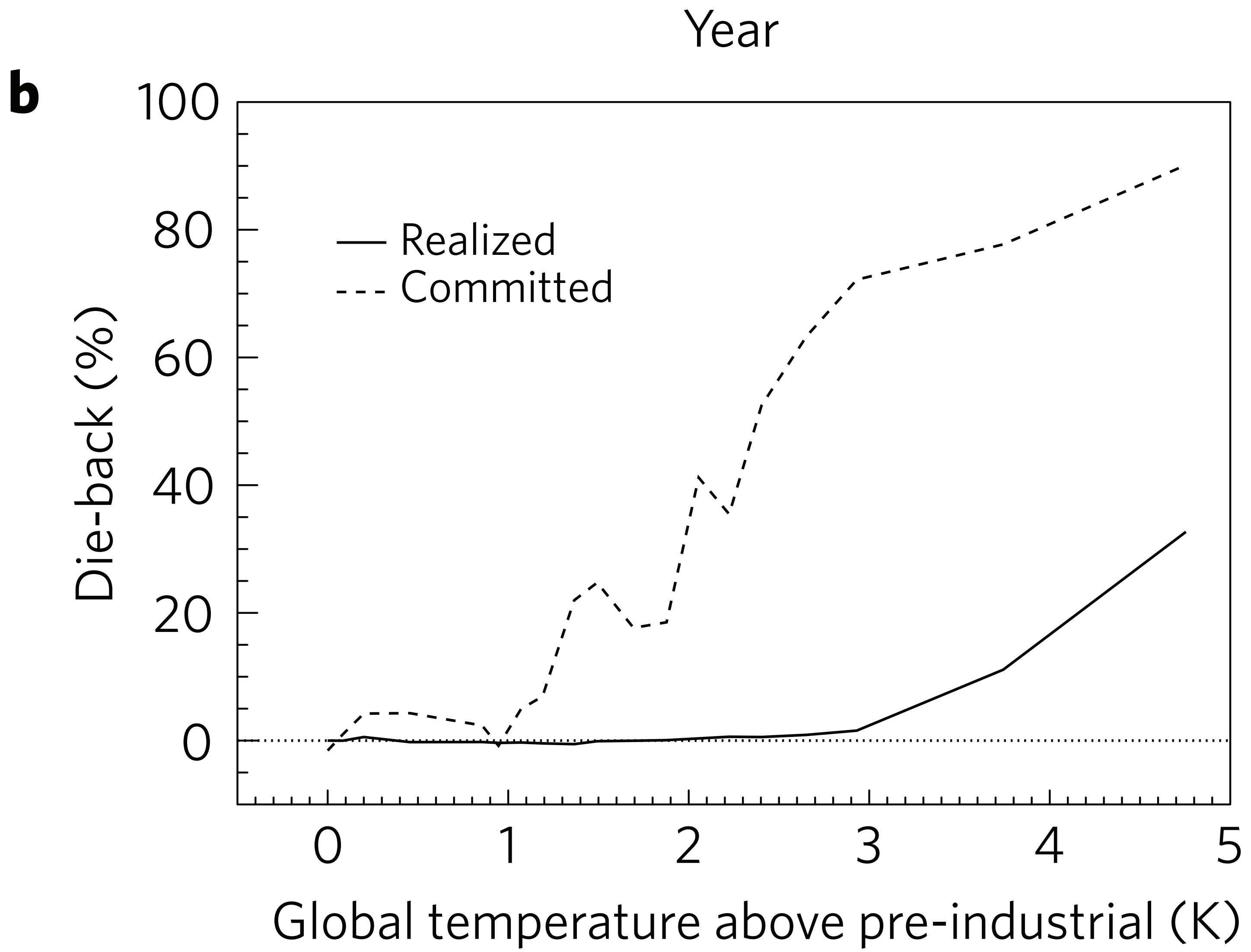
Timothy M. Lenton*†, Hermann Held‡, Elmar Kriegler‡§, Jim W. Hall¶, Wolfgang Lucht‡, Stefan Rahmstorf‡, and Hans Joachim Schellnhuber†‡‖**



Committed vs. realized changes

Many ‘tipping elements’ exhibit a long lag between commitment and realization – and thus may be more important for the long-term future of the Earth system than typical economic/adaptation timescales.

Small lags are most likely for tipping elements involving what are conventionally called ‘fast feedbacks’ – atmosphere, surface ocean, sea ice. Other elements (ice sheets, permafrost, large-scale ecosystems) likely exhibit long lags.



Example: Amazon forest cover per Jones et al. (2009), SRES A2 simulation, 1900-2100

Illustrative candidate climatic tipping elements

Candidate	Main impact pathways	Potentially Gladwellian
Regional North Atlantic convection	regional temperature, precipitation	yes
Atlantic Meridional Overturning Circulation	regional temperature, precipitation; global mean temperature; regional sea level	yes
El Niño-Southern Oscillation	regional temperature, precipitation	yes
Arctic sea ice	regional temperature, precipitation	yes
West African Monsoon	regional temperature, precipitation	yes
Coral reefs	ecosystem services	yes
Atmospheric superrotation	climate sensitivity (cloudiness)	yes
Greenland ice sheet	sea level	no
Antarctic ice sheet	sea level	no
Permafrost carbon	greenhouse gas emissions	no
Methane hydrates	greenhouse gas emissions	no
Amazon rainforest	ecosystem services; greenhouse gas emissions	no
Boreal forest	ecosystem services; greenhouse gas emissions; albedo	no

Kopp et al. (in rev.)

Illustrative potentially climate-related social tipping points

Candidate
Environmental policy change ('punctuated equilibrium' model)
Technology learning curves (mitigation or adaptation)
Technology diffusion (mitigation or adaptation)
Migration
Conflict-development trap

Kopp et al. (in rev.)

Illustrative potentially climate-related economic catastrophes

Economic catastrophes are often confused with physical tipping points in the integrated assessment literature – but there is no necessary relationship between the two.

Economic catastrophe	Illustrative effect
Environmental disaster	~15% output reduction for >20 years due to 1-in-100 country-year cyclone
Civil war	~15% output reduction for >10 years if combined with strengthened executive power
Temperature-induced growth rate effects	Potential stalling of growth in warm countries with low productivity growth
Twin currency/banking crises	~10% output reduction for >10 years
International war on country's own soil	Transient per-capita output drop of > 50% in Europe during World War II
Large-scale political and economic restructuring	45% drop in GDP/capita in Russia from 1989 to 1996

Kopp et al. (in rev.)

Some paths forward

For ***climatic tipping elements:***

– What is the probability of occurrence? (Role for expert elicitation, combined with models of physical processes?)

– What are the consequences of crossing a critical thresholds? (Use physical models to determine magnitude, timescale of resulting physical changes? Use empirical models and sectoral process models to assess how those physical changes translation into economic costs?)

For ***social tipping points:***

– What is the landscape like? What are the relevant social mechanisms driving positive feedbacks? How can they be characterized?

For ***economic catastrophes***:

– What causes economic catastrophes, and how might they be influenced by climate change? (Clearest links for environmental catastrophes, civil conflict, temperature effects on growth)

Kopp et al. (in rev.)

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