Extreme event risk and earth system models

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Future of Earth System Modeling
Caltech, May 16, 2018

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Outline

- Why model extreme event hazard
- How model extreme event hazard
- A couple of examples (about hurricanes, but some aspects are more broadly relevant)

Based in part on a few years of interaction with the insurance industry, and (to a lesser extent) climate impacts people

Why model extreme event hazard?

- Risk assessment in the present − depending on time scale may or may not need to assess climate change delta. Maybe obs-based empirical approaches are enough.
- Event attribution − need ESMs & need delta (present-past).
- Projection − need ESMs & need delta (future-present).

Disaster losses are “fat-tailed” − big ones dominate.

From hazard to risk

- Hazard = probability of event with given characteristics
- Risk = hazard*exposure*vulnerability
- “Catastrophe model” represents the whole thing − output is most often financial loss.
- Exposure and vulnerability can be represented at many scales. Often data-limited.

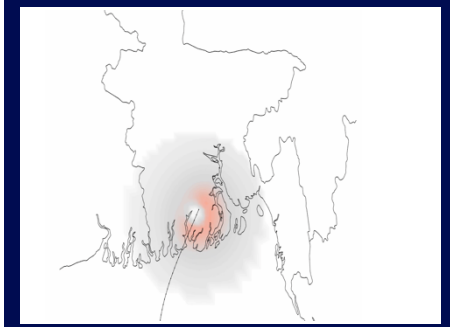
Risk modeling applications

- (Re)insurance: Contracts written one year at a time, so "climate change will be priced in as it happens". Exposure/ vulnerability data relatively good. Model can be calibrated on past claims. Mature business!
- Climate adaptation or impact studies. What is the cost (however measured) of action X or its absence? In principle much broader set of possible impacts and longer time horizons. Exposure/vulnerability data may be much worse.
- Energy policy: explicit event risk calculations could also in principle influence, e.g., social cost of carbon.

CLIMADA simulation platform: Probabilistic risk analysis and adaptation responses/options appraisal

regional scenarios

weather → hazard



adaptation responses/ options

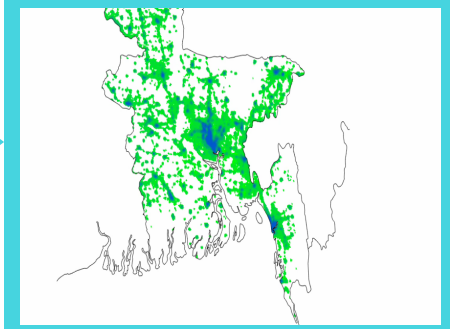
climada (open source[1]): fully probabilistic event-based simulation

risk analysis + risk mapping, early warning...

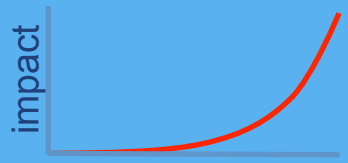
adaptation responses/ options appraisal (incl. effectiveness, cost/benefit)

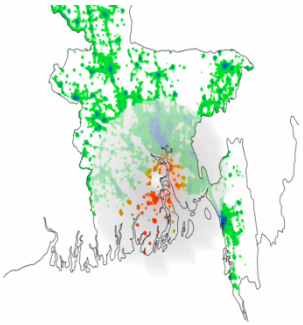
Development scenarios

exposure



vulnerability





Welker, Martius, Stucki, Bresch, Dierer & Brönnimann, 2015
Schwierz, Köllner-Heck, Zenklusen, Bresch, Vidale, Wild, Schär, 2010
Della-Marta, Liniger, Appenzeller, Bresch, Köllner-Heck, Muccione, 2010

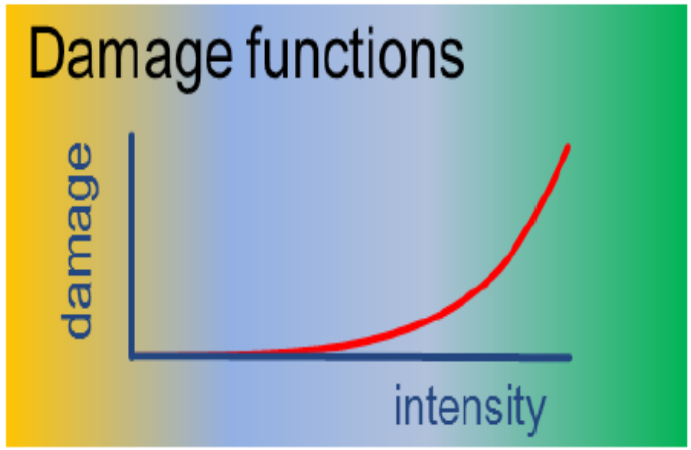
CLIMA DA

[1] https://github.com/davidnbresch/climada

Slide from David Bresch, ETH

Damage generally quite nonlinear, so absolute magnitude of physical variables matters!

New hurricane damage functions



$$\text{Damage} = \alpha \times f_1(\text{Hazard}) \times f_2(\text{Socioeconomy})$$

$\neq 1$ → $f_2 \propto \text{GDP}^{\beta_{GDP}}$

$\neq 1$ → $f_2 \propto \text{Pop}^{\beta_{Pop}} \times \text{GDPpc}^{\beta_{GDPpc}}$

Slide from Tobias Geiger, PIK

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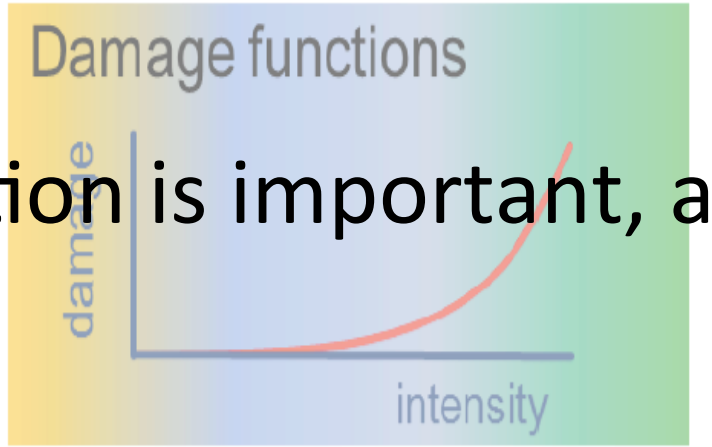

Thus resolution is important, as are biases!

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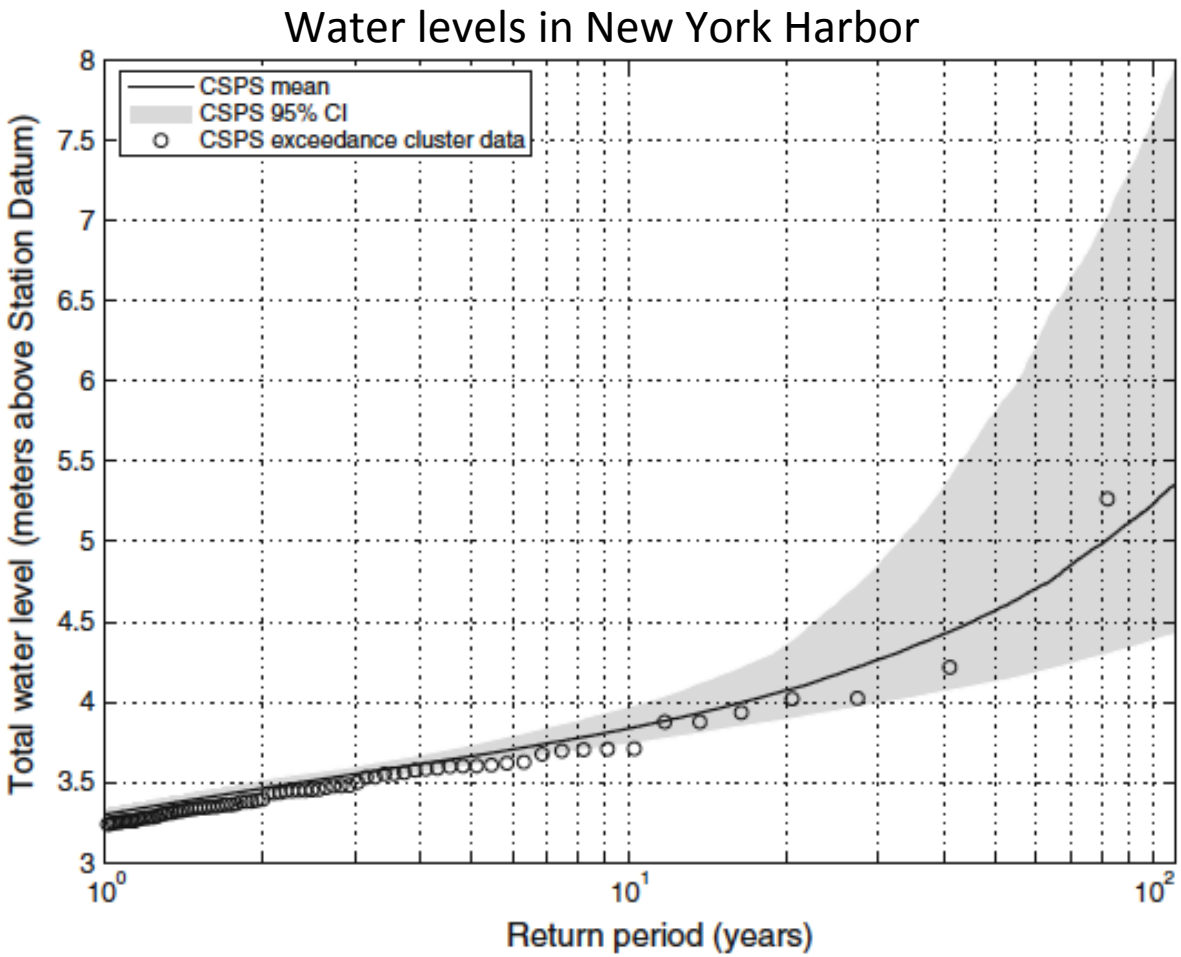
How model extreme event hazard?

- Extreme value theory − extrapolate from short data records to get rare event probabilities.
- Monte Carlo models that generate synthetic events mostly based on historical record.
- Downscaling models, statistical, dynamical, or in between, in which event probabilities and characteristics are conditional on given large-scale climate fields.
- ESM!

Extreme value theory: given IID data, the distribution of extremes (block maxima or peaks over threshold) has a specific functional form



Lopeman et al. 2015

Stationarity is a problem.

Jain and Lall, 2001

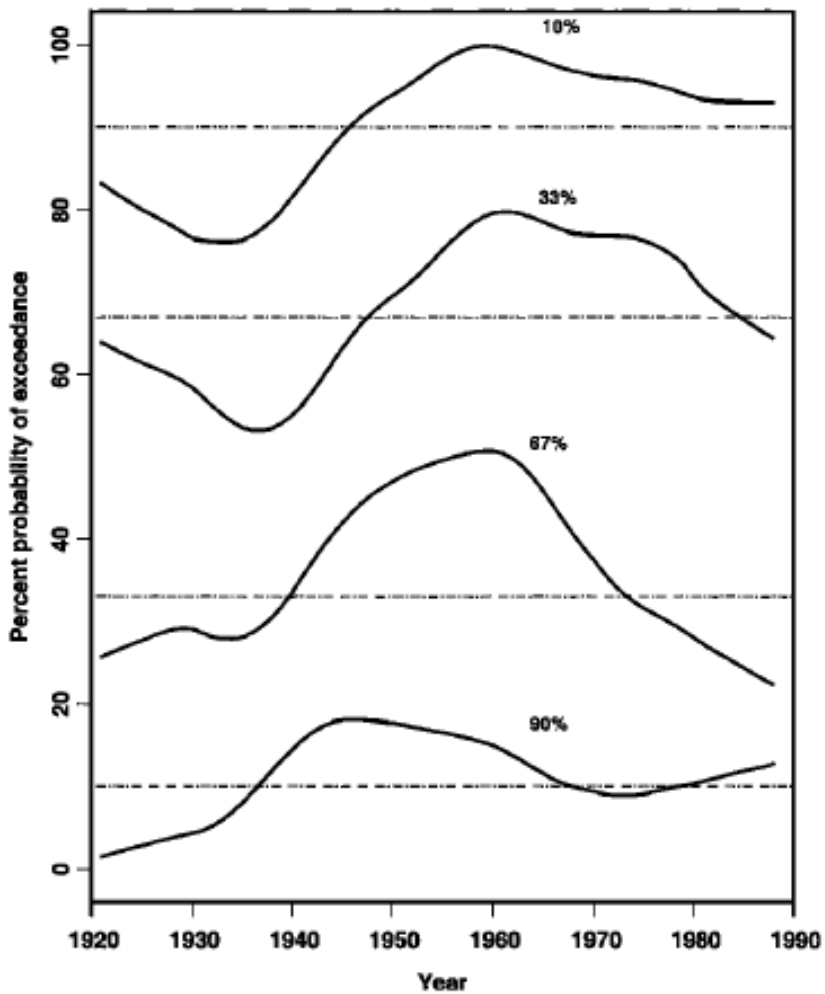
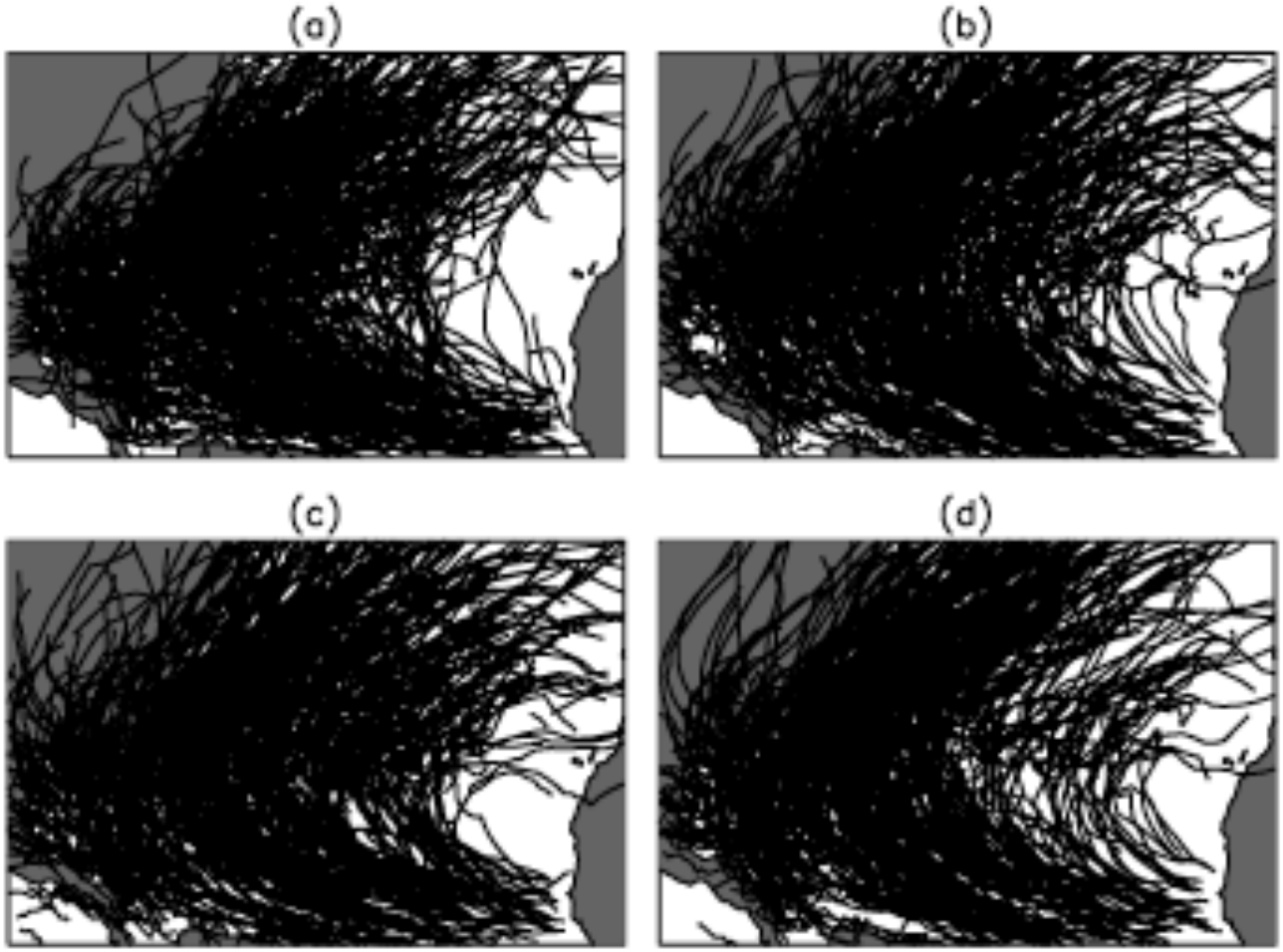


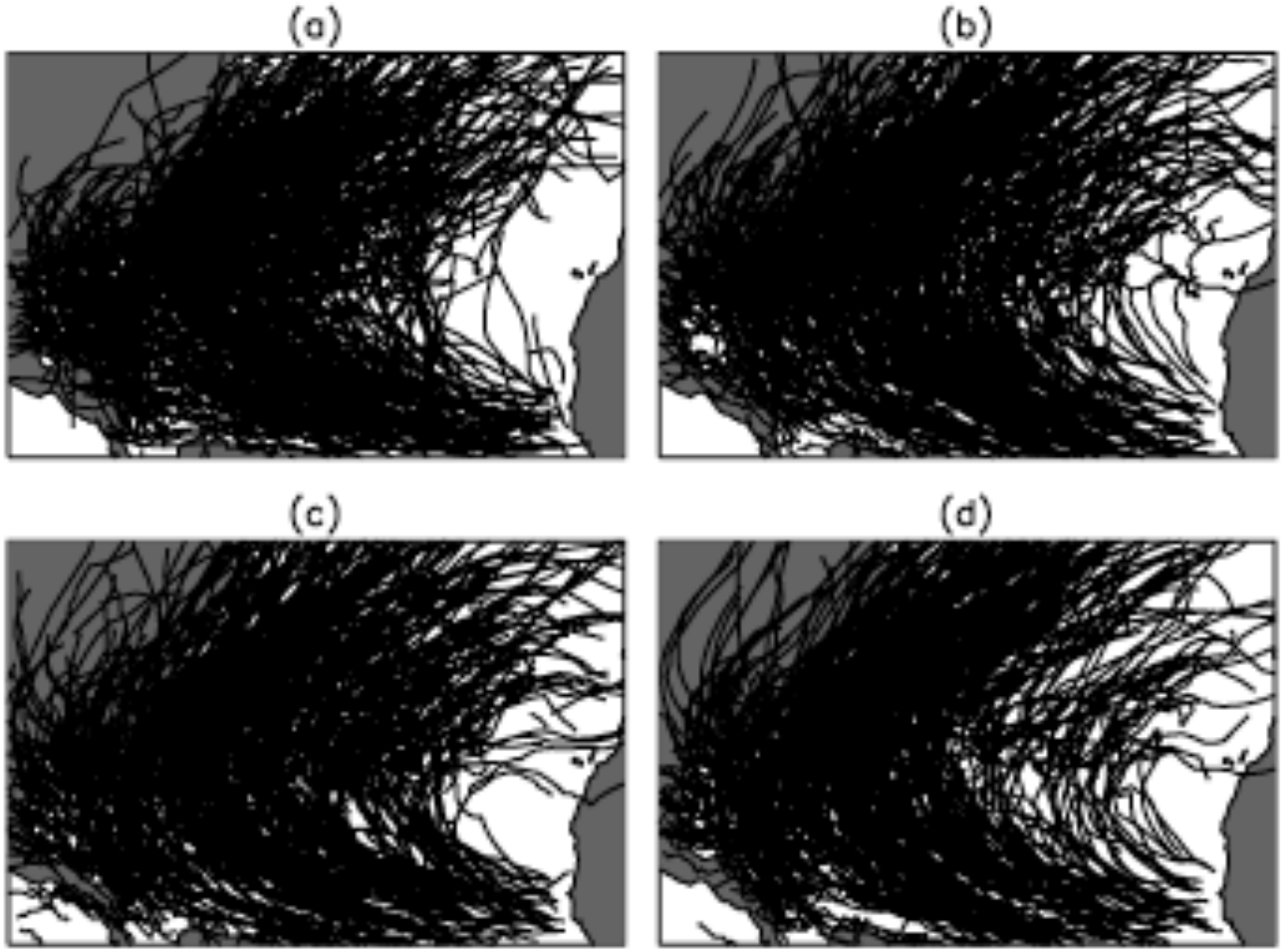
Figure 2. Trends in some key percentiles (10th, 33rd, 67th, and 90th) of the annual maximum flood for the Similkameen River. The trends were estimated nonparametrically using local regression of a threshold exceedance process with a 40-year window. The estimates near the ends of the flood record may be discounted since they have higher variance. Dashed-dotted lines represent the percentiles estimated from the full record that correspond to the threshold exceeded. Changes in the "spread" and monotonic trends in these percentiles reflect changes in the underlying probability distribution as a response multidecadal-to-secular forcings, which, in turn, may modulate the interannual (e.g., El Niño) modes.

Hazard models that generate synthetic event sets based primarily on historical record using Monte Carlo approaches. Maybe a couple of bulk environmental predictors (e.g., basin SST, ENSO).



Hall and Jewson (2007)

A whole cottage industry exists around these kinds of models!
Methodologies generally proprietary...

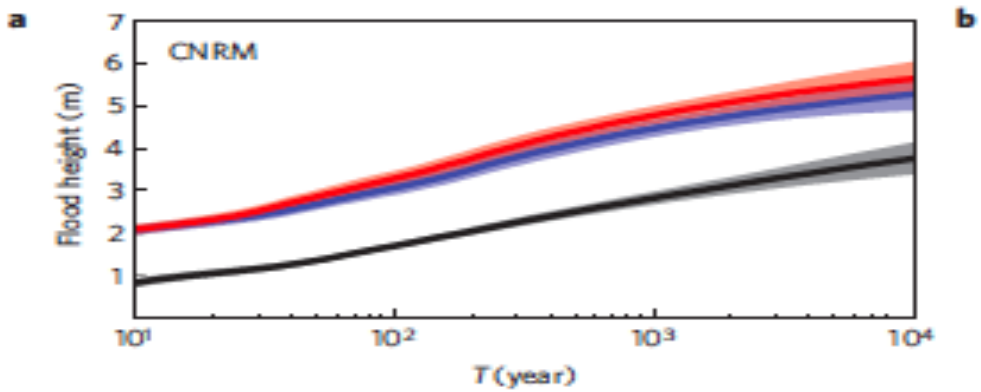


Hall and Jewson (2007)

Emanuel (2006, 2008) hybrid statistical-dynamical TC downscaling (aka hazard modeling) system

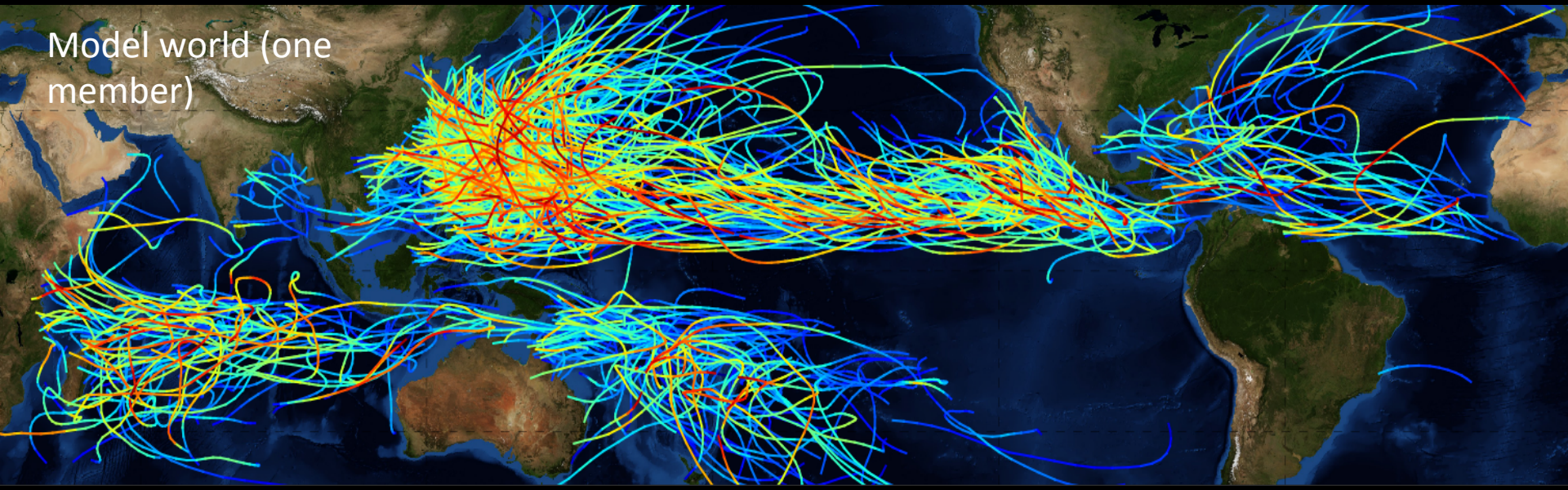
- Embed a high-resolution, deterministic, coupled air-sea hurricane model in a large-scale flow determined from global reanalyses or climate models
- Genesis determined by random seeding followed by natural selection using the deterministic model to predict intensity
- Tracks determined by a simple beta-and-advection model
- Feasible to simulate 100,000 events

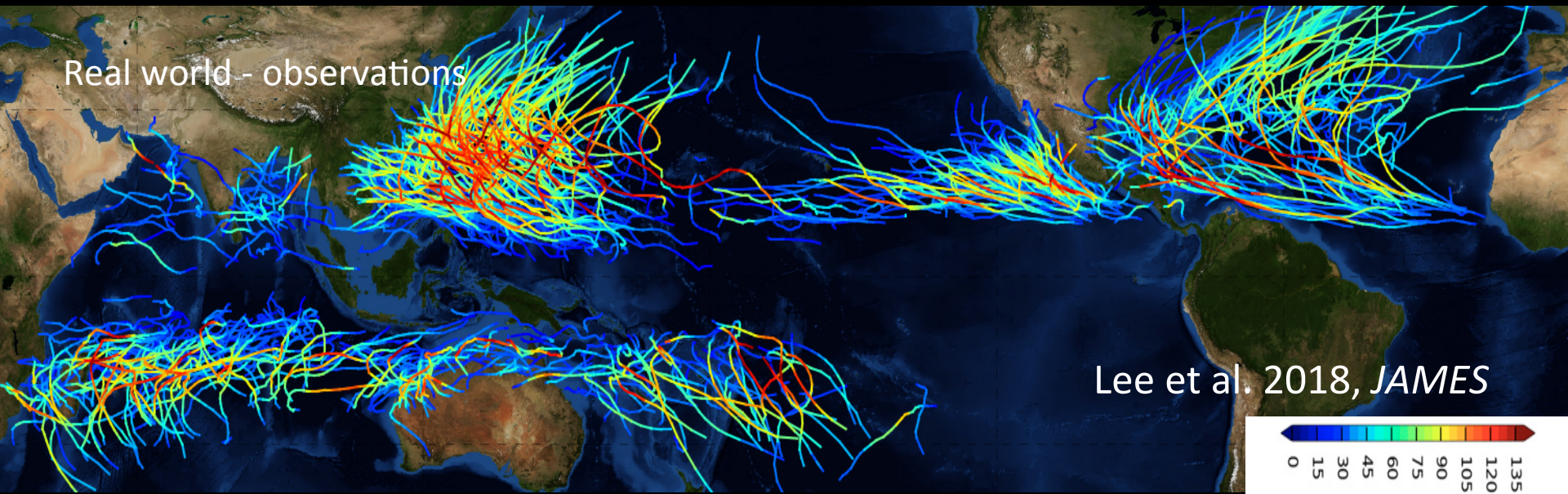
For 2100 warming scenario, and 1m sea level rise, increase of ~2-20 in annual probability of Sandy-level flood in NYC.



Lin et al. 2012, *Nature Climate Change* **2**, 462-467.

Columbia TC Hazard model – a different statistical-dynamical hybrid. Still uses environmental data.

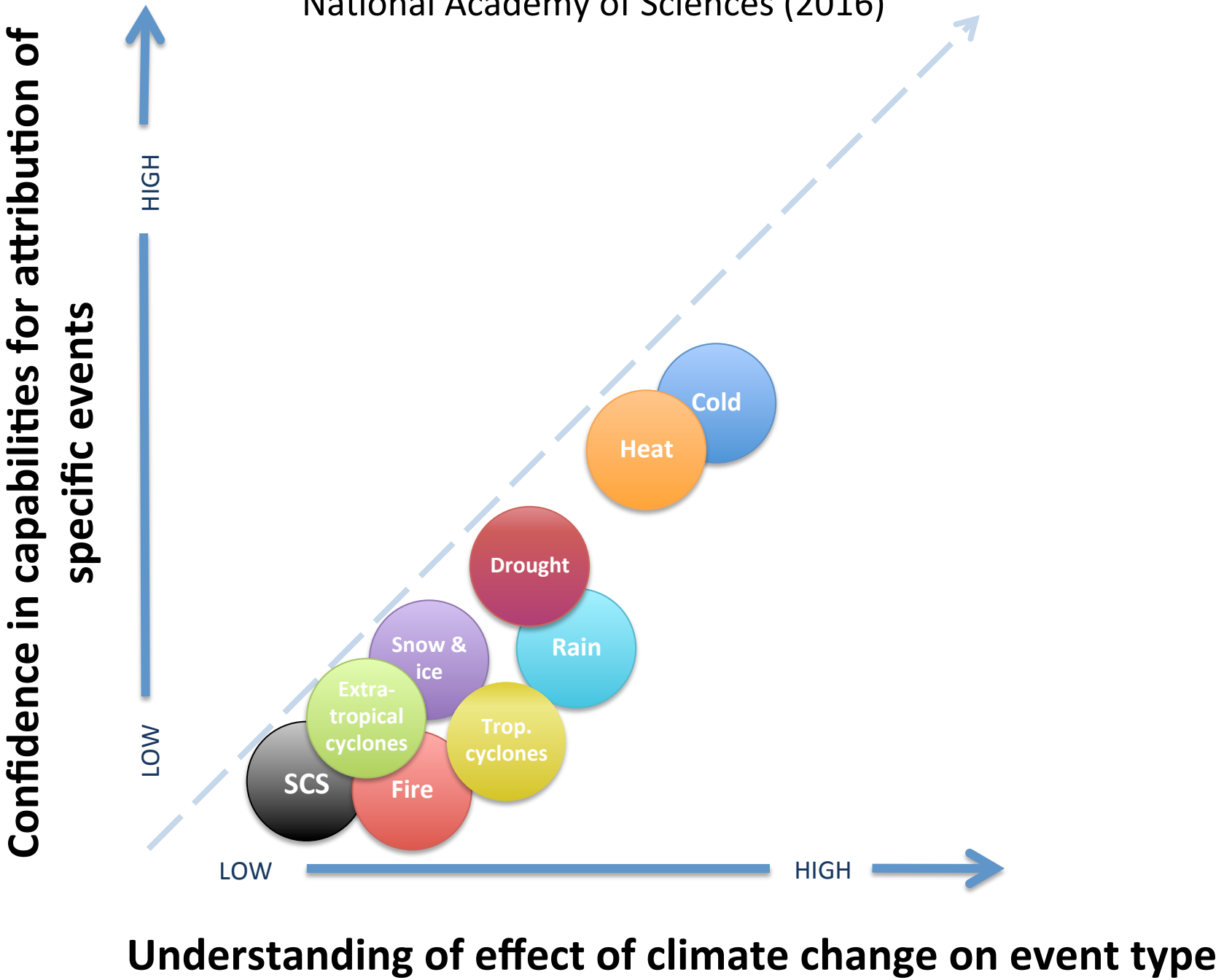




Use an ESM?

- Pro: internally consistent solution for both climate and extreme events.
- Con: events may not be represented well, esp. those with small scales (meaning, most storms).
- Any downscaling scheme still requires an ESM to do future projection, prediction, or attribution.
- Biases!

National Academy of Sciences (2016)



A couple of specific applications...

“Medium term” TC rates

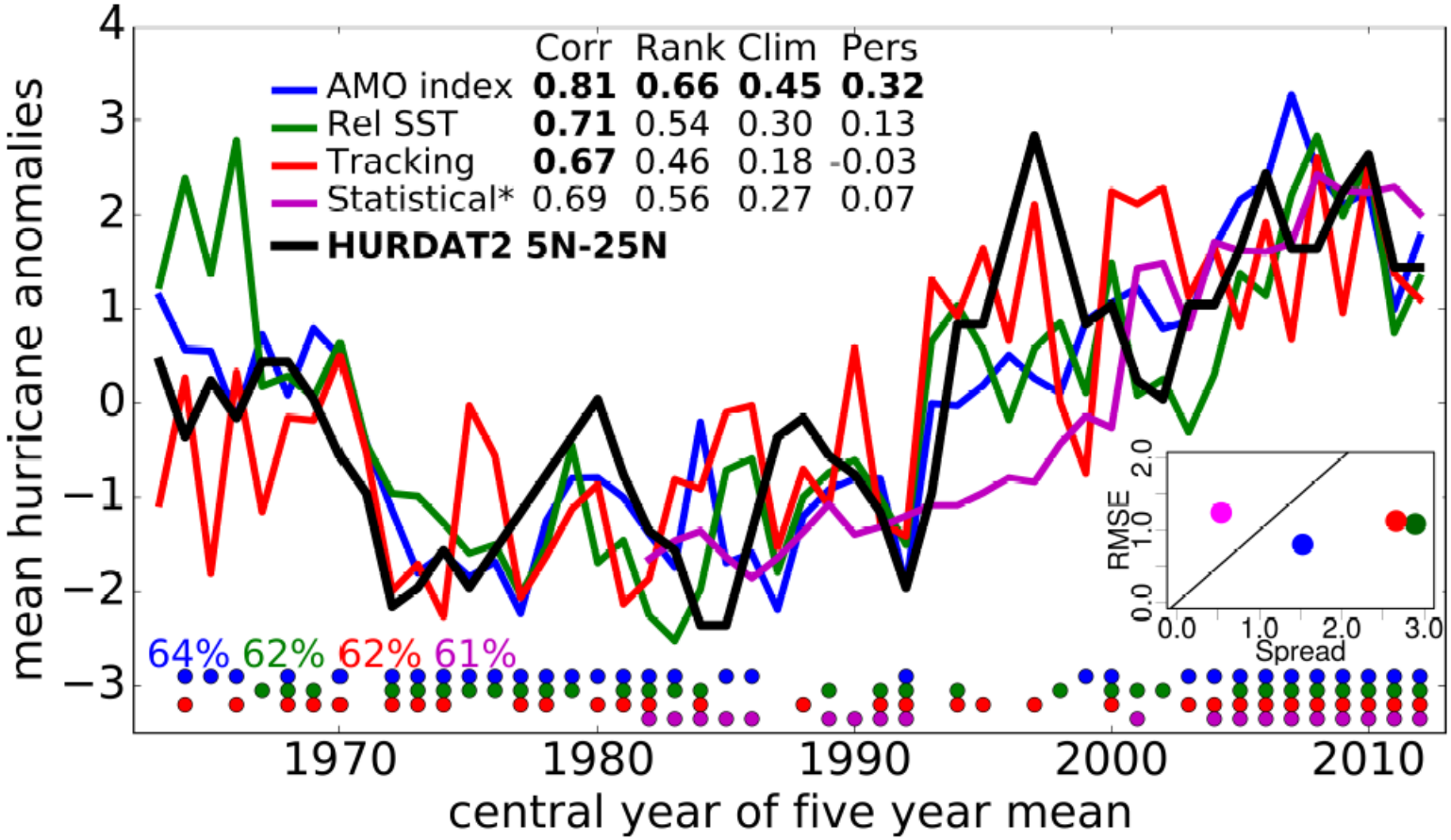
- Pre-2004: TC risk estimates based on long-term climatology
- 2004-05: major losses, climate change debate heats up
- Post-2005: key industry players introduce “medium term” (5-year) rates for Atlantic
- 2018: the medium term forecasts haven’t done too well.

RMS

How We Serve Products & Services

Impact of the 2017 North Atlantic Hurricane Season on the RMS Medium-Term Rate

There is even a little skill in 5-year predictions of hurricane activity itself (but these are not used, yet...)



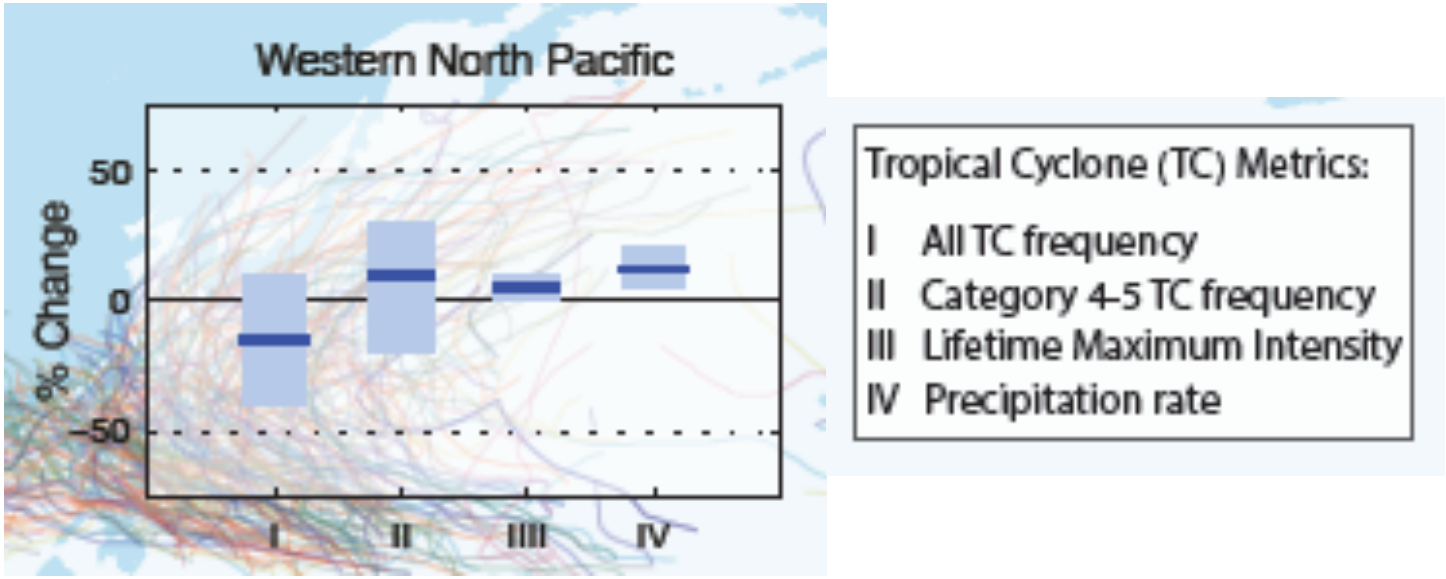
Caron et al. 2018

TC frequency and warming: a history

- Old days: number of TCs (NTC) should increase with warming, because higher SST
- Early-mid 2000s: not necessarily; relative SST, PI are better predictors than absolute SST
- Mid-late 2000s: hi-res (~10-50 km global models) say NTC goes down with warming.
- More recently: NTC goes up downscaling CMIP5 (Emanuel 2013) or in latest coupled model (Bhatia and Vecchi 2018)

TC frequency and warming

- I think we basically have no idea whether TC frequency should increase or decrease with warming.
- Unlike for TC intensity (or water vapor feedback, lapse rate feedback etc.) there is no theory. So our confidence in any model prediction is small.



Closing thoughts

- For a number of applications in extreme event risk, more empirical approaches and/or downscaling are still favored over ESMs...
- esp. in applications where climate change is less important - maybe anything short time scale, or where natural variability or other uncertainties >> warming trend
- For climate change signals, robustness may not be enough; theoretical understanding is important to bolster confidence in ESM results.