Synthesizing climate uncertainties and decision making in complex interdependent coastal systems

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Computational Physics and Methods (CCS-2)

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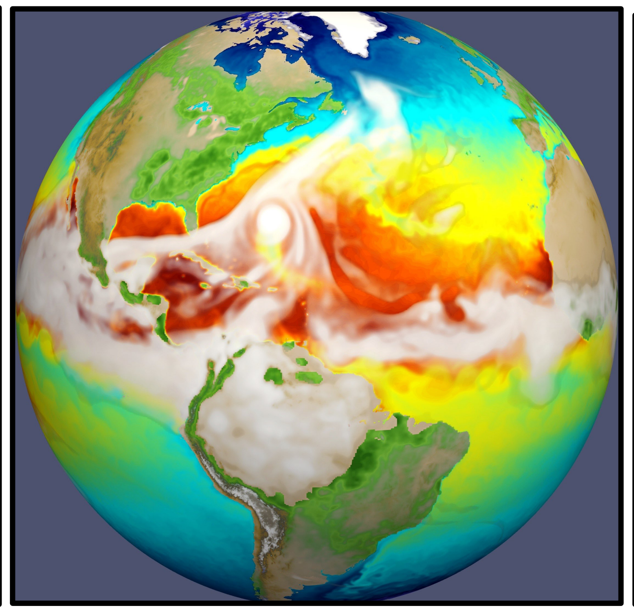
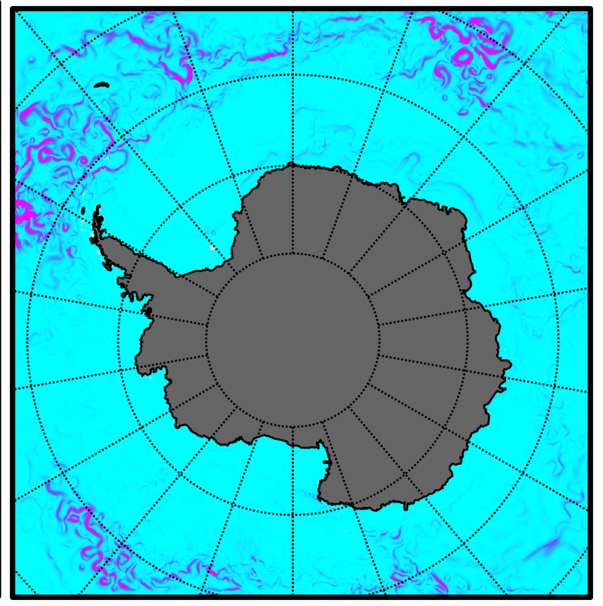
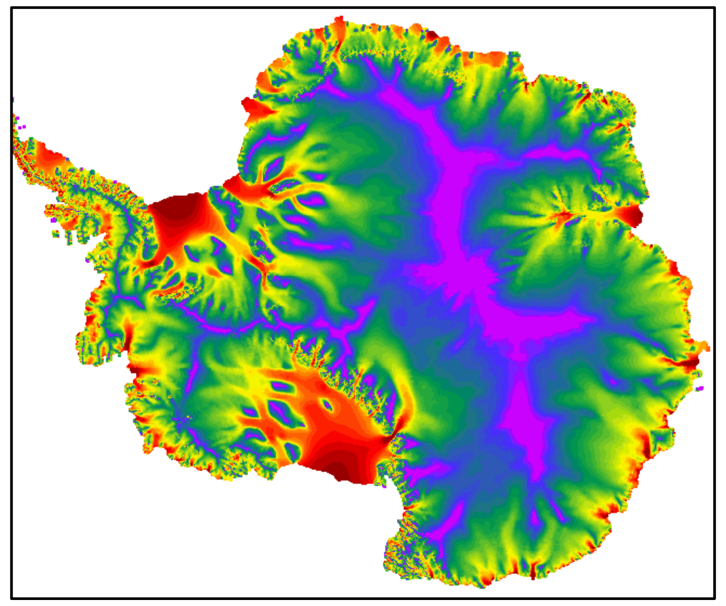
… and others …

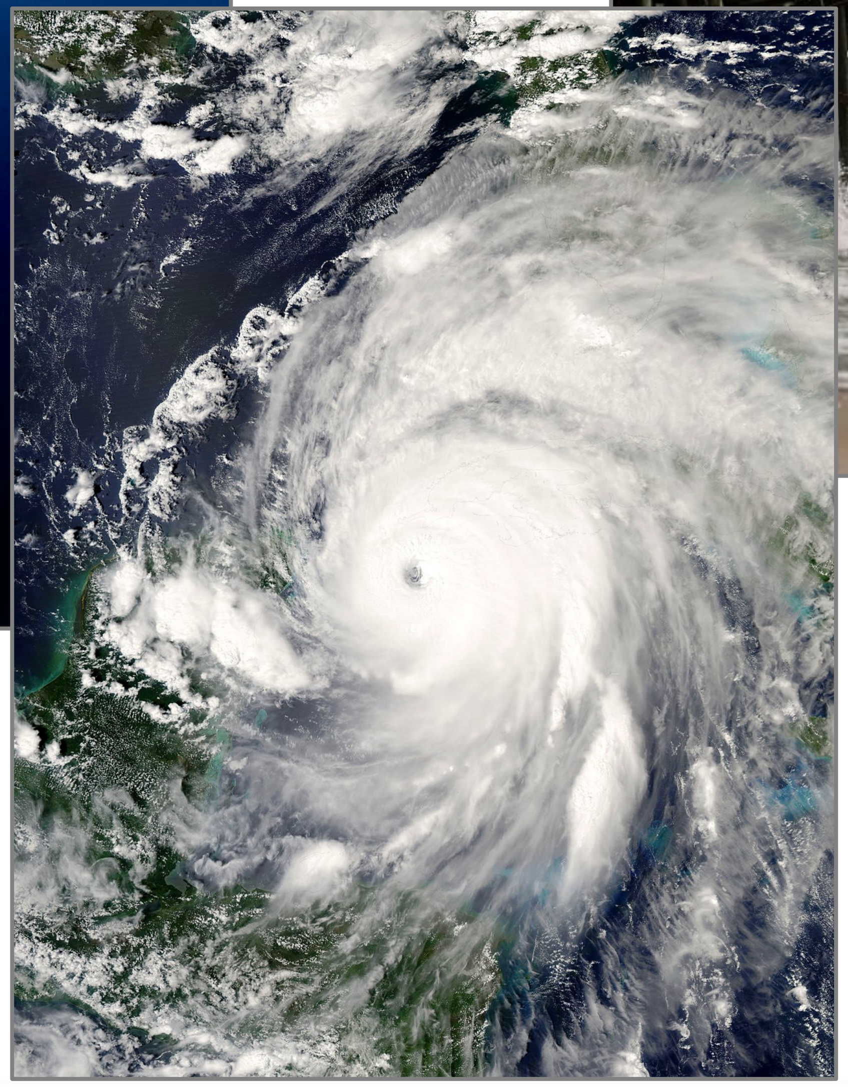
     

DOE ECR, "Combining System and Model Dynamics to Learn about Climate Uncertainties" (Urban)
LANL LDRD, "Adaptation Science for Complex Natural-Engineered Systems" (Pasqualini, Urban, Rowland)
DOE BER, "High-Latitude Application and Testing of Earth System Models" (Weijer, Rasch, Maslowski)

LA-UR-19-24103

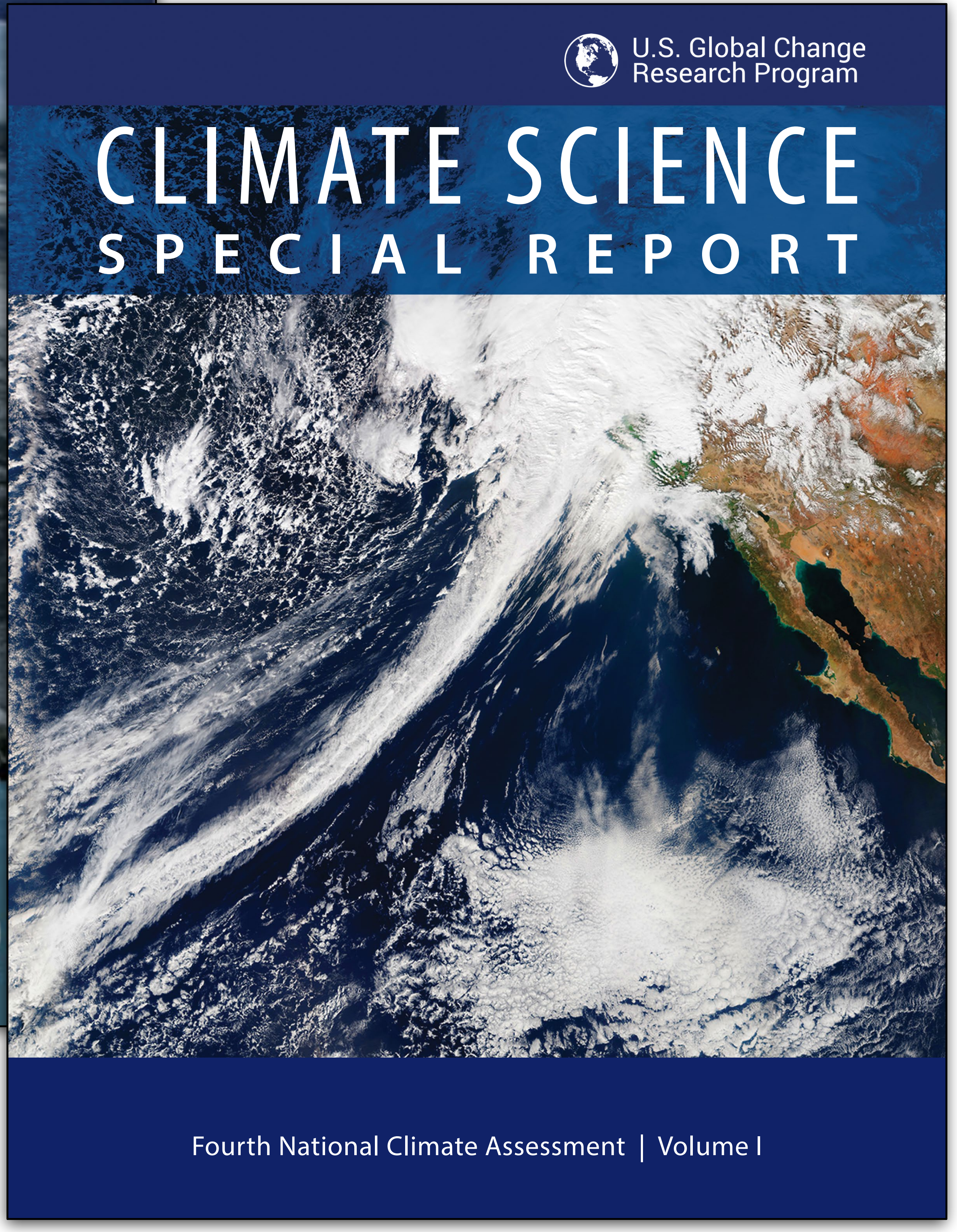
Coastal resilience: Science questions, science gaps

1. How do we **combine information** from scientific studies to arrive at actionable predictions that are useful for coastal decision making?
2. How do we **make decisions** about complex, large-scale, interdependent coastal systems in the presence of uncertainty?

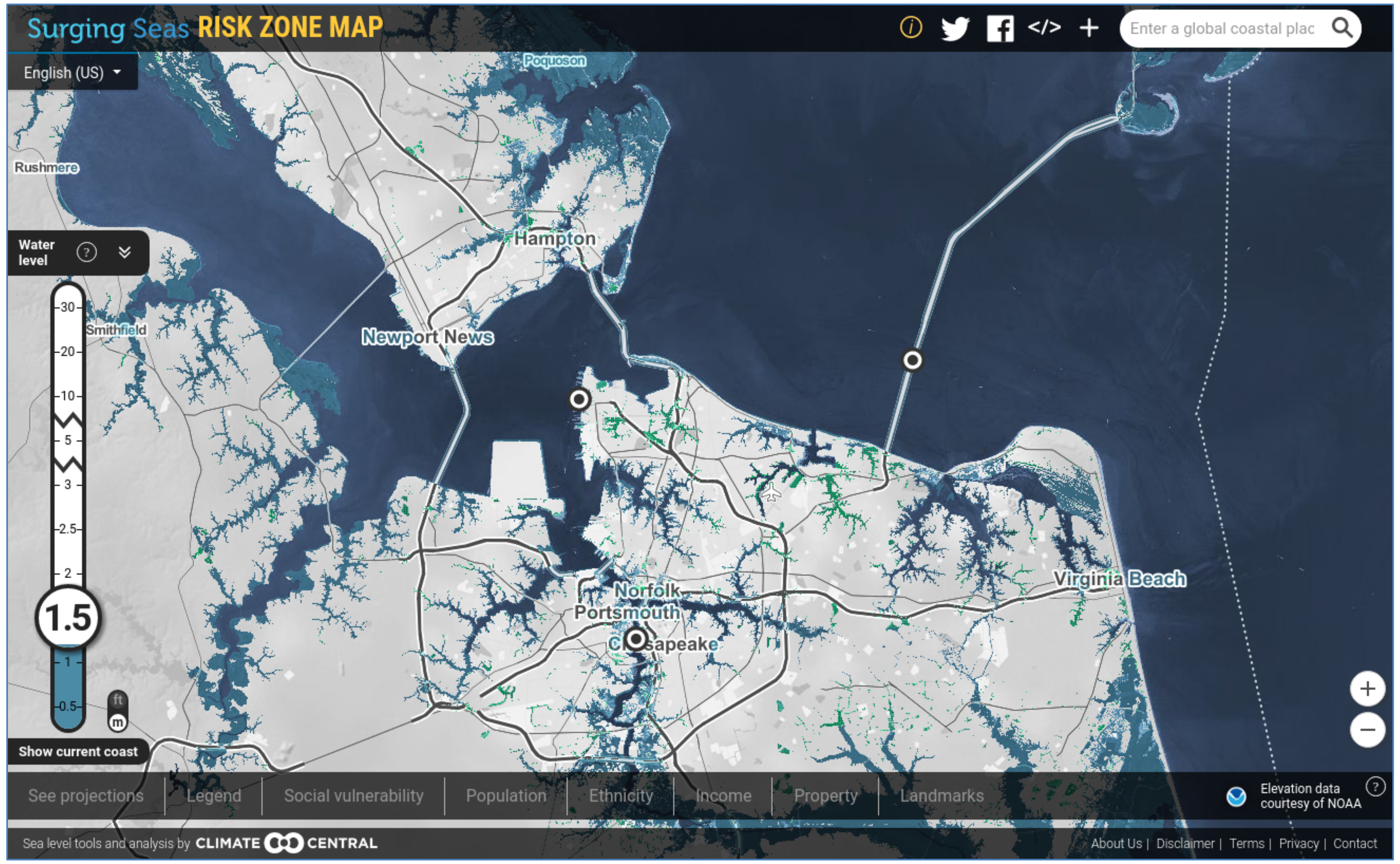


From synthesis reports to synthesis products

IPCC AR5 (2013)



NCA4 (2018)

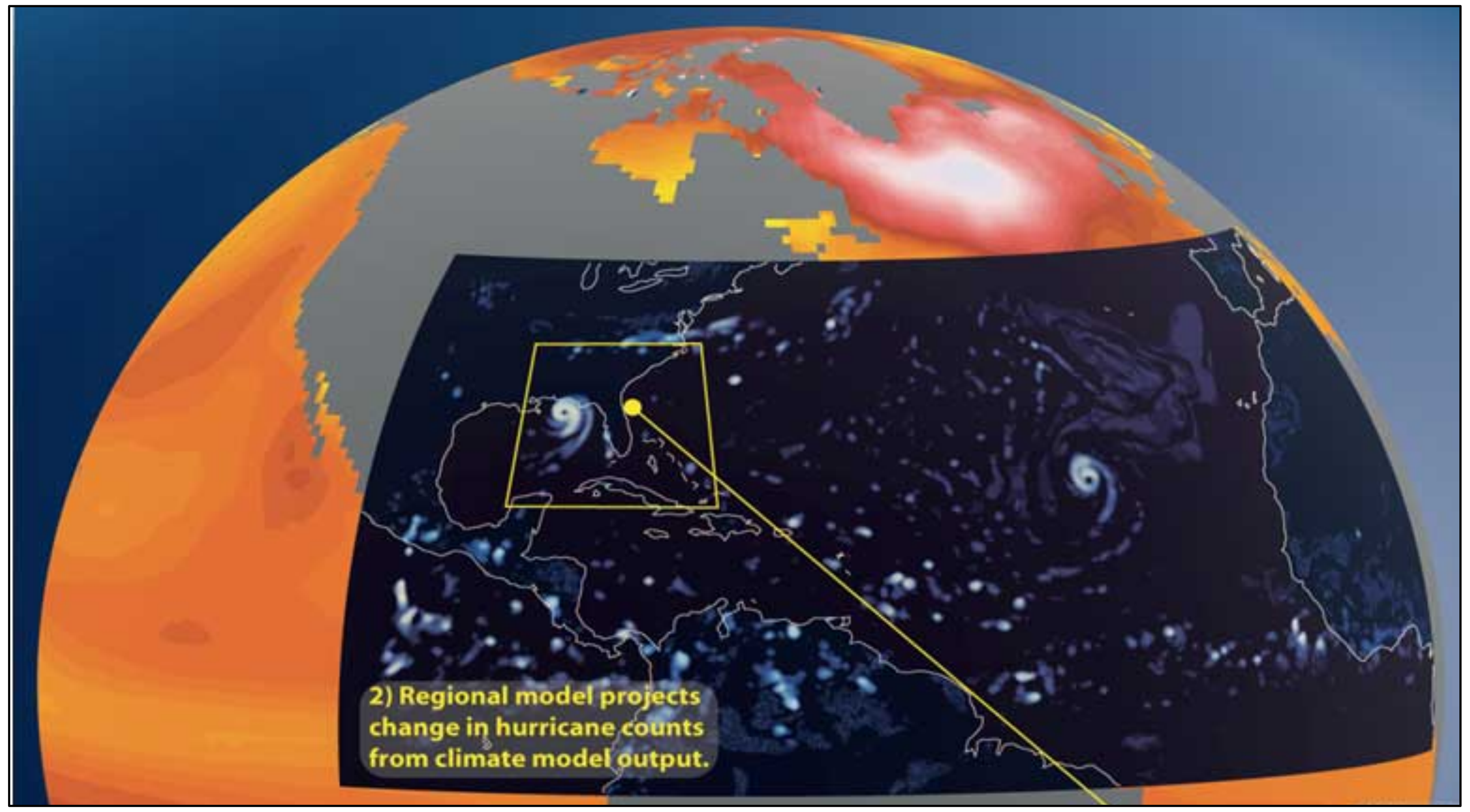


Climate Central

"Translational science": from climate models to decisions

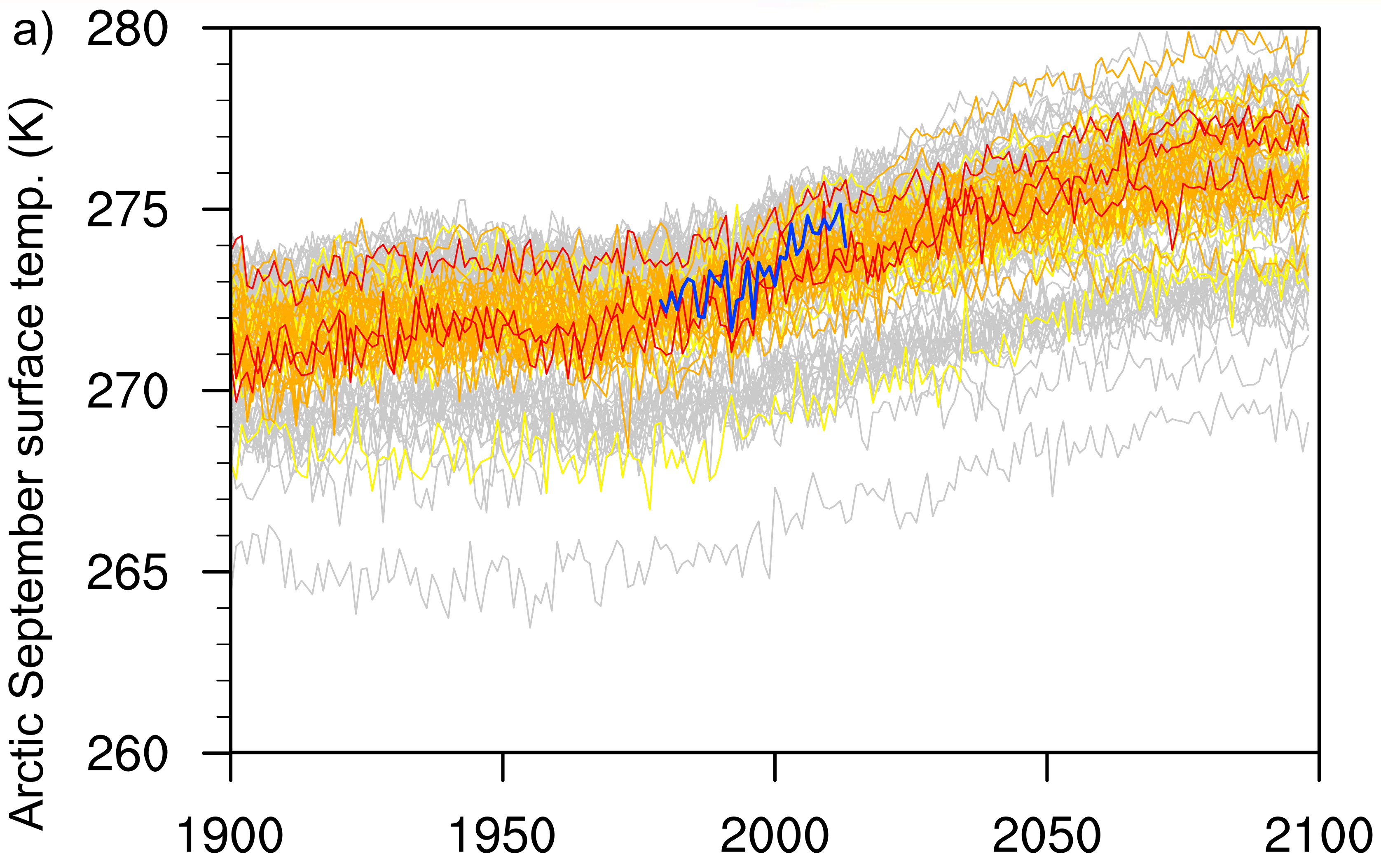
Downscaling

NOAA GFDL



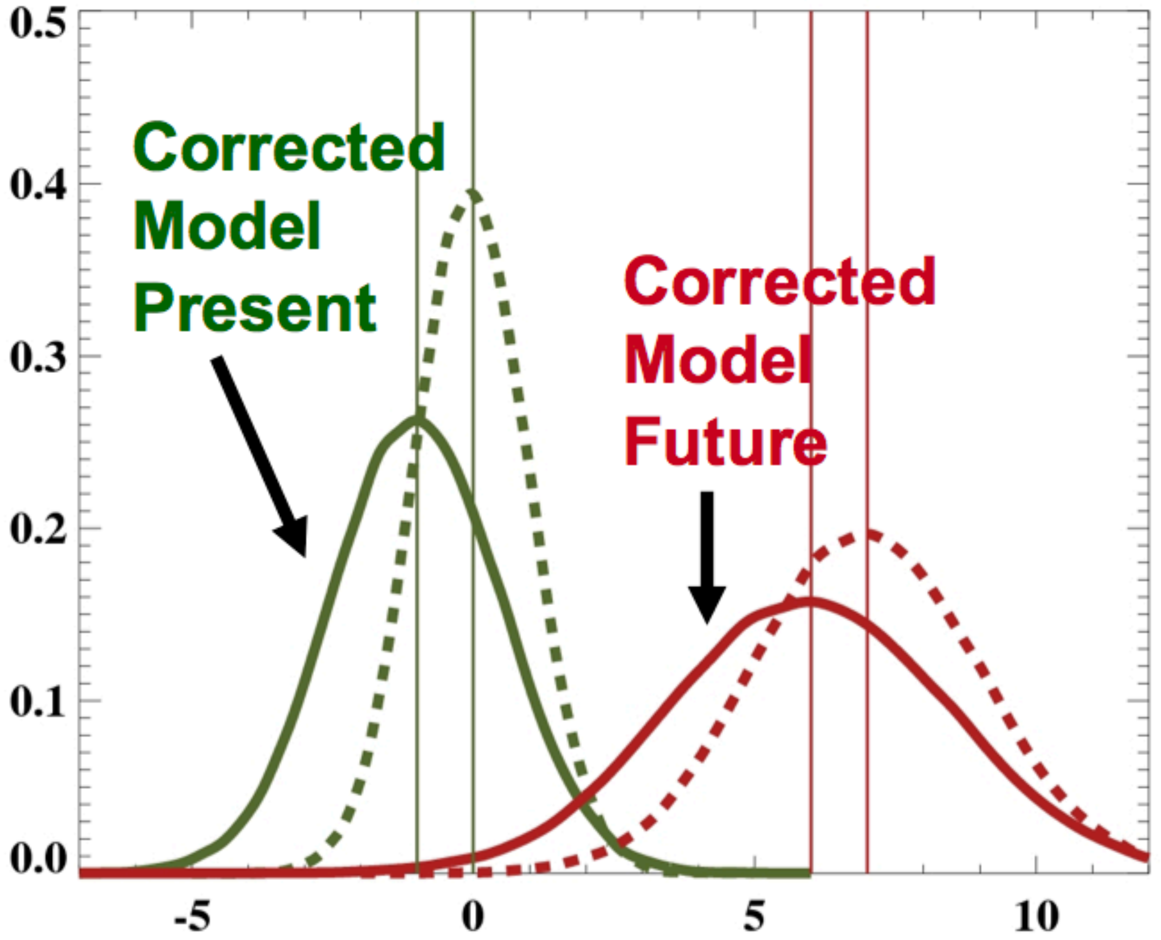
Model skill weighting

Knutti et al. (2017)



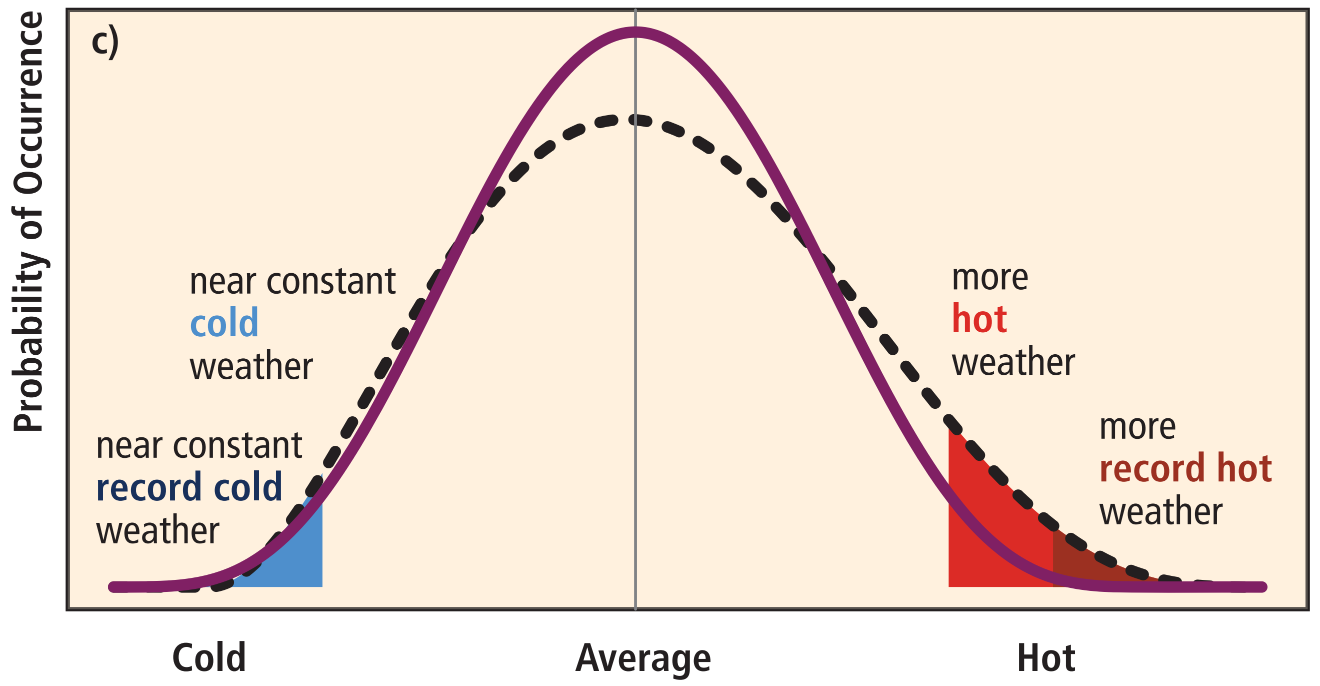
Bias correction

IS-ENES



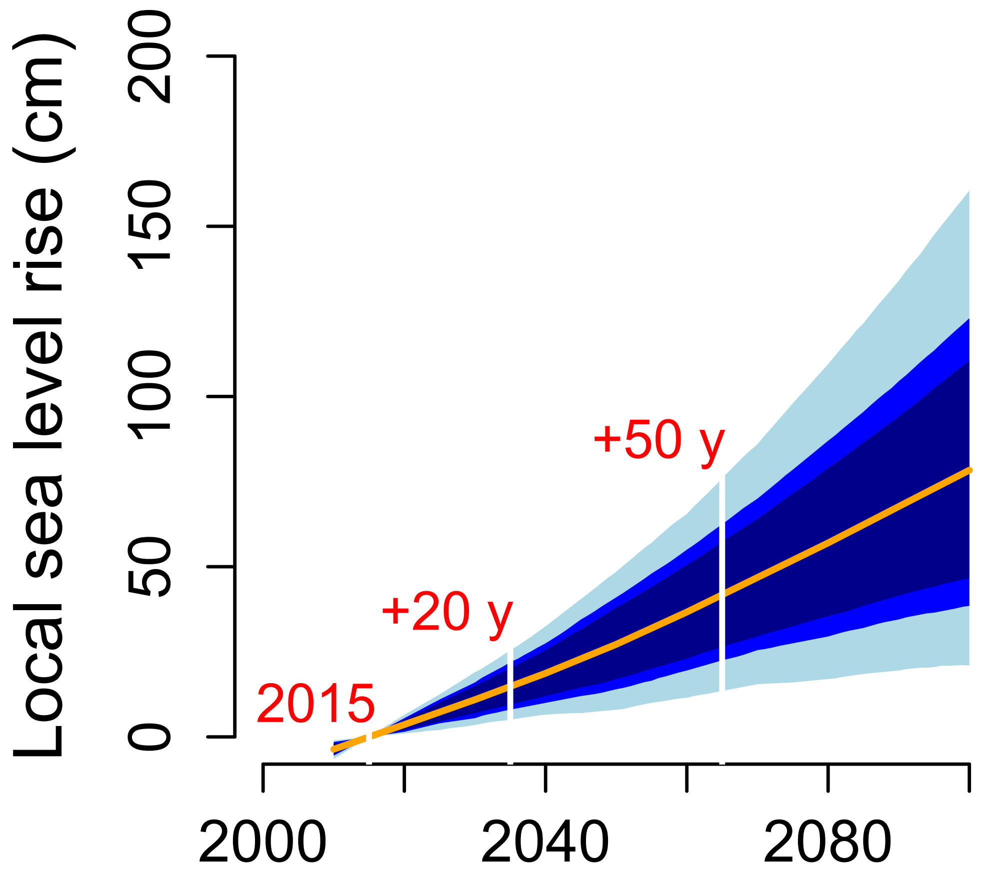
Extreme statistics

SREX (2012)



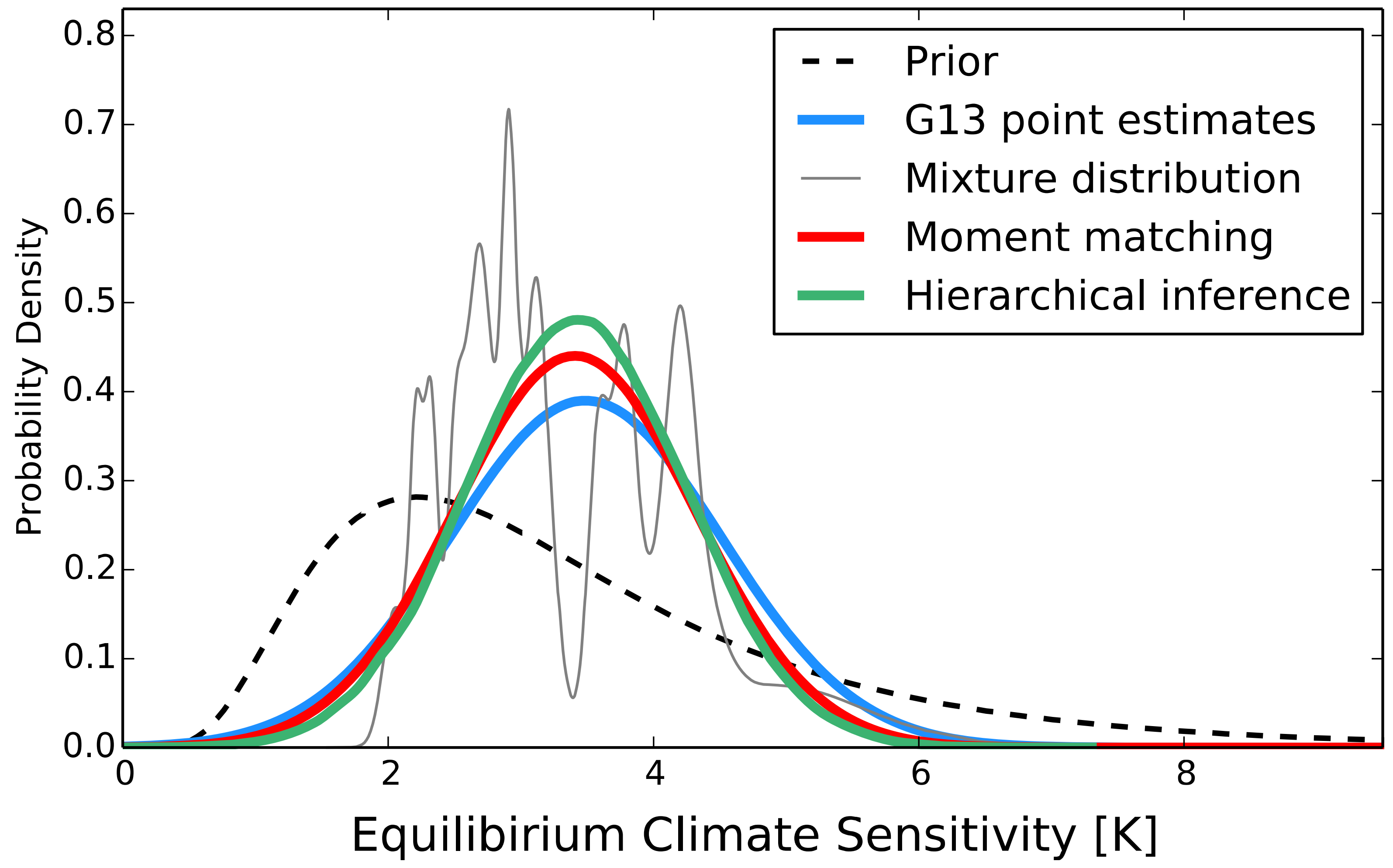
Uncertainty quantification

Kopp et al. (2014)
DHS (2015)

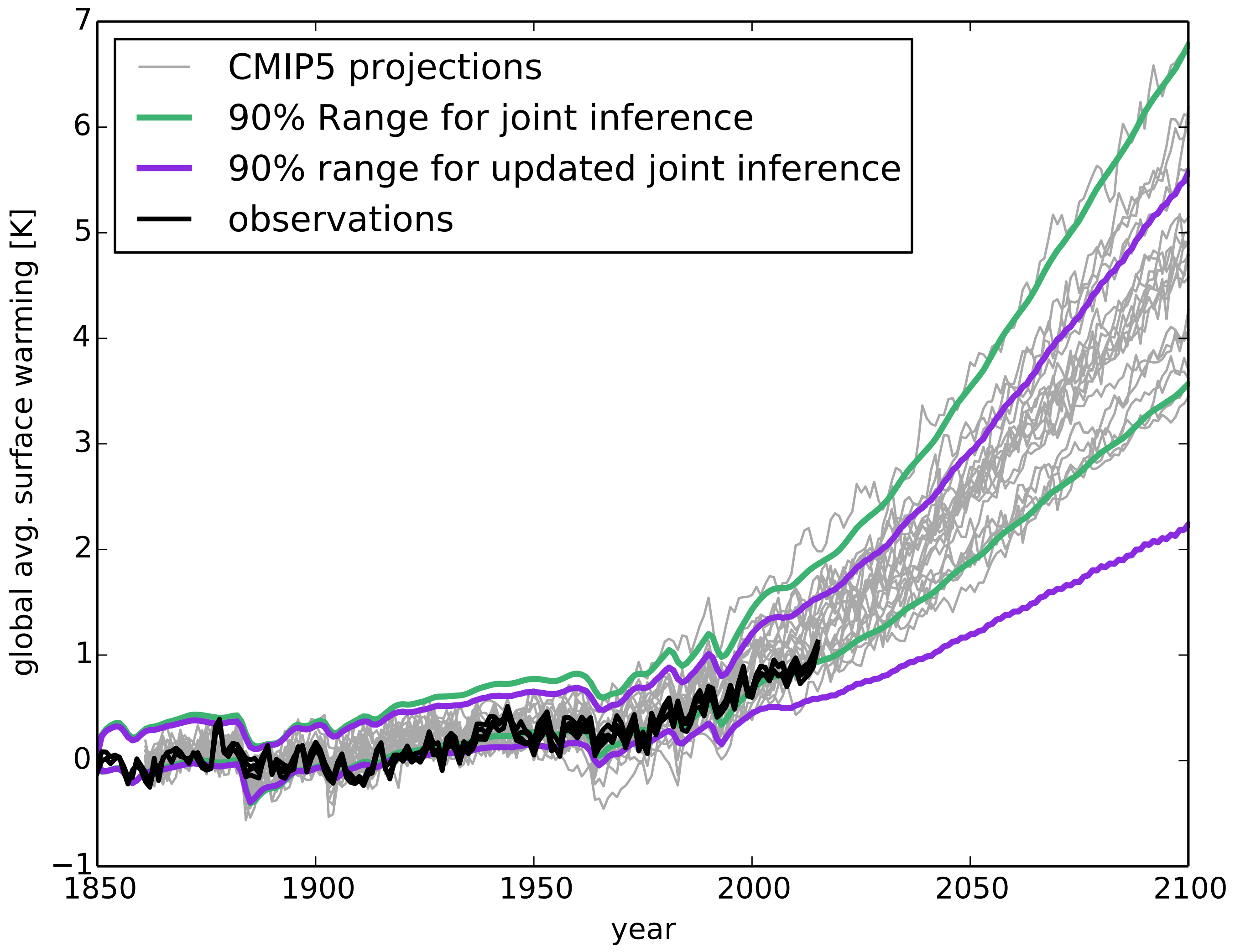


Where are there still science gaps in climate synthesis products?

Multi-model "blending"

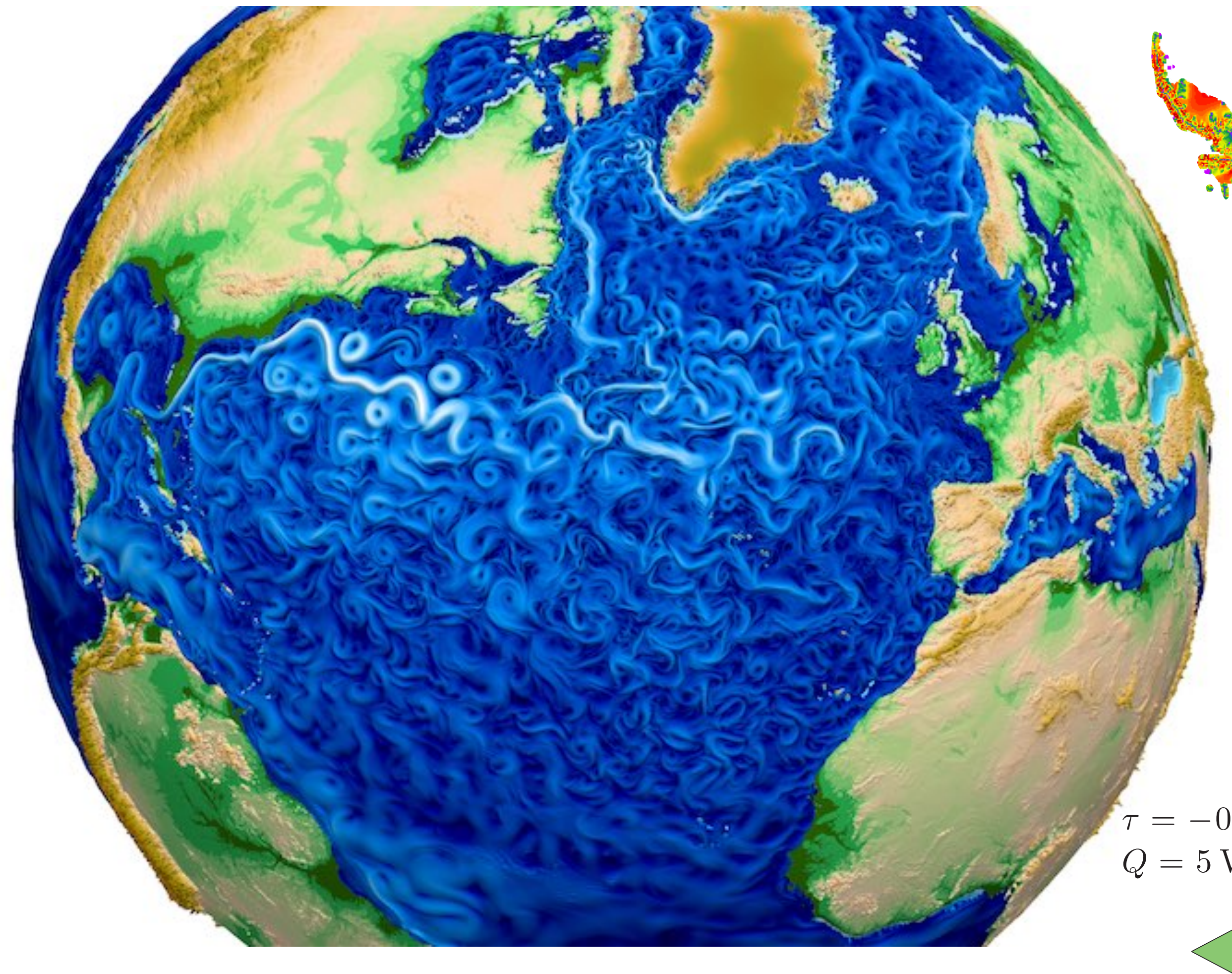


Data-model fusion
Dynamical bias correction

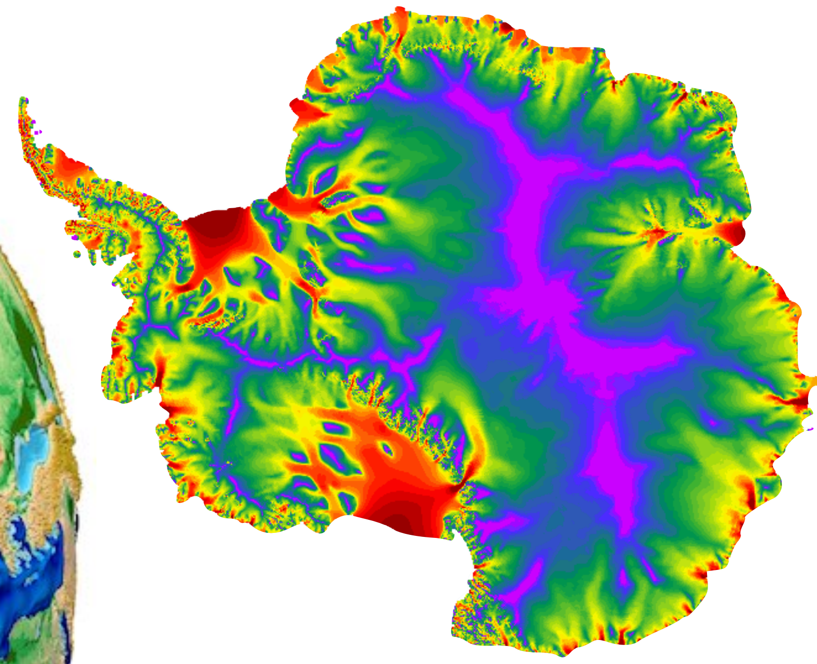


Jonko et al. (2018)

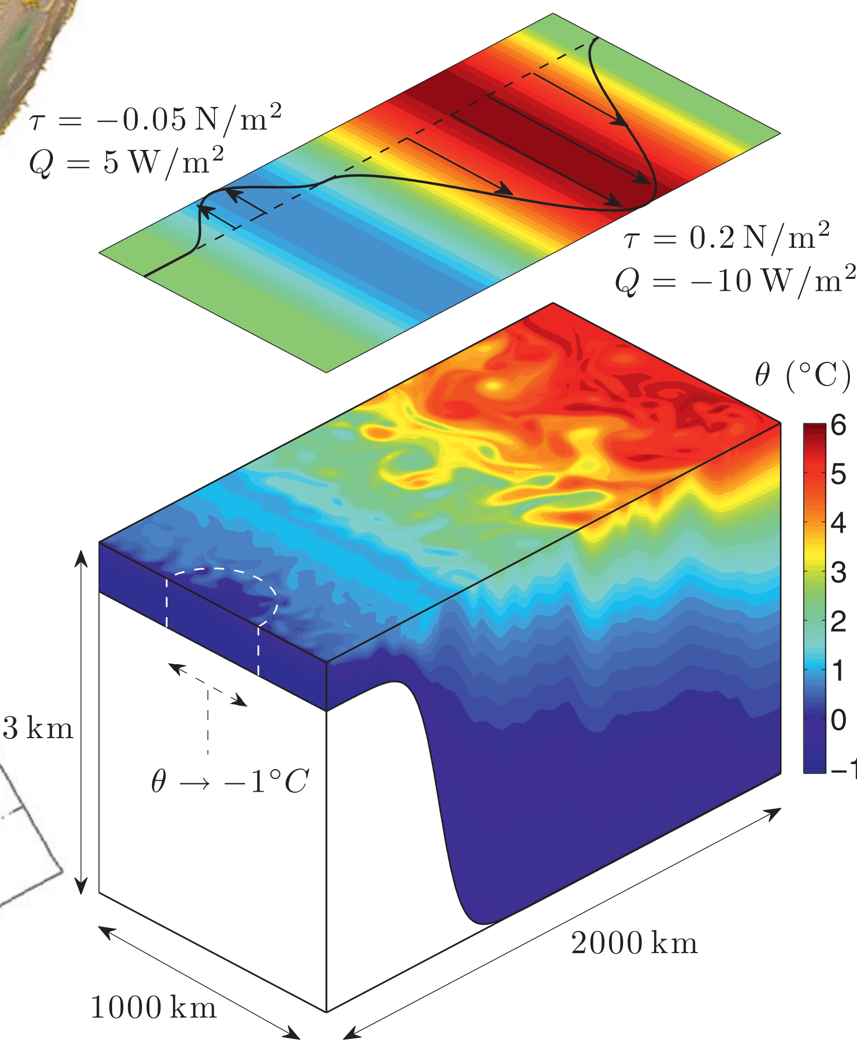
Combining hierarchies of models



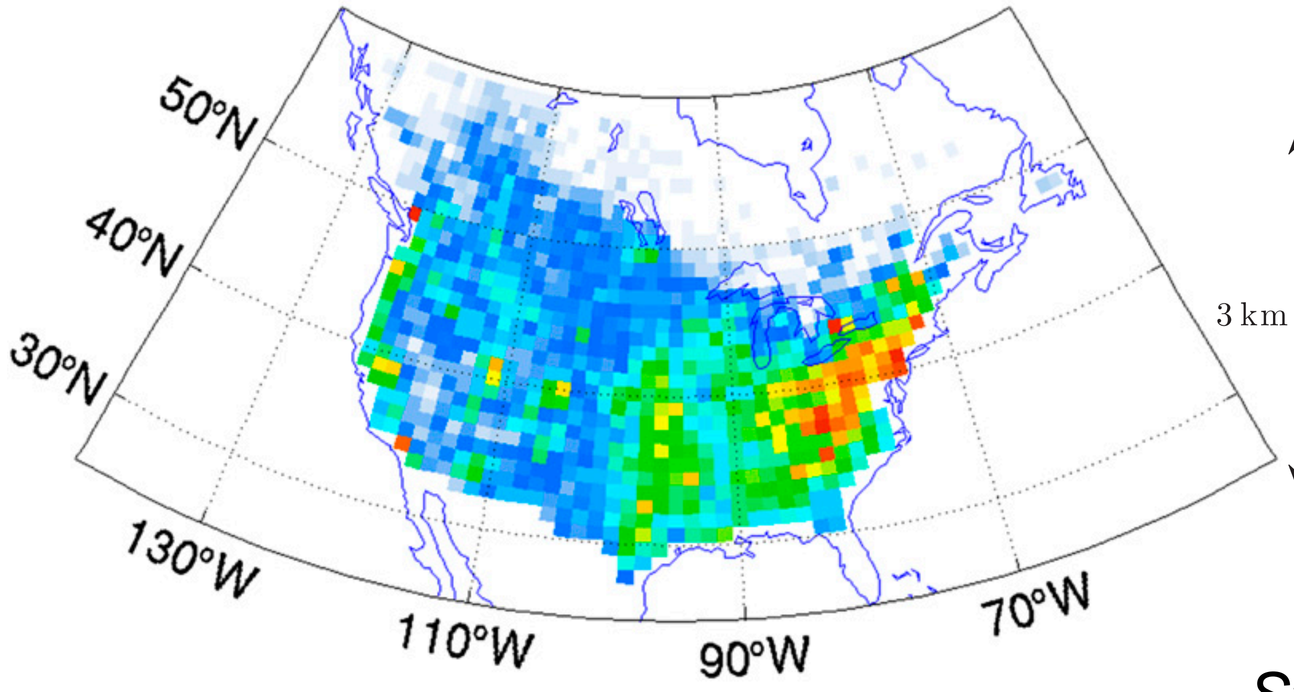
DOE E3SM/MPAS-O



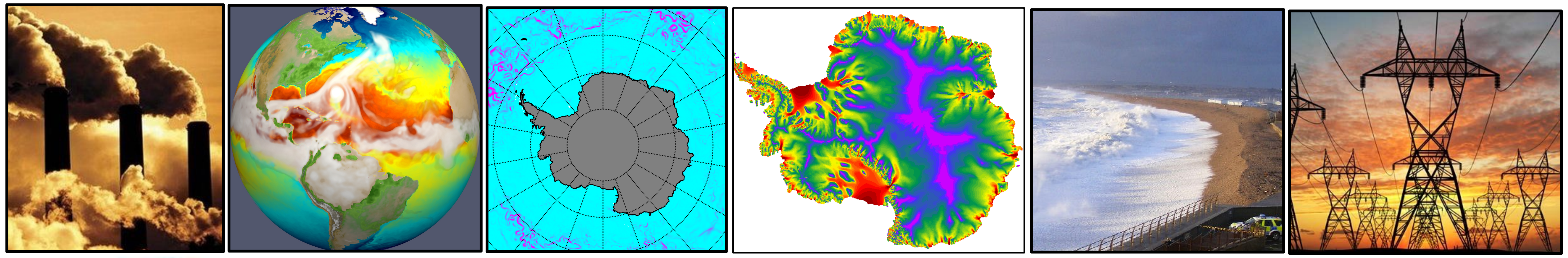
NCAR CISM



Stewart & Thompson (2016)



Gervais et al. (2014)



End-to-end uncertainty propagation

We still don’t have high-fidelity, multi-model SLR uncertainties

High-resolution multi-model uncertainty in nonlinear ice-ocean instabilities

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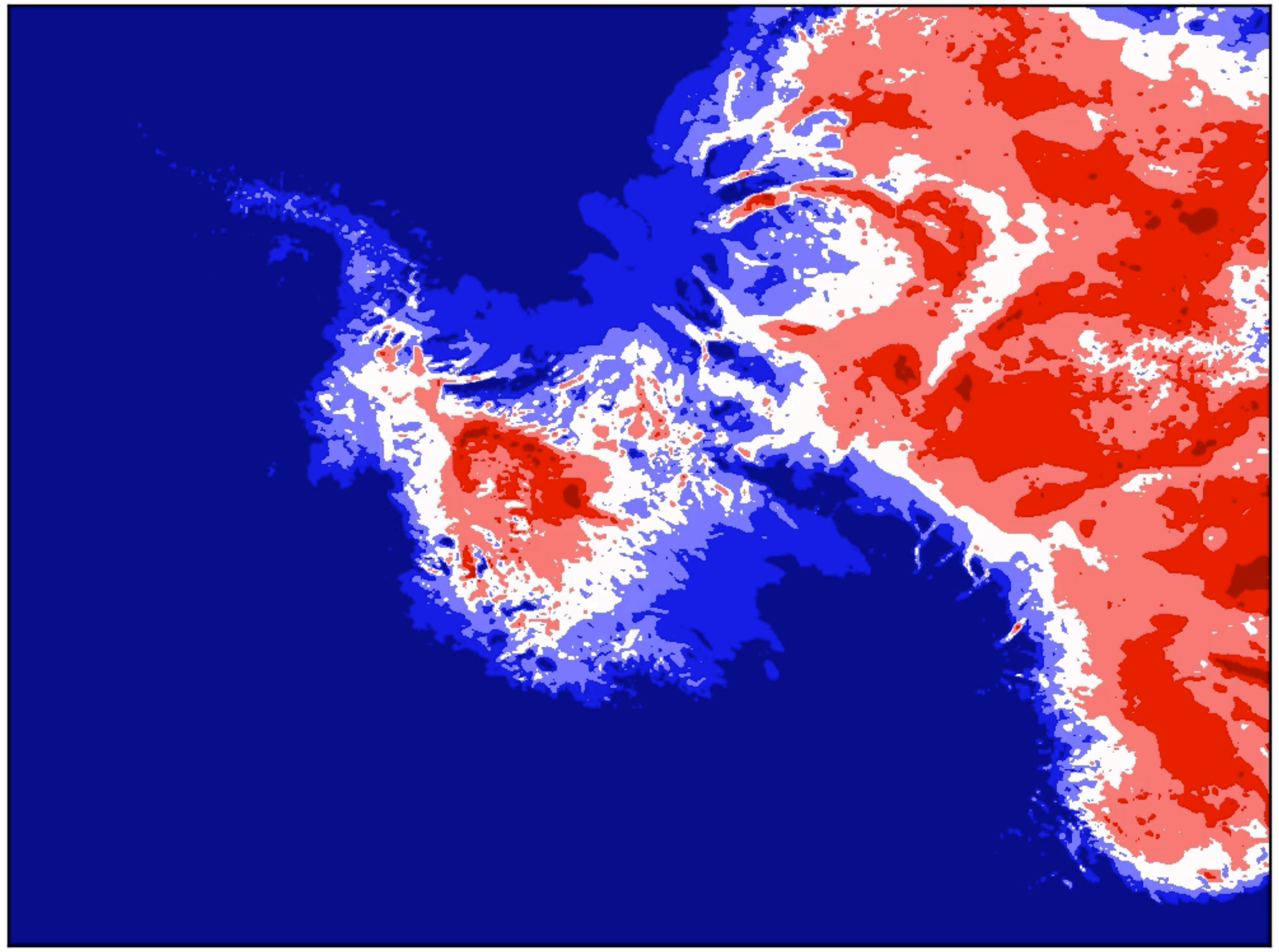
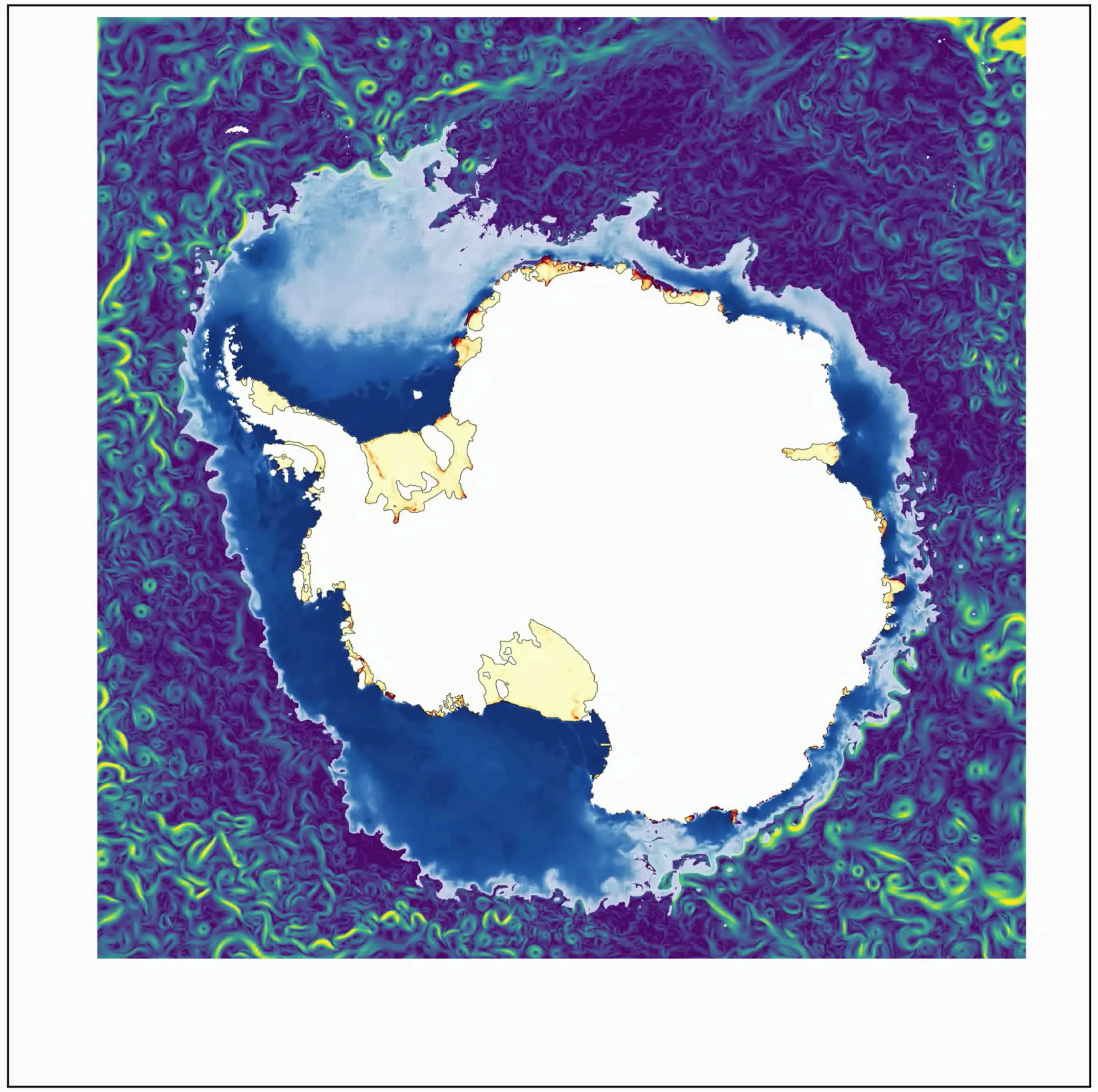


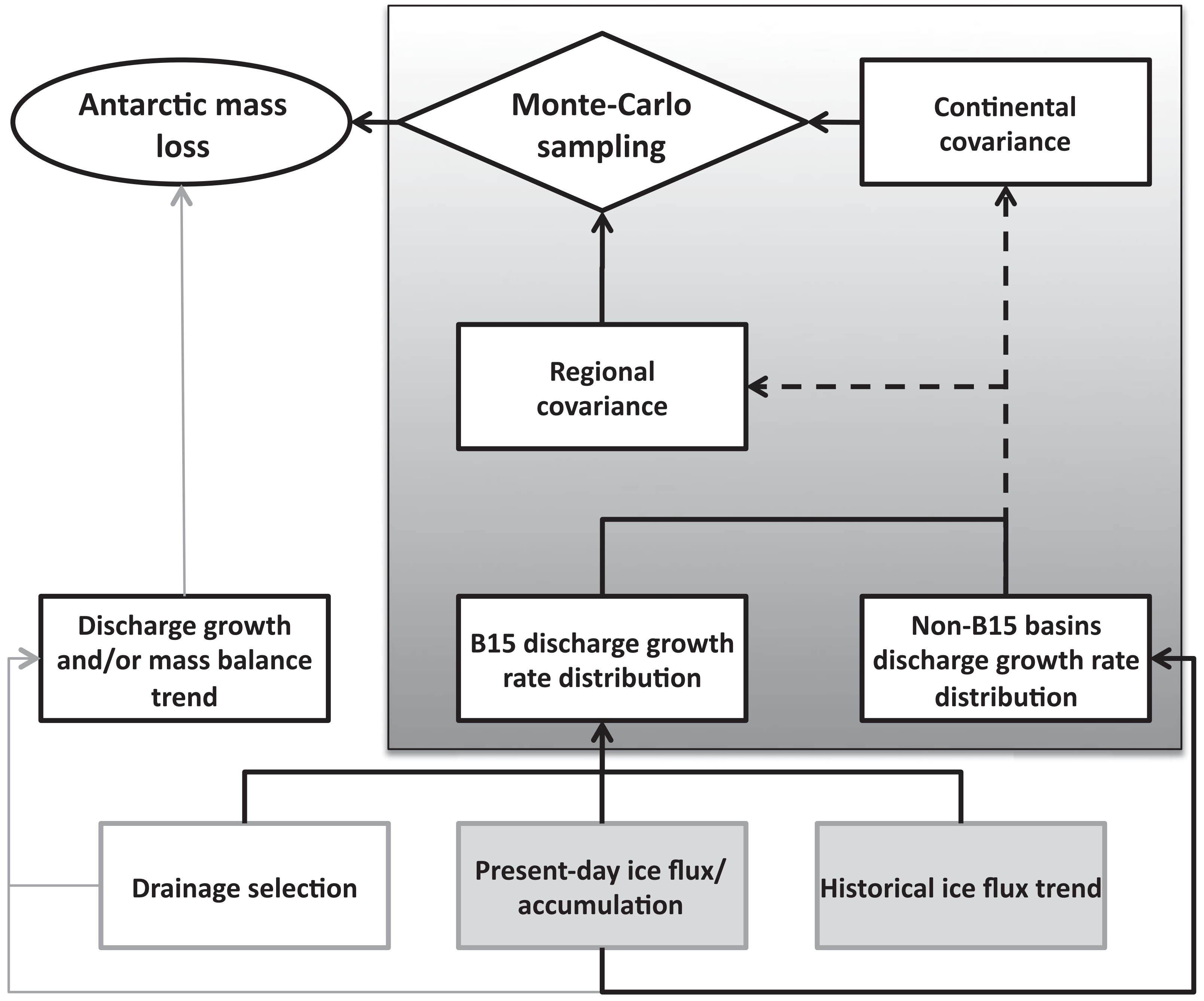
Berdahl et al. (in prep)

High-resolution multi-model dynamical downscaling of eddy-driven ocean heat transport

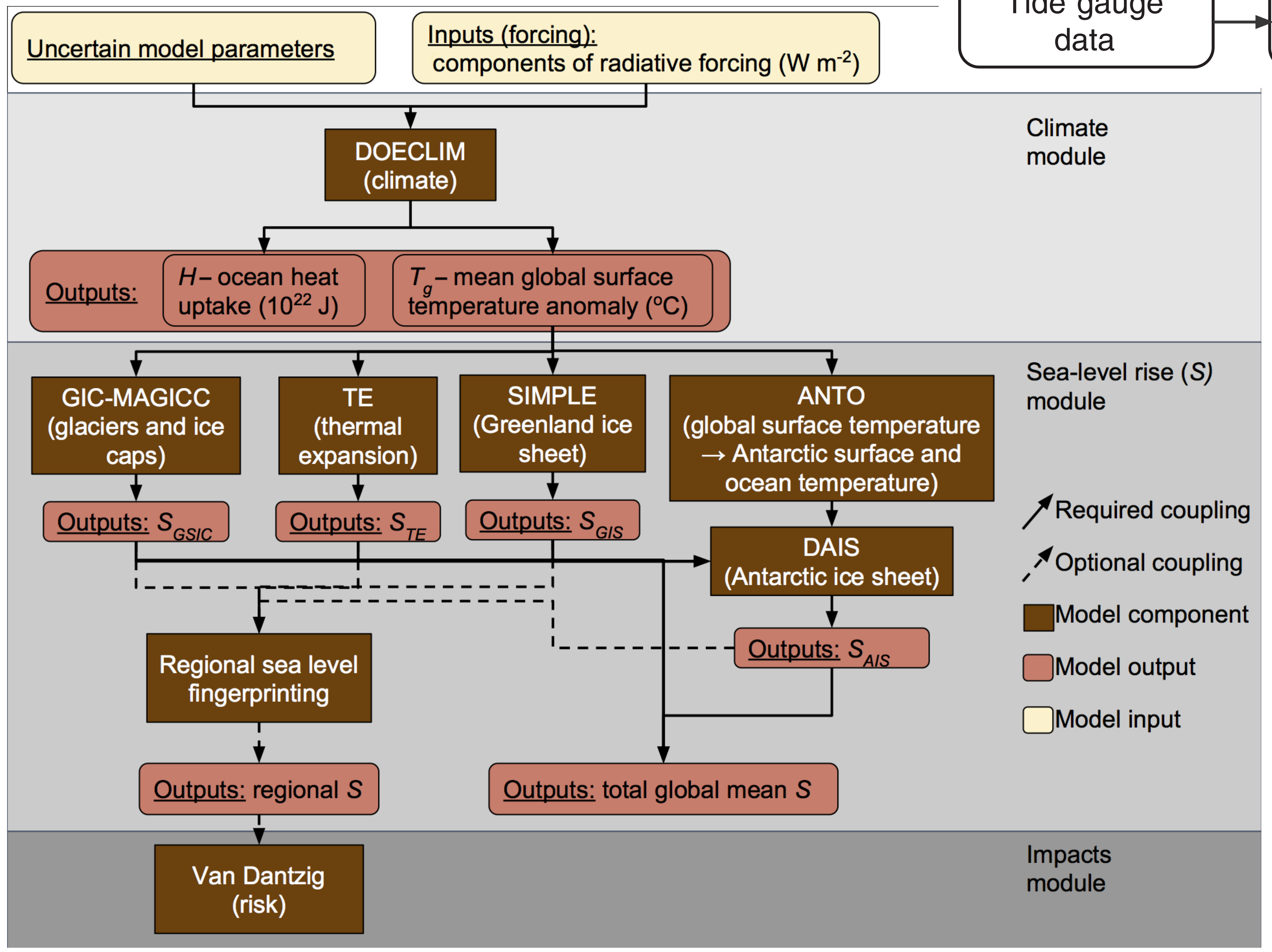


Barthel et al. (in prep)

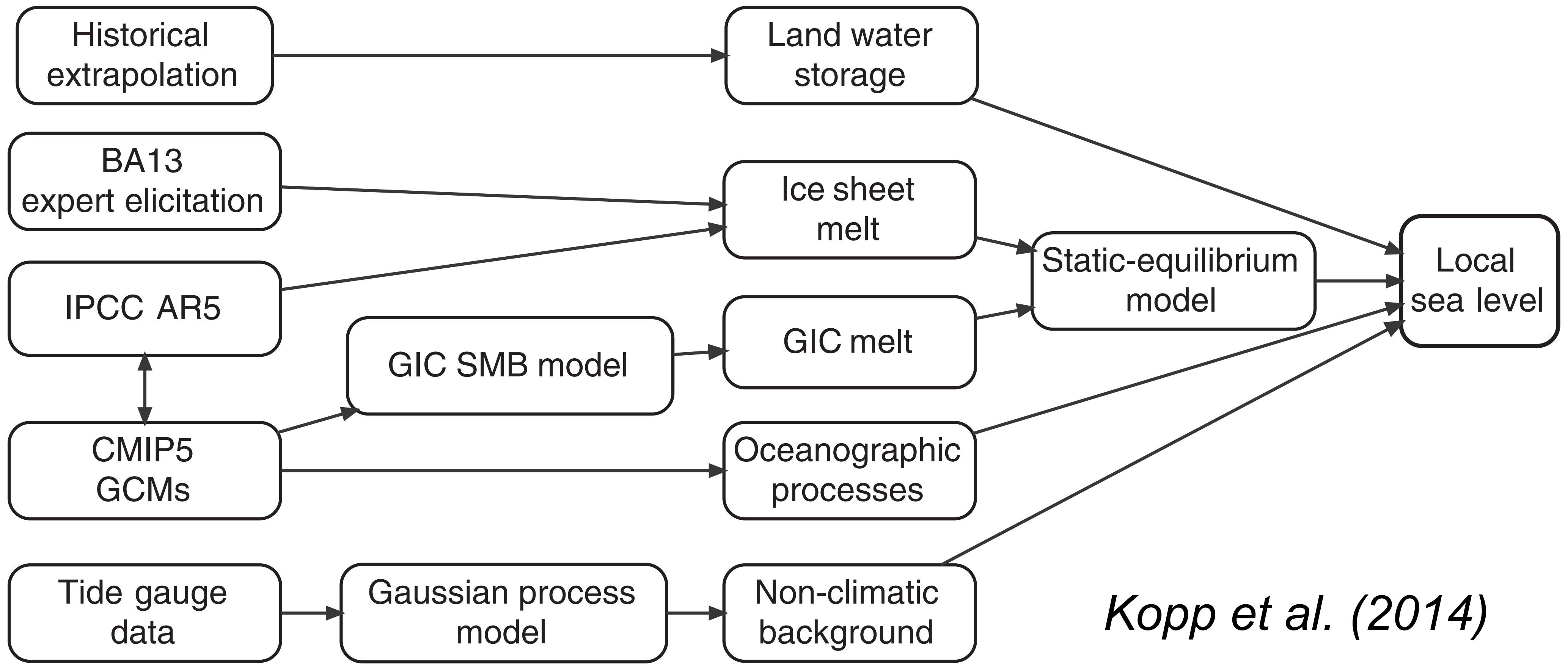
Towards modular frameworks for data-model information fusion



Little et al. (2013)

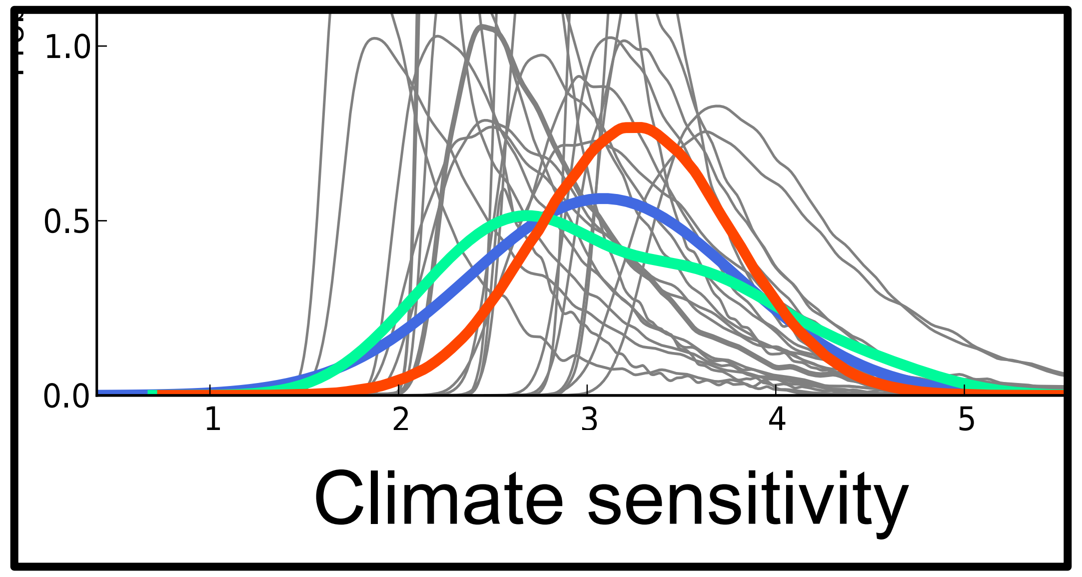


Wong et al. (2017)

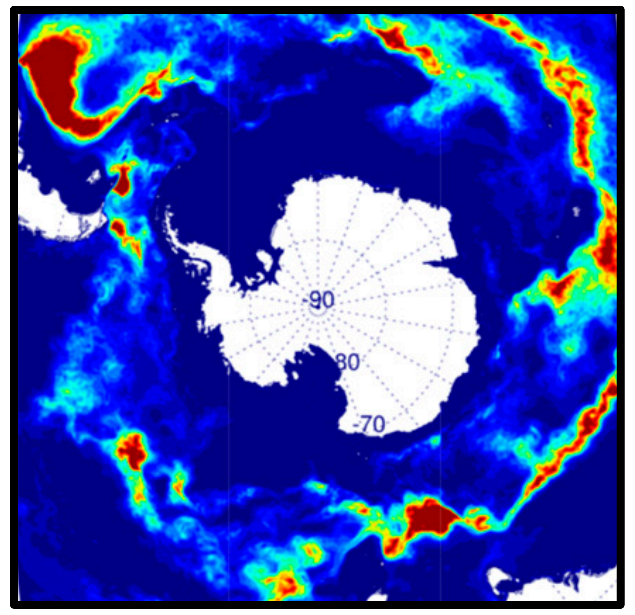


Kopp et al. (2014)

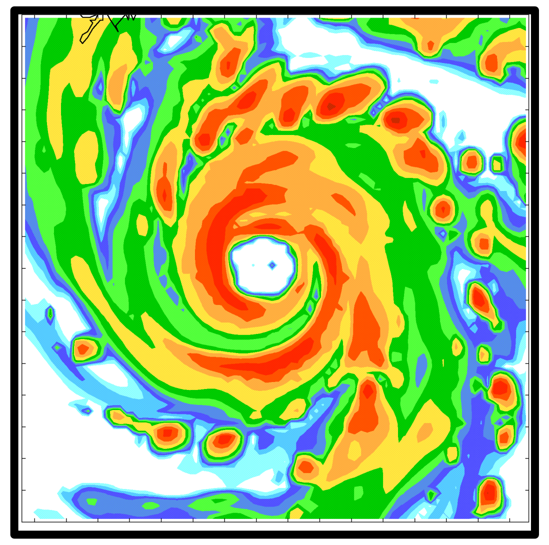
Modular information fusion for coastal resilience



Atmospheric radiative feedbacks



Ocean eddy heat transport to ice shelves



Future hurricane statistics

surface warming

Southern winds

ocean warming

circumpolar deep water

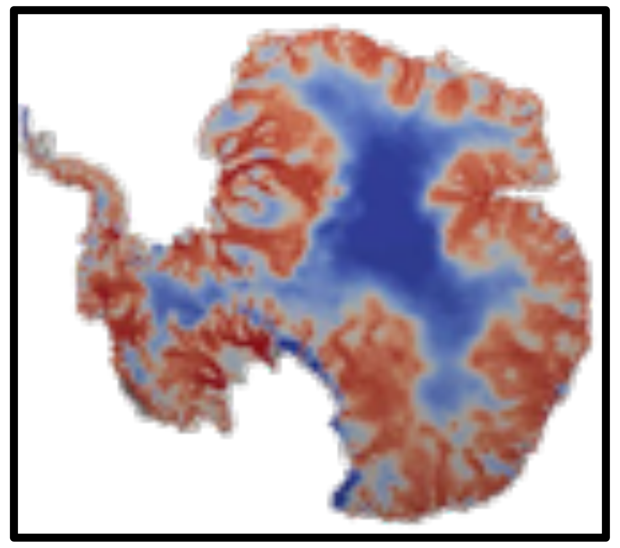
submarine melting

storms

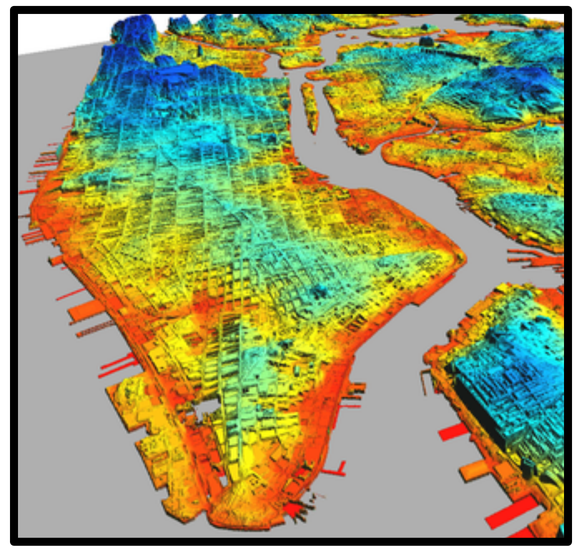
ice retreat

sea level rise

coastal flooding



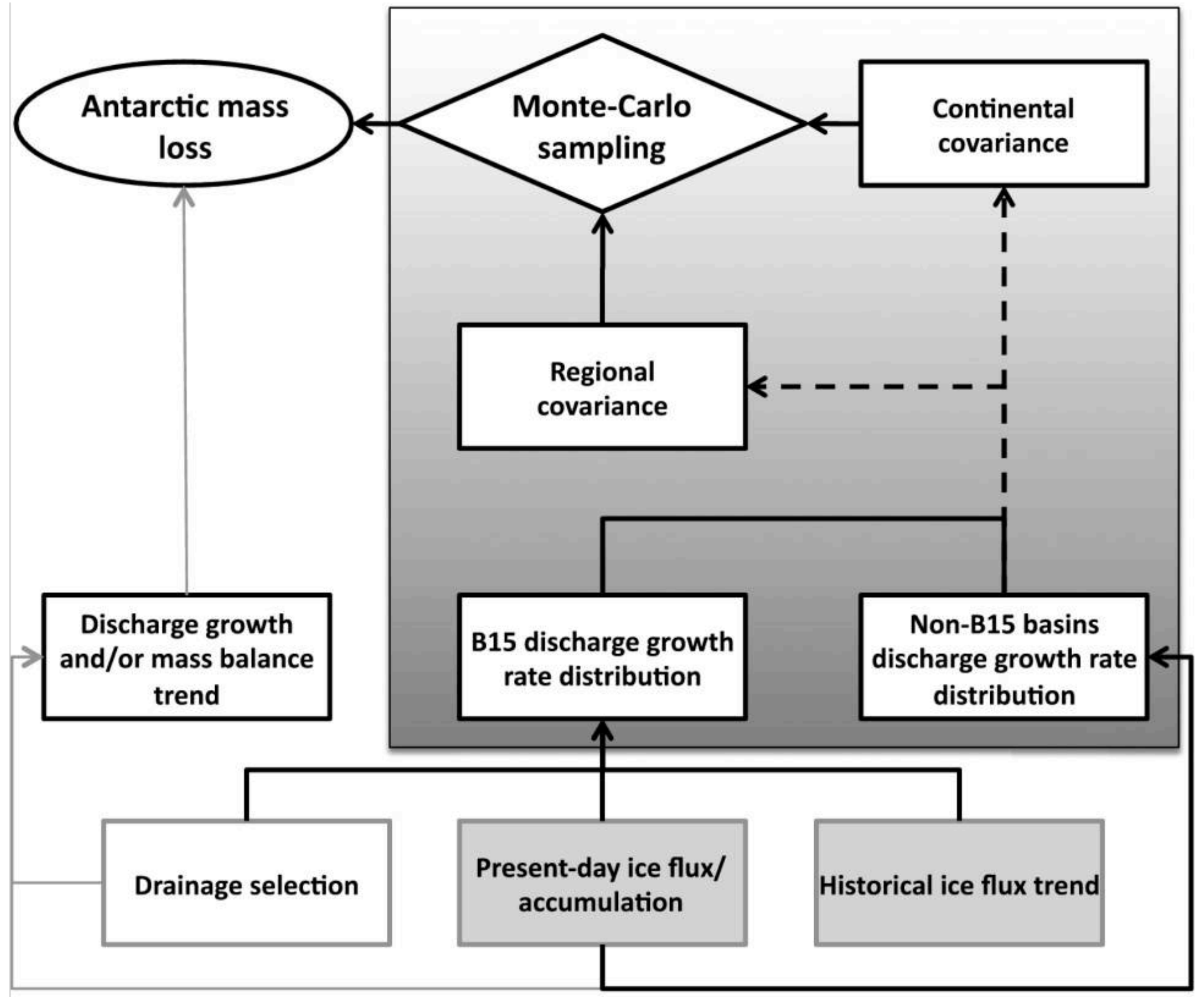
Ice mechanical fracture processes



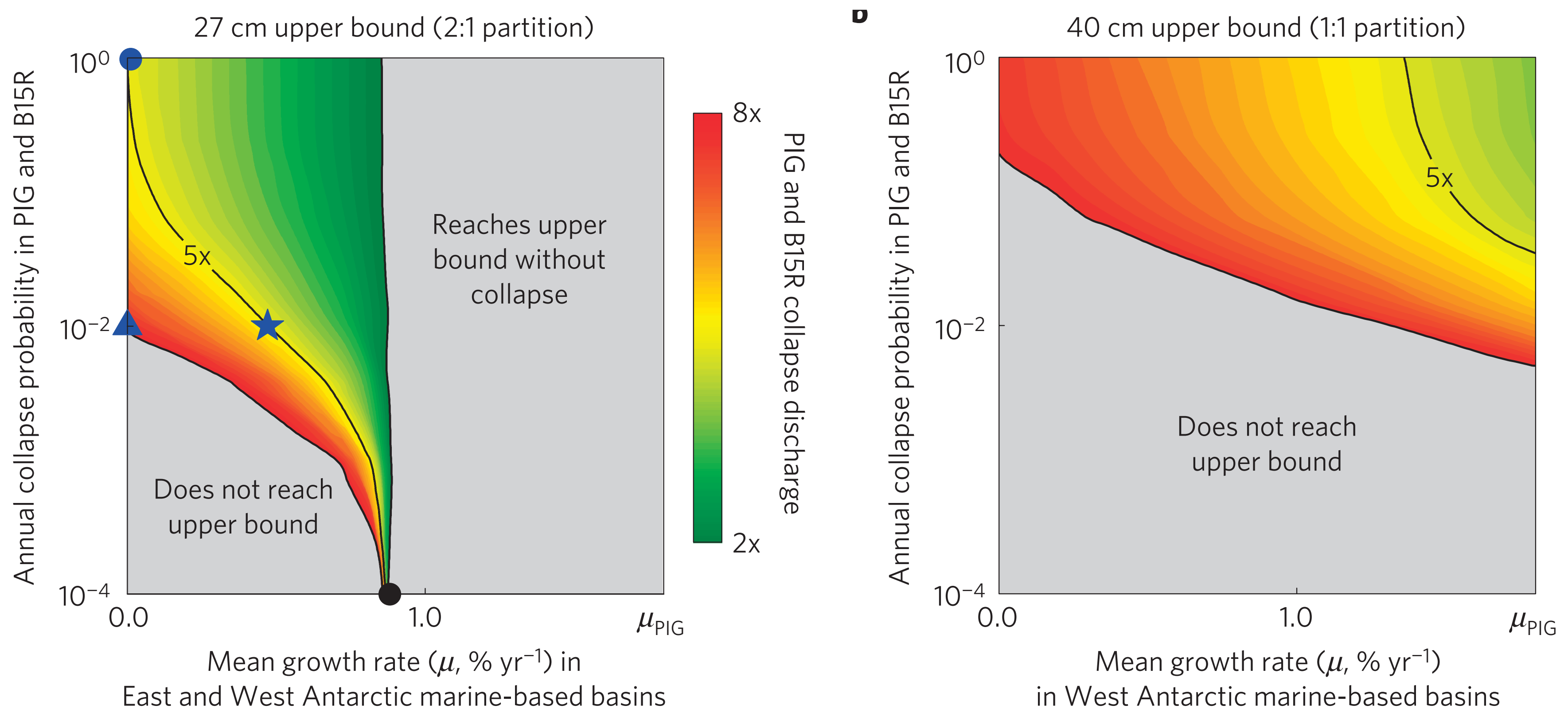
Local flood dynamics

Need for quantitative, transparent, traceable, up-to-date synthesis

- Can we devise a synthesis process that is more quantitative, transparent, and traceable (and "updatable")?
  - Allow experts to study, challenge, change assumptions; examine impact on conclusions
  - Update with new (perhaps customized) studies and analysis
  - Reconcile disparate scenarios / assumptions
- Modular information fusion decomposes problem into digestible questions about about system responses
  - What is the range of future global ocean warming? How does basal melt depend on ocean warming? How does ice disintegration depend on basal melt?
- Formulate probabilistic, quantitative answers to each question; insert your own models / data/ judgment

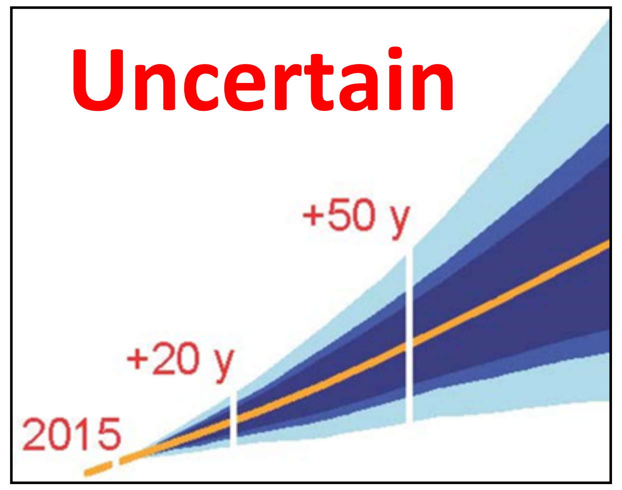


Little, Urban, Oppenheimer (2013); Little, Oppenheimer, Urban (2013)

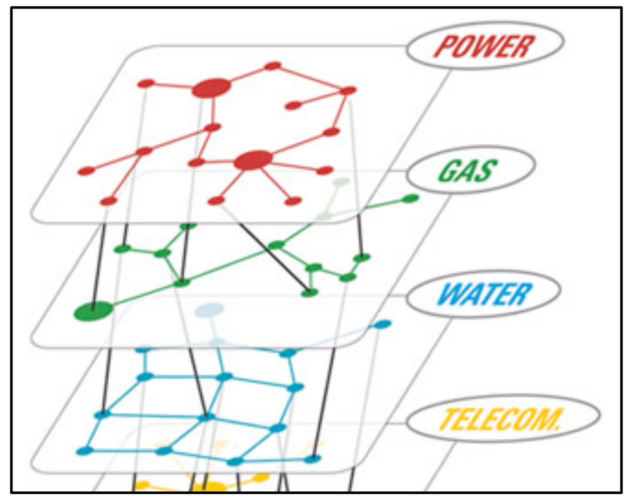


The science of complex adaptive systems

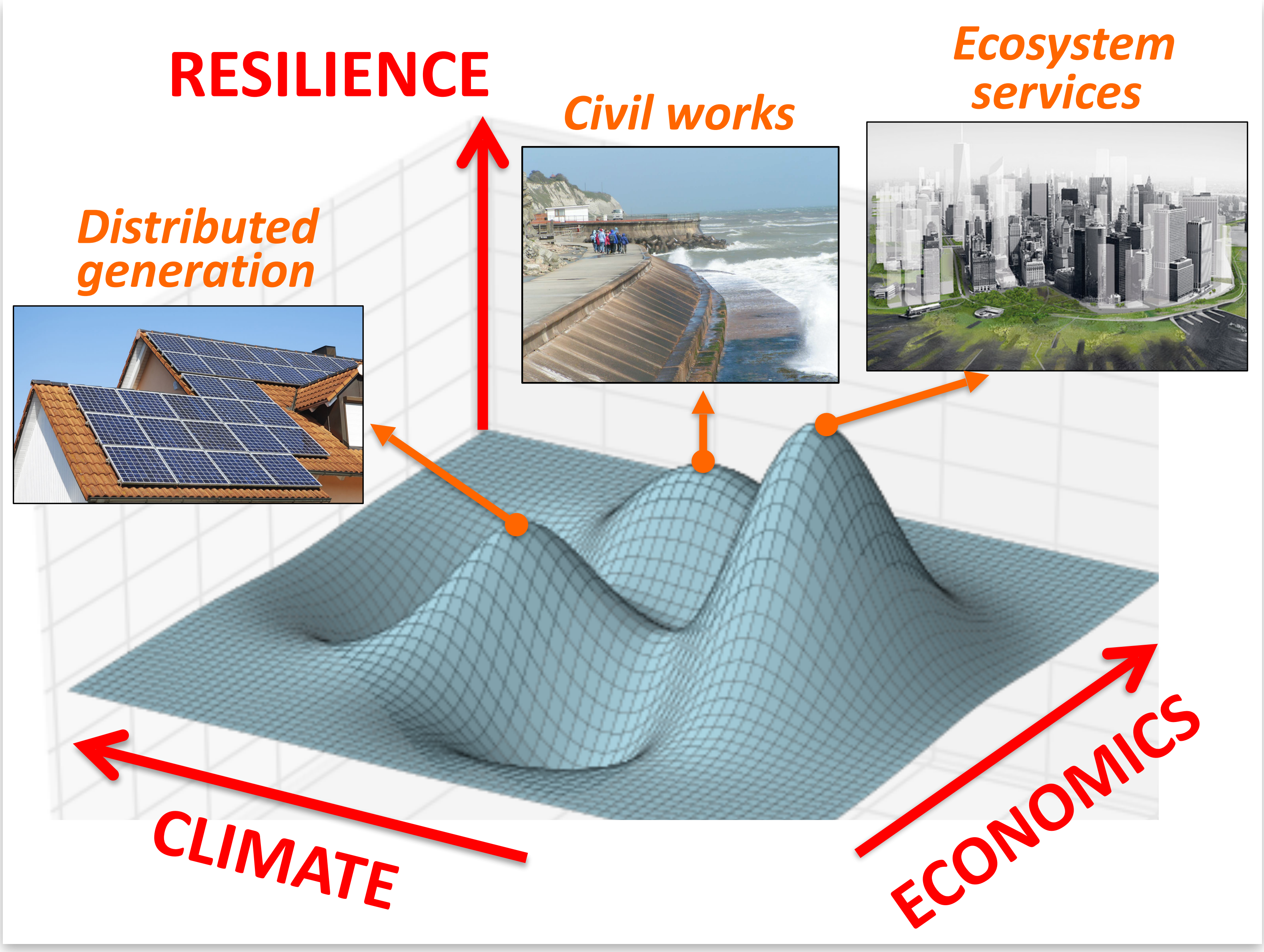
- Consider integrated resilience planning in a major coastal region
- Sectors: power, water, transportation, communications, housing, industry…
- The number of affected systems and possible decisions is vast
- “Everything influences everything”: many tradeoffs and constraints
- What does the “landscape” of resilience strategies look like?

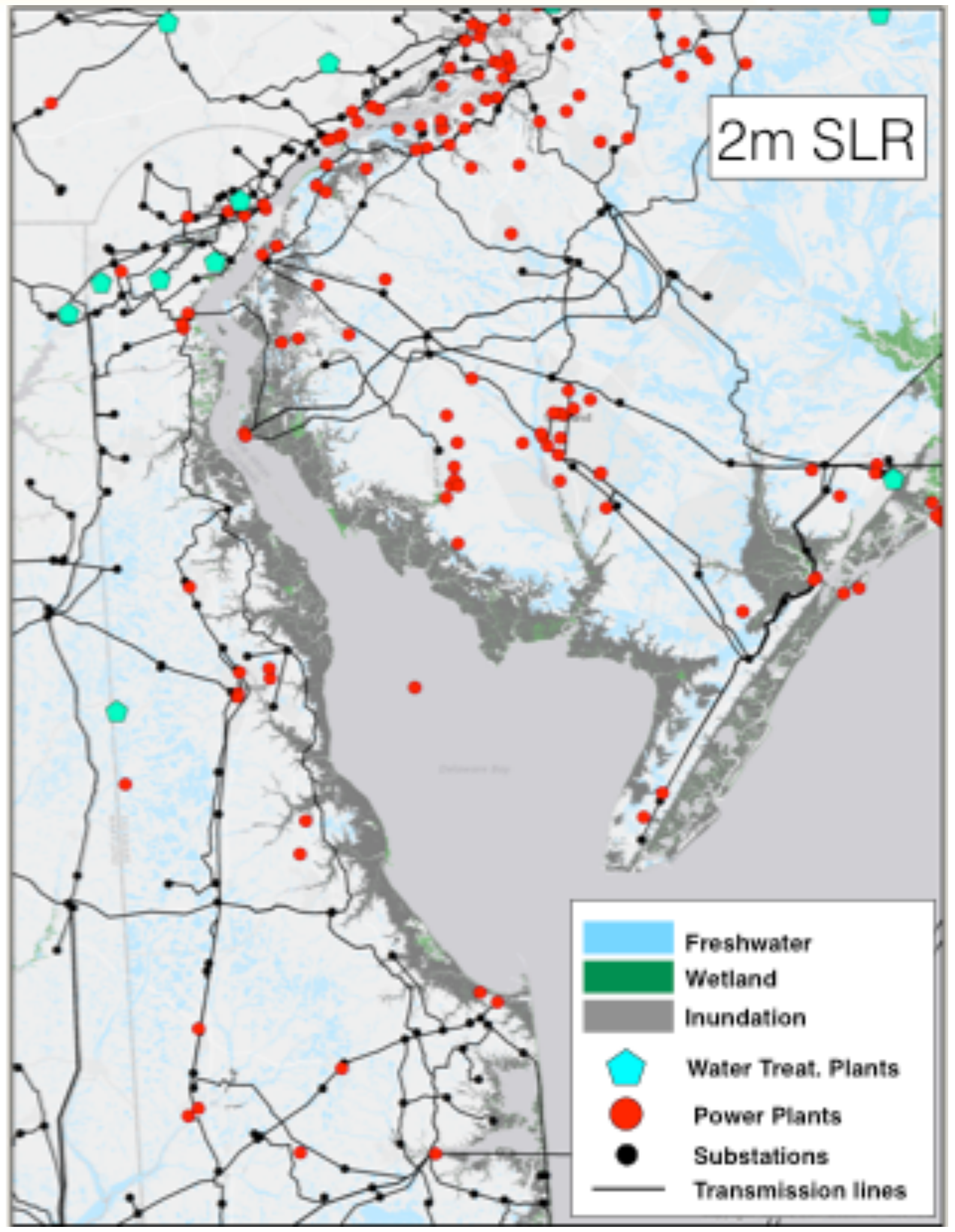


Time-evolving



Interdependent

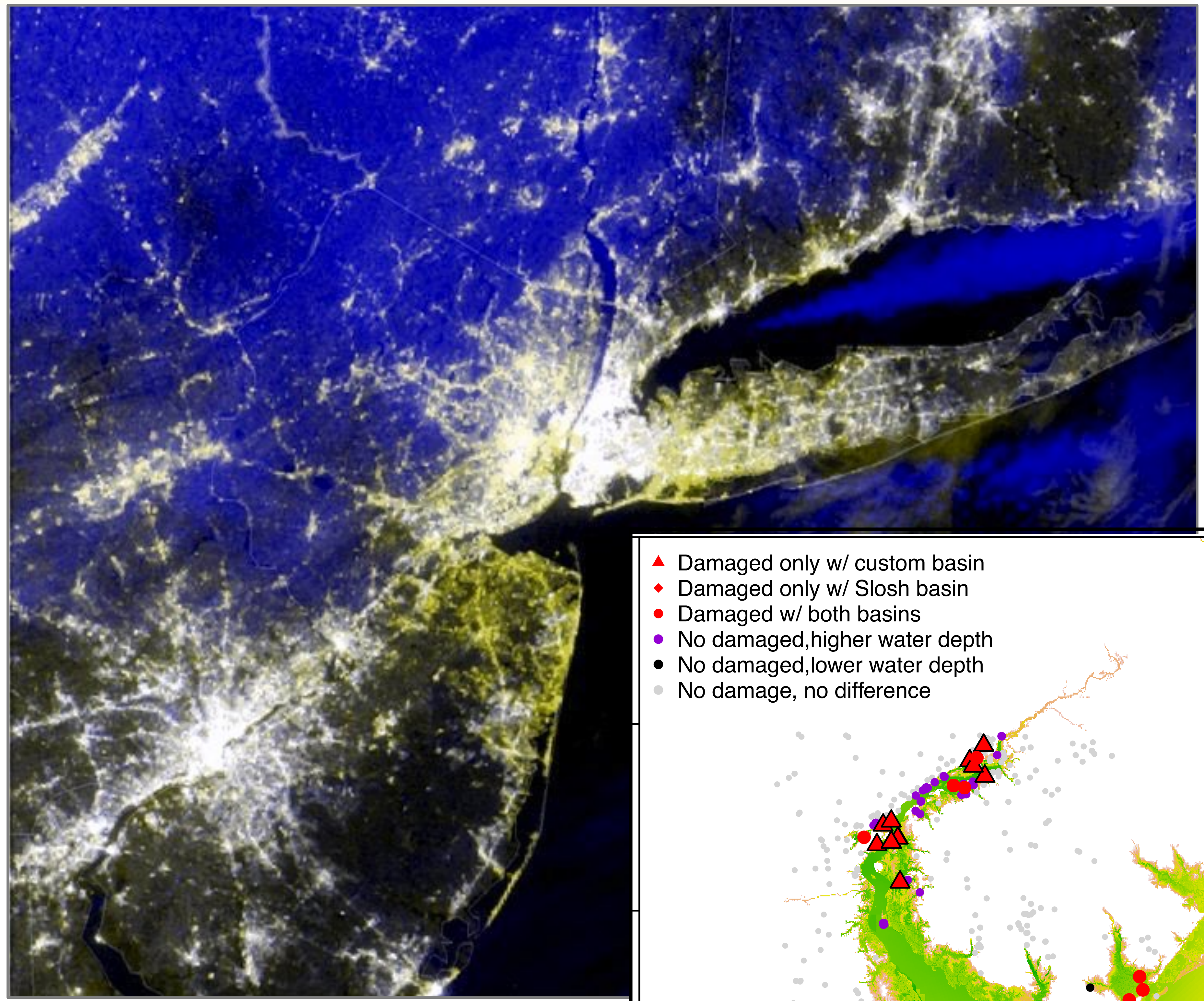




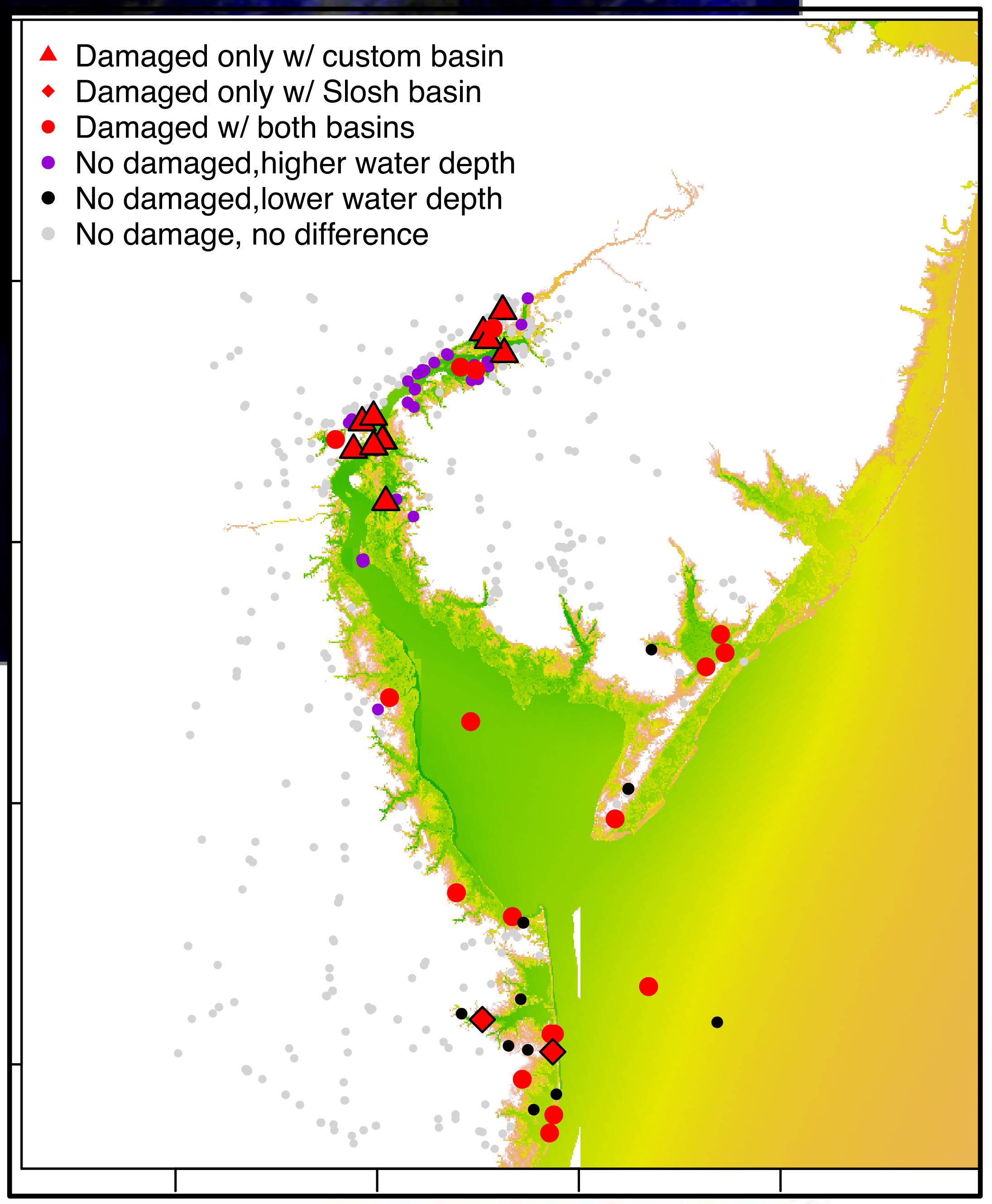
Pasqualini et al. (2017)

Some characteristics of planning in complex adaptive systems

- Motivating example: regional U.S. power grid
- Thousands of assets to manage
- Networked system; cascading failures
- Multiple interacting planning agencies (e.g. utilities)
- Interconnected web of decisions (flood protection, capacity expansion, shift toward renewables / distributed generation, …)
- Hazards and effects of decisions are global not local
- To understand vulnerabilities, <u>it is not sufficient to superimpose a map of impacts on a map of assets</u>



NASA SPoRT



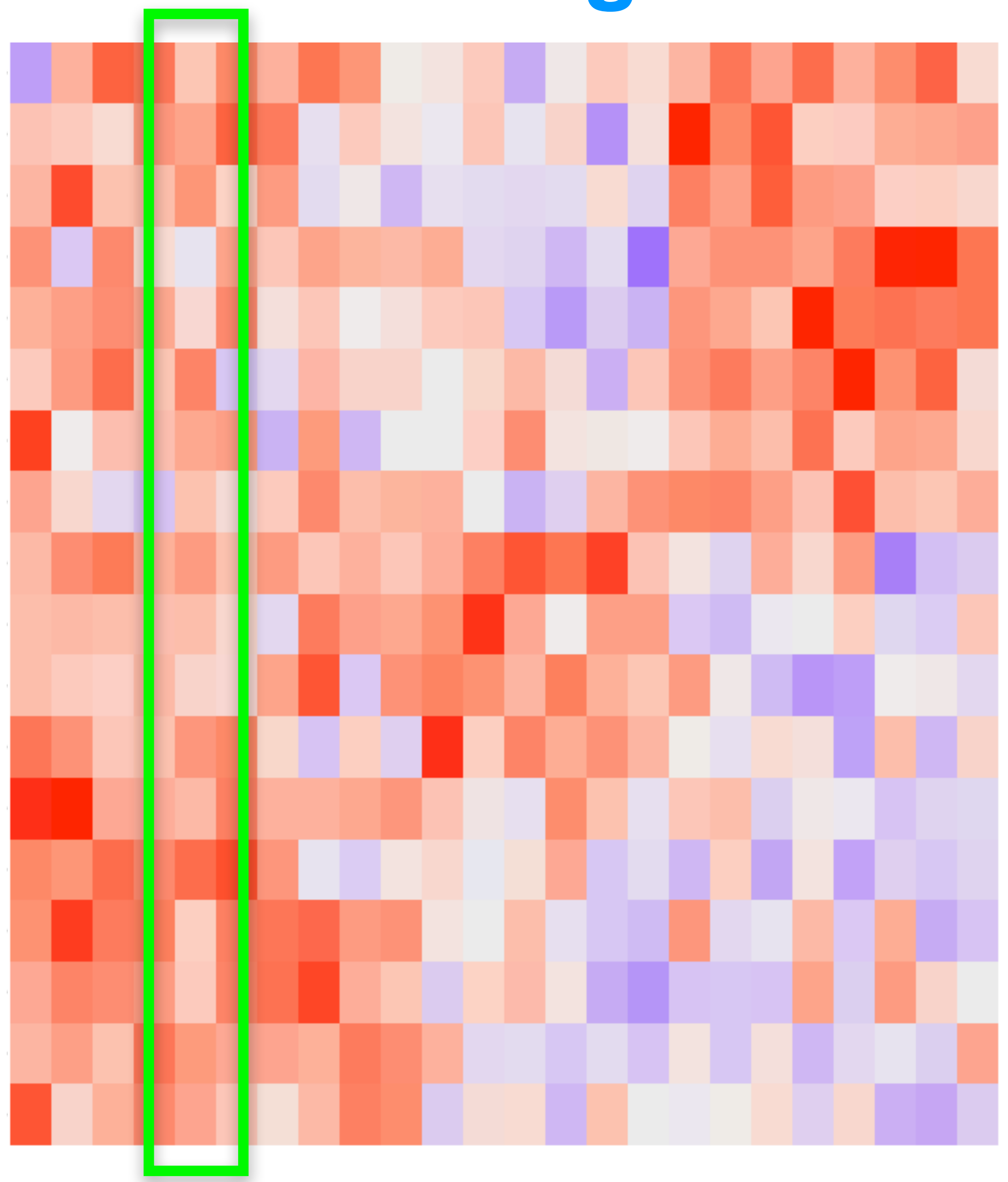
Pasqualini et al. (2017)

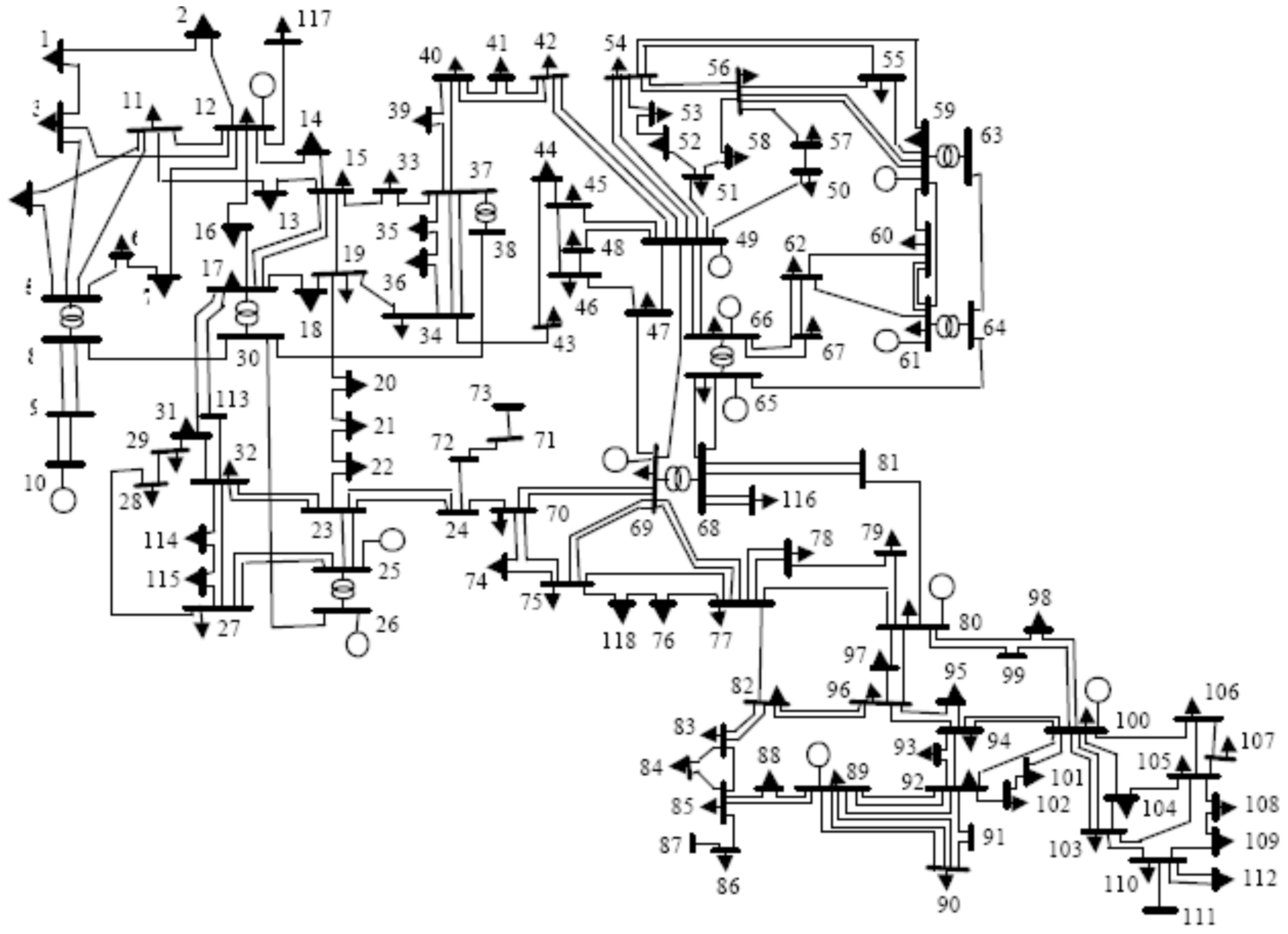
We can’t always determine all the “good” options in advance

- Common approach: generate a set of impact scenarios; evaluate them against a stakeholder-specified “menu” of decision options
- In complex interdependent systems, with cascading consequences, this does not always help us understand what to do!
  - Can’t easily anticipate the downstream consequences of actions
  - Decision space is exponentially large
  - May be impossible to pre-specify the set of options worth considering

Strategies

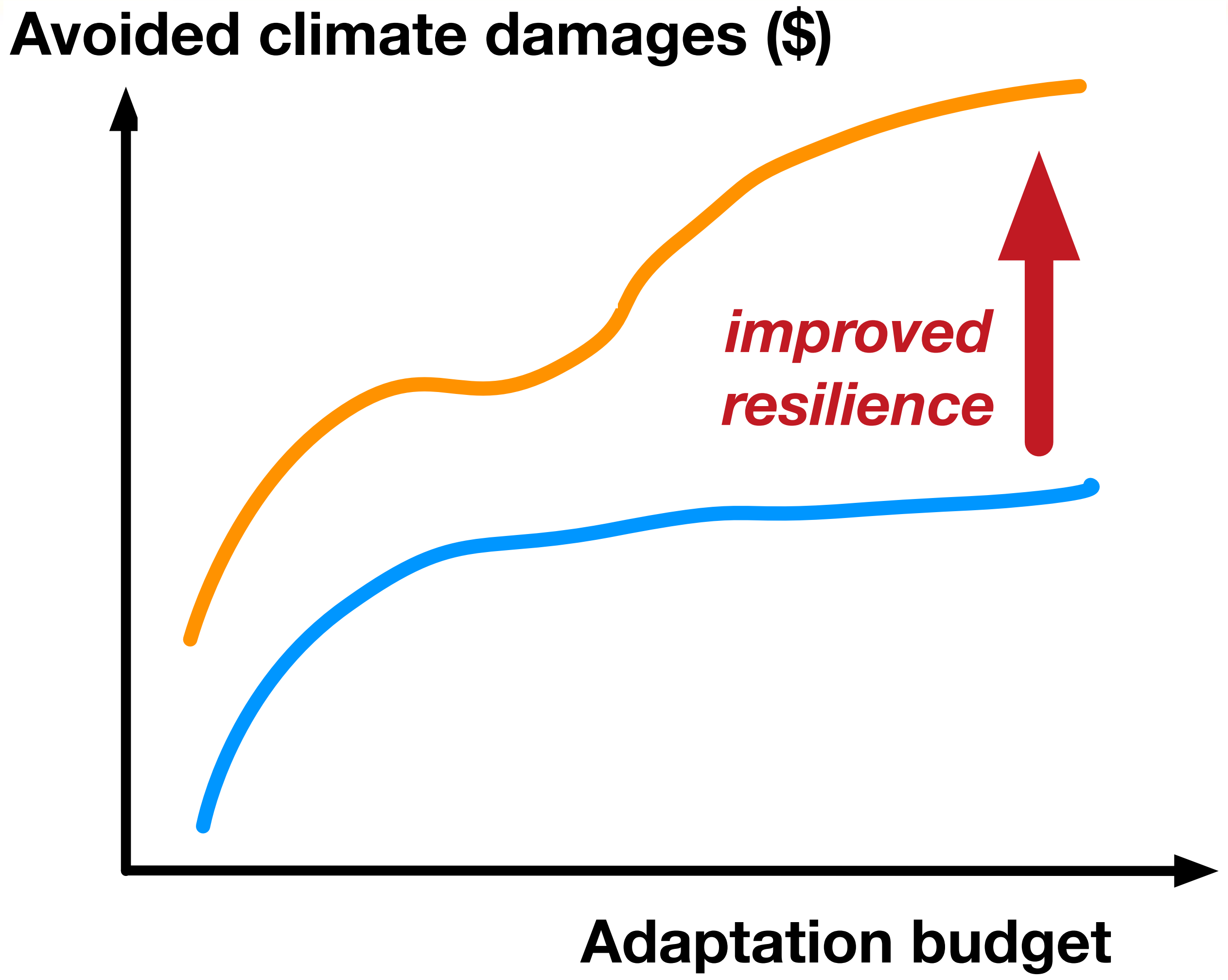
Scenarios

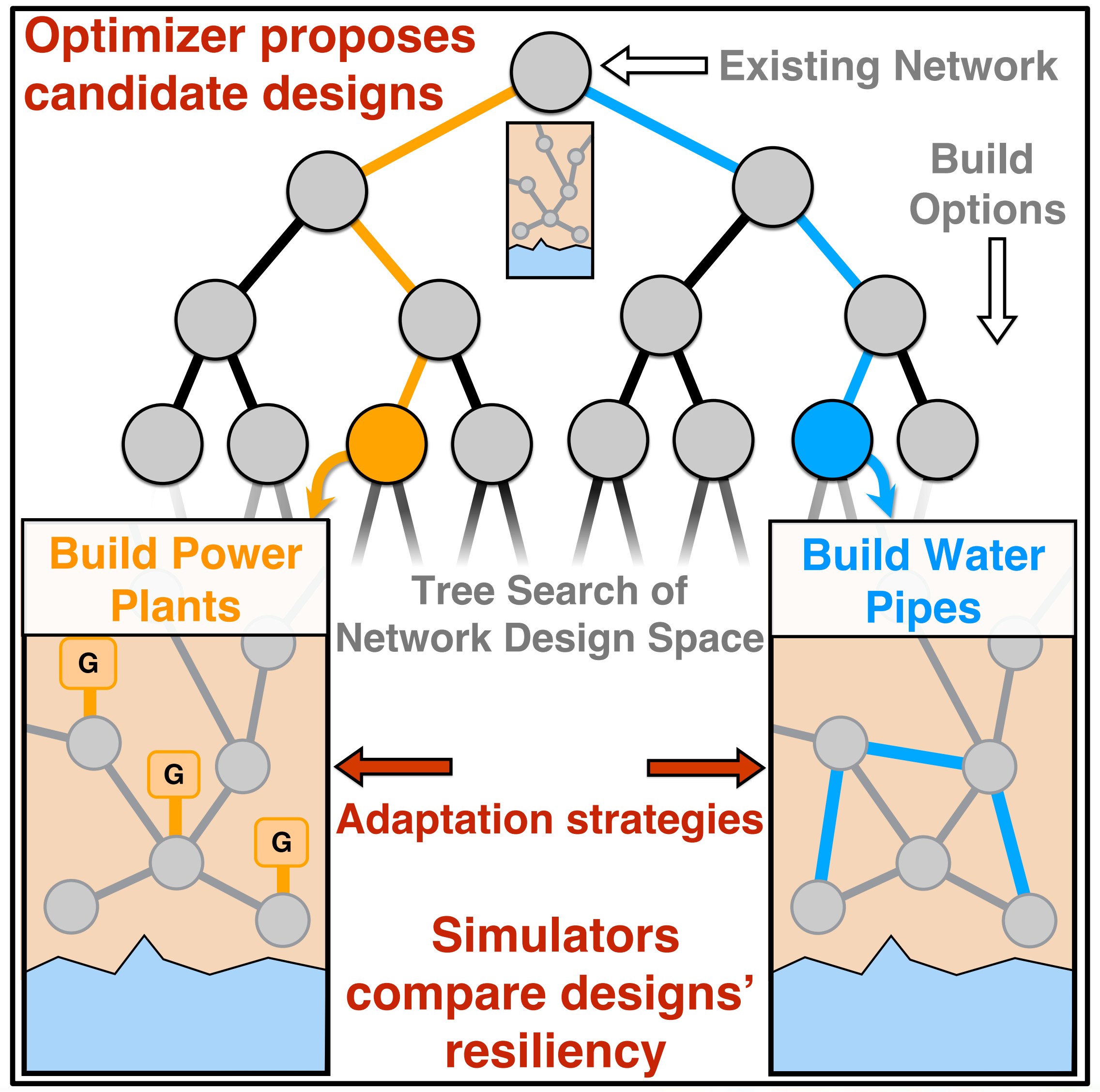




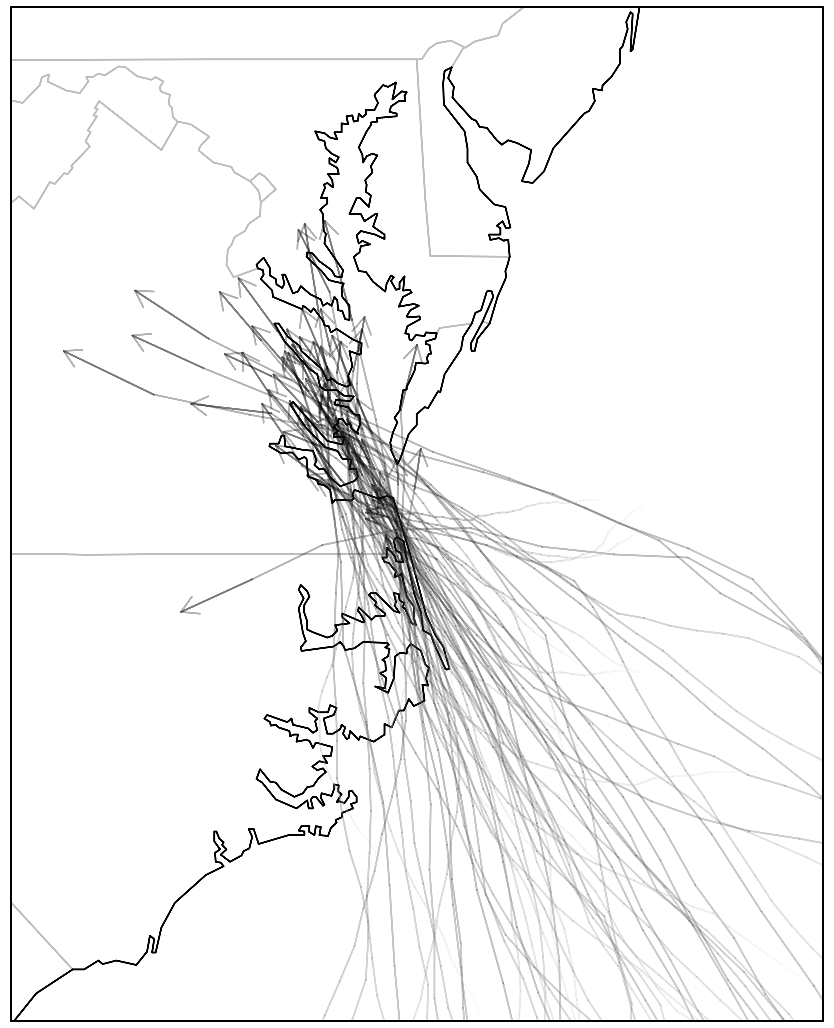
Simulation and computational decision search for complex systems

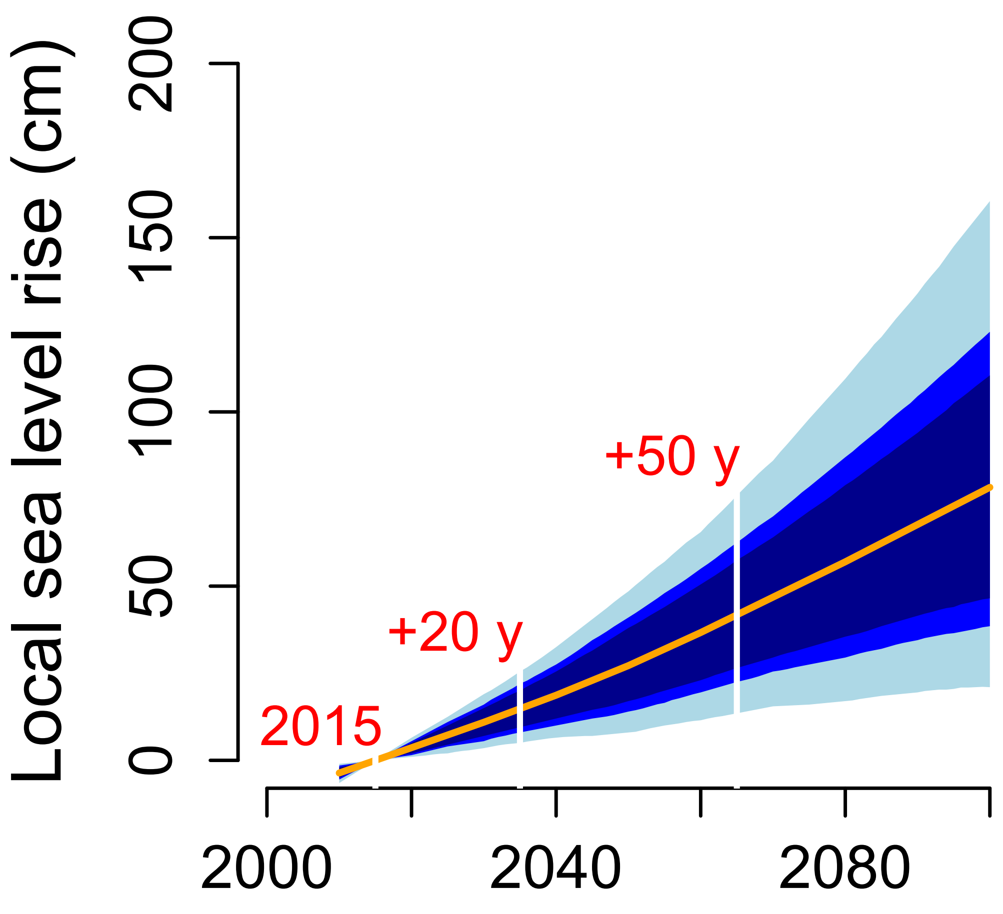
- “SimCity” vulnerability analysis: simulate regional natural-human-engineered system over <u>probability distribution</u> of impacts
  - system dynamics, not just GIS hazard maps
- Interdependent infrastructures, economics, ecosystems, …
- Computationally-aided decision search to intelligently/efficiently search for strategies meeting design objectives, e.g.:
  - minimize cost
  - achieve required level of reliability
  - respect physical/engineering design constraints
  - respect geographic/political/stakeholder constraints
- Decision support tools to identify potentially useful tradeoffs in complex decision problems that unaided humans might not find

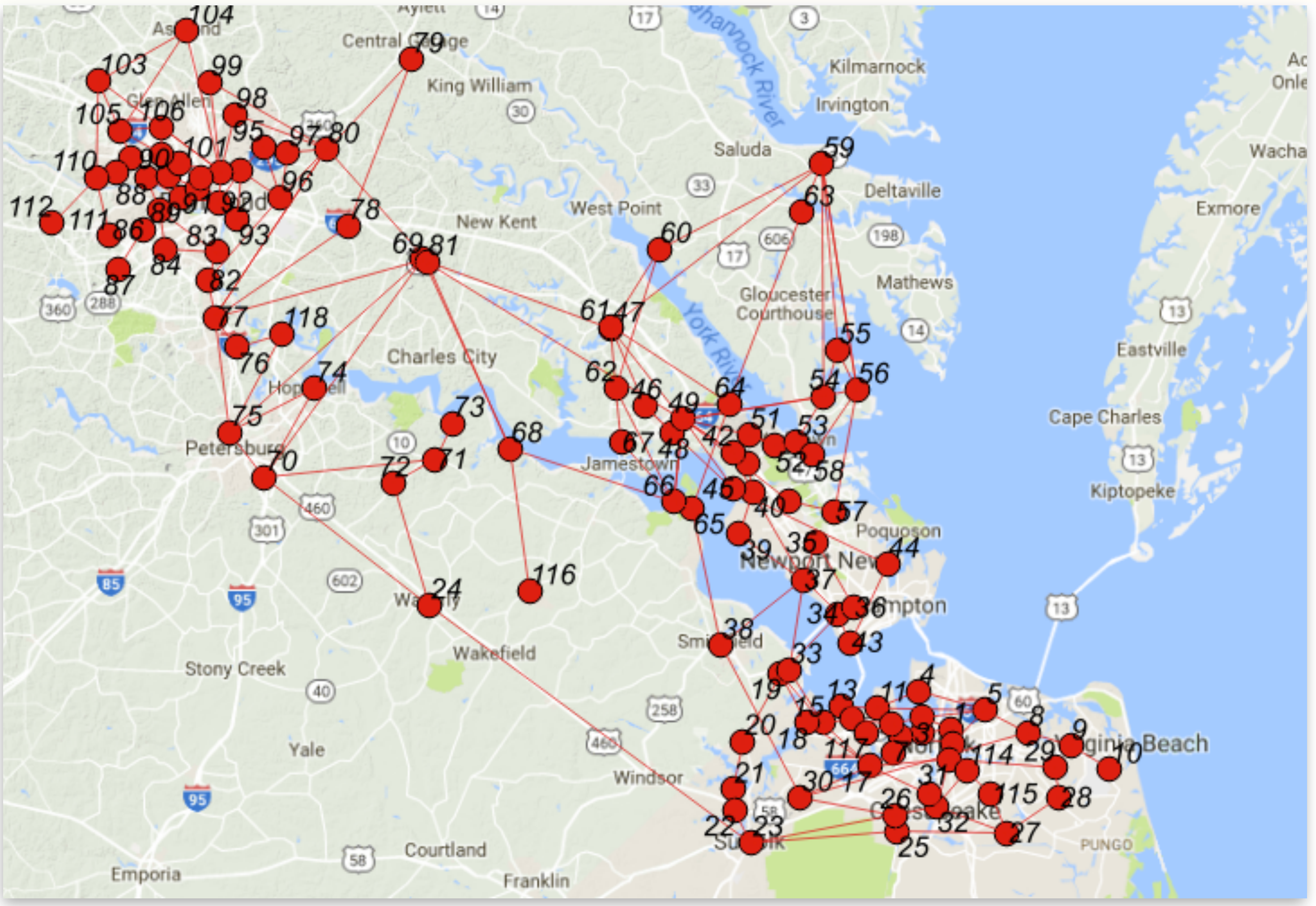




Complex network adaptation can find lower-cost reliable strategies



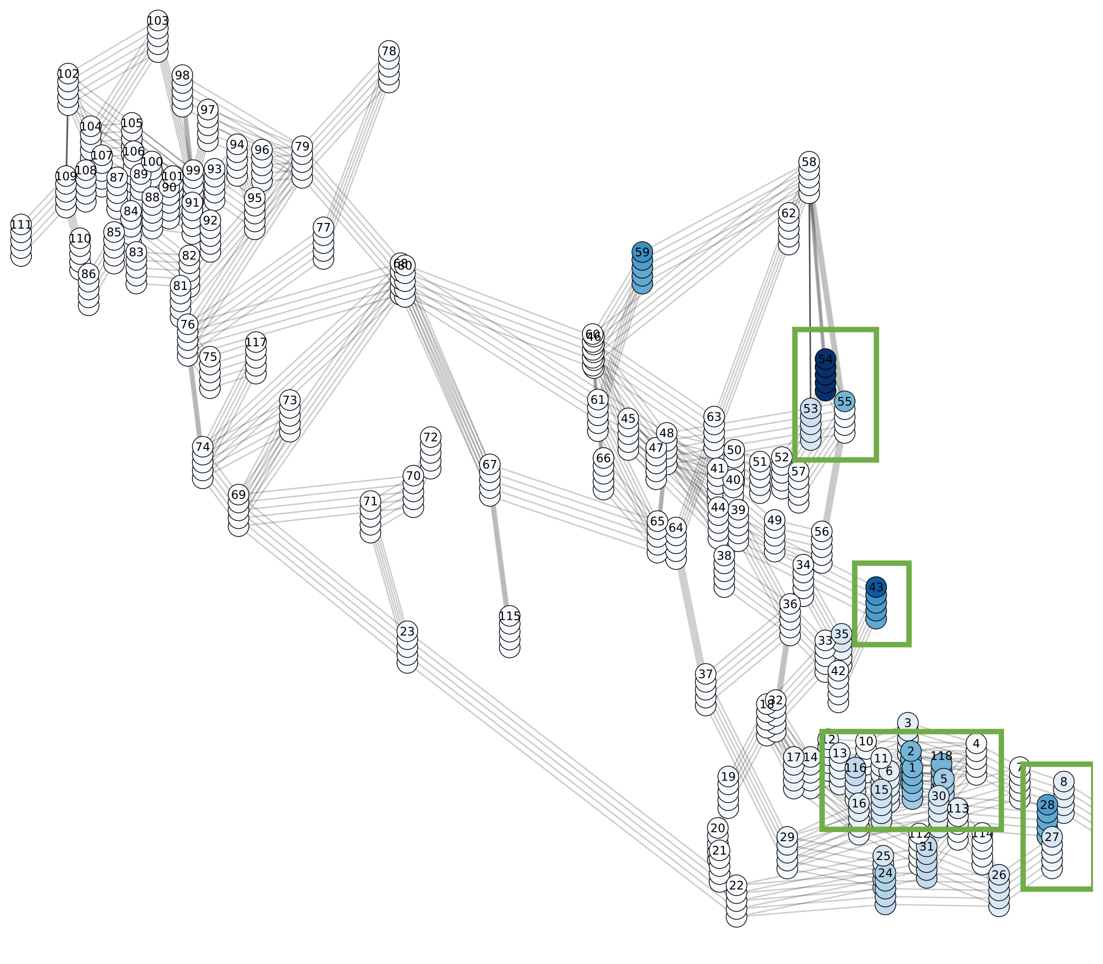




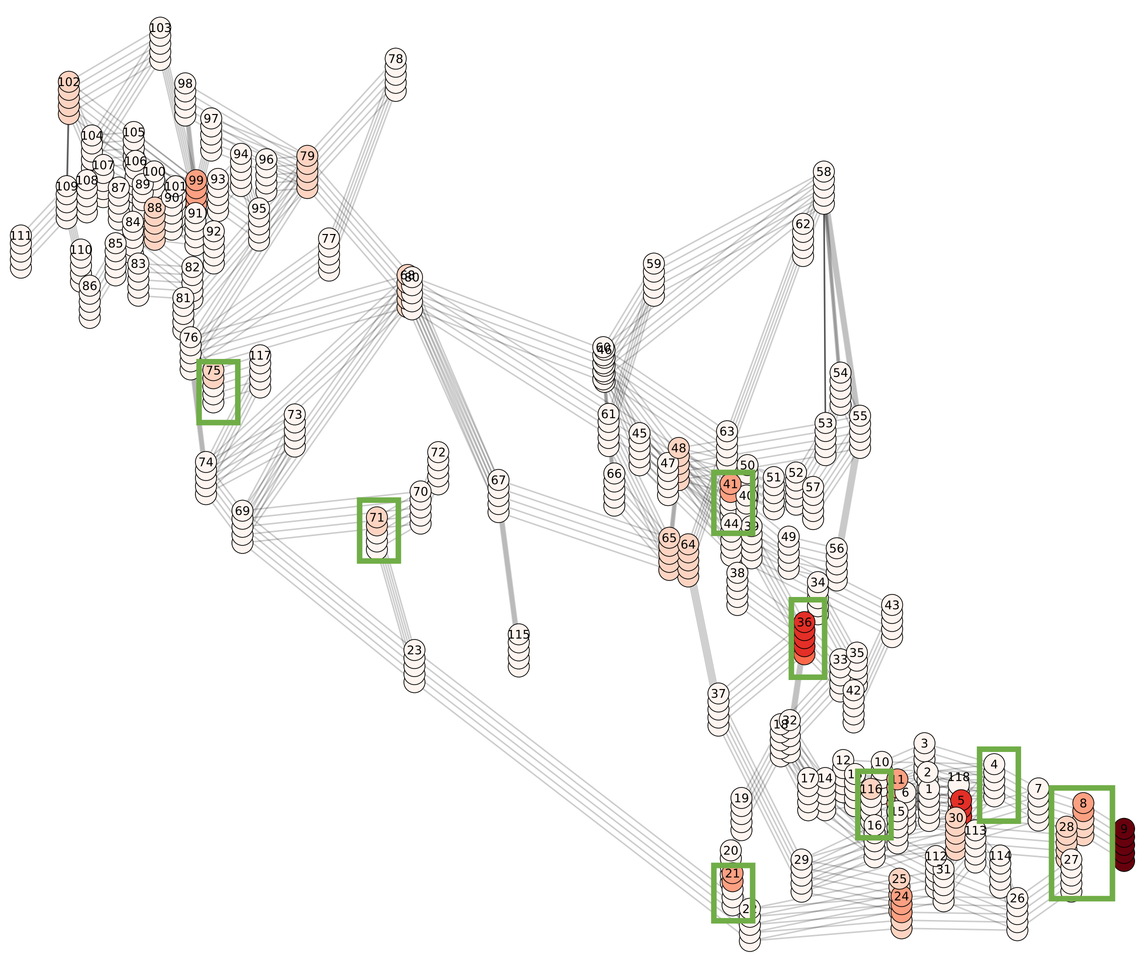
- Toy “Norfolk” power grid
- Joint flood hardening and capacity expansion planning for storm surge and sea level rise
- Find probabilistic reliability guarantees at minimum cost

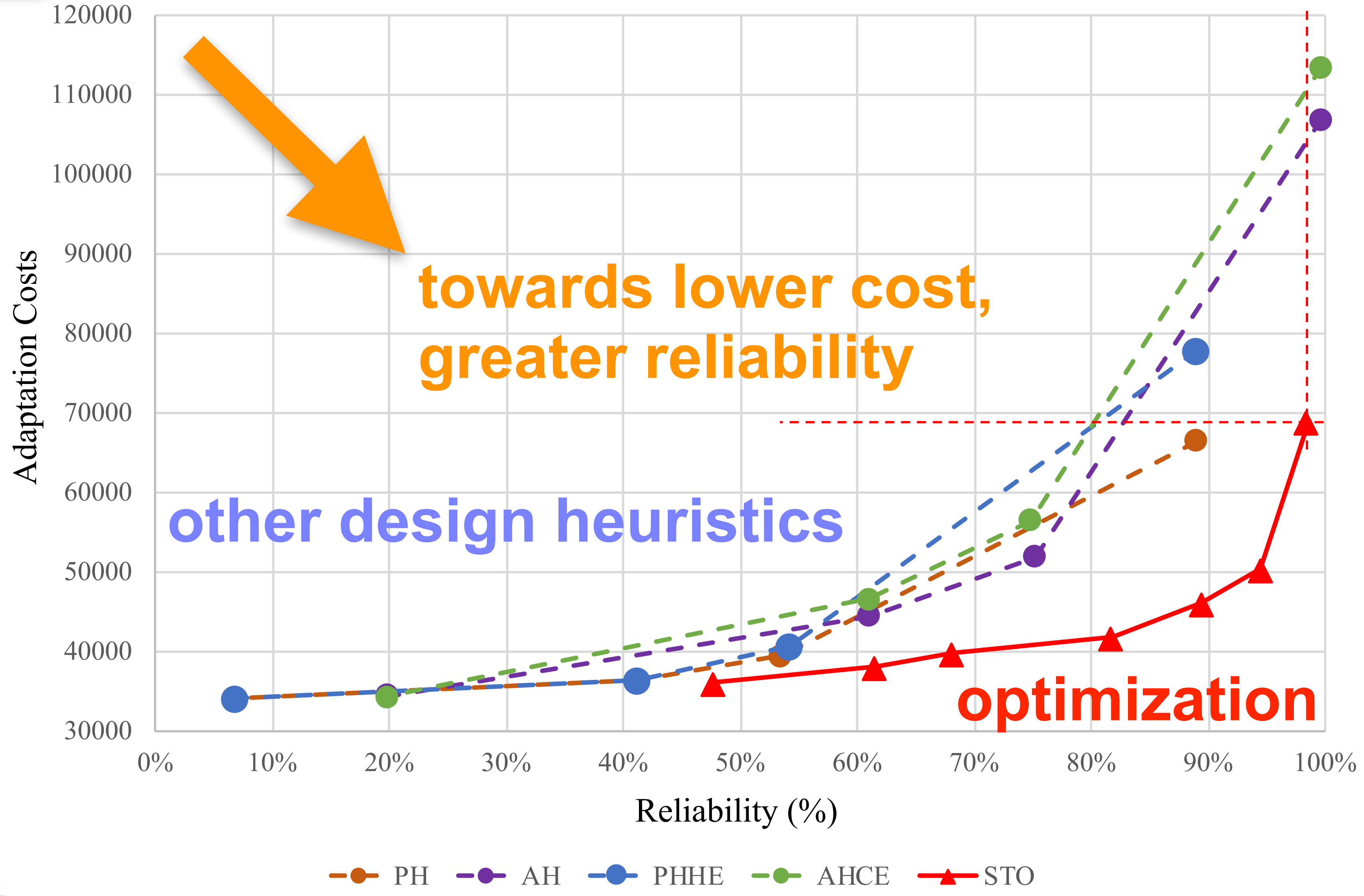
Wang et al. (in review)

Hardening Costs: 15467



Expansion Costs: 31999





Conclusions

- Coastal planning will require increasingly sophisticated synthesis data products based on agile, state-of-the-art science
- We can’t afford to “leave science on the table”: translate diverse studies into usable predictions
- Synthesis grand challenge: Combining diverse collections of different, specialized models and data sets, each with their own biases and uncertainties
- … a more formalized quantitative version of IPCC/NCA assessment science
- Integrated adaptation challenges exist in a complex, difficult-to-understand space of consequences, goals, tradeoffs, and constraints
- A more formalized decision science may be needed to solve these complex adaptation problems