

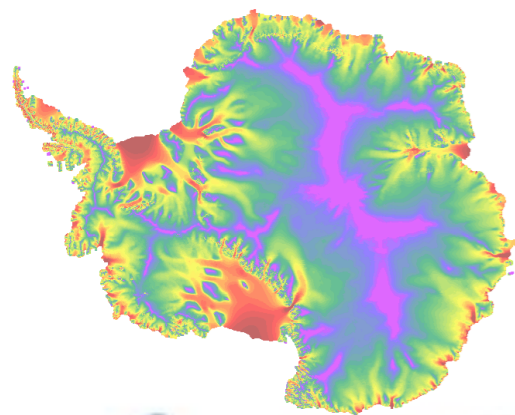


# Sea level rise uncertainty quantification

Nathan Urban

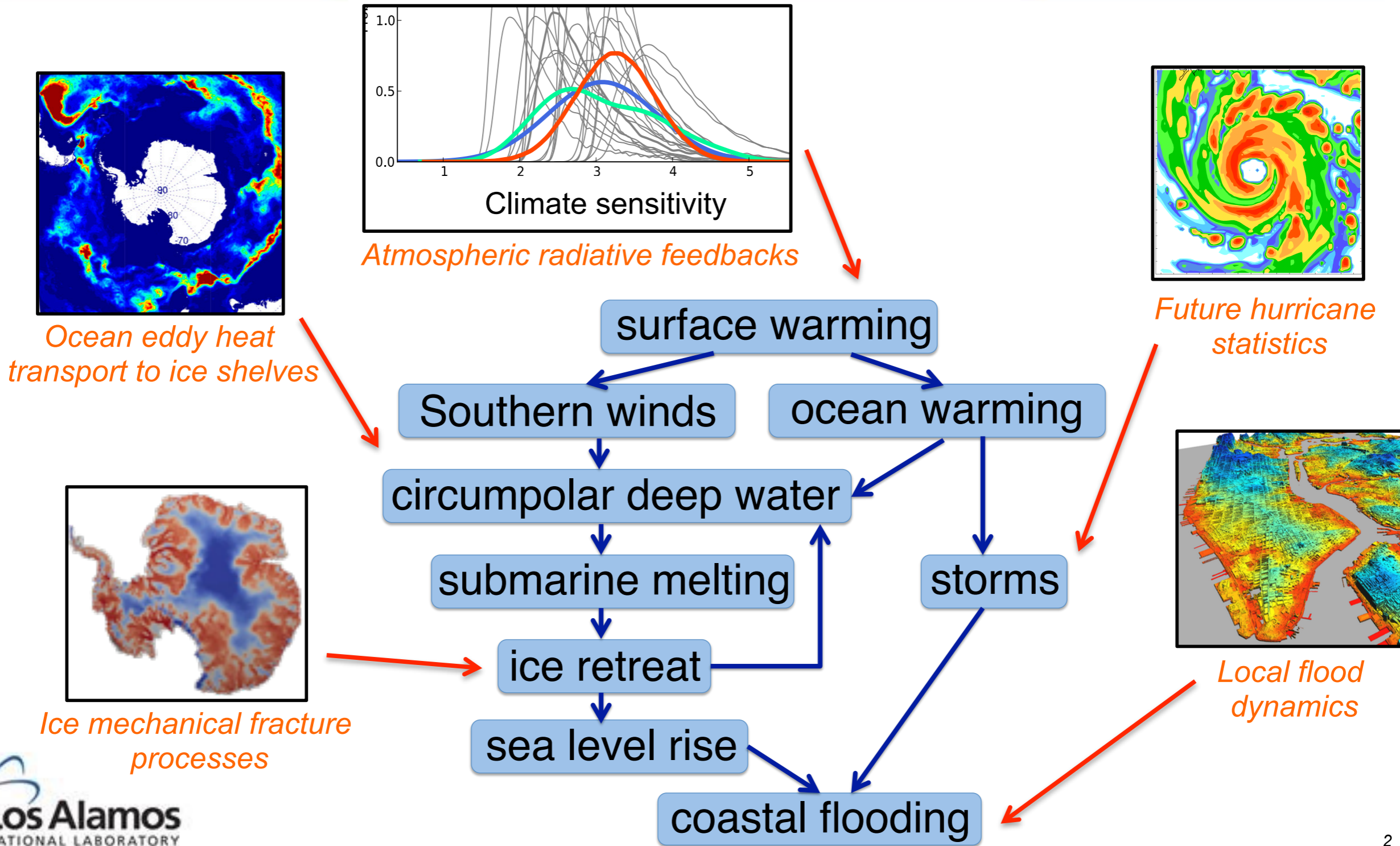
Los Alamos National Laboratory

with Alice Barthel (LANL), Mira Berdahl (LANL), Mike Dinniman (Old Dominion),  
Matthew Hecht (LANL), John Klinck (Old Dominion), Gunter Leguy (NCAR),  
Bill Lipscomb (NCAR), Chris Little (AER, Inc.), Milena Veneziani (LANL)



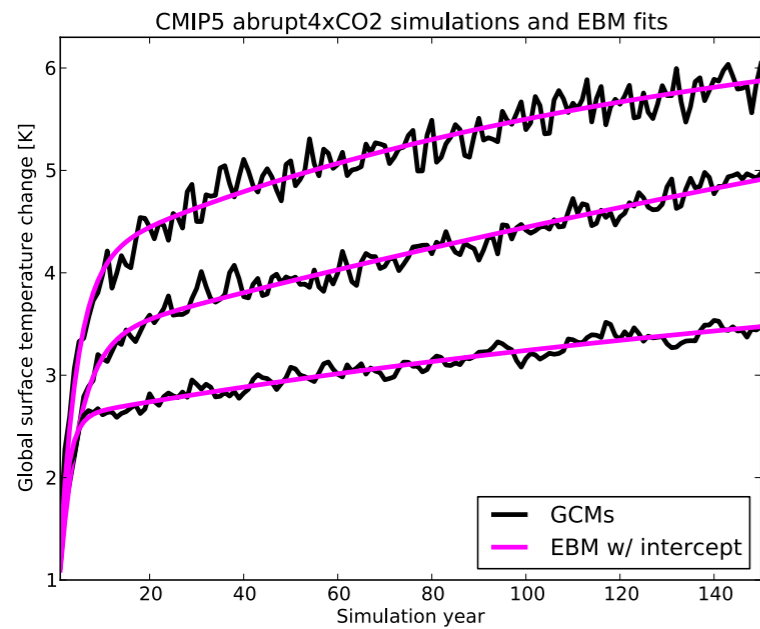
January 10, 2018

# Towards a modular framework to quantify uncertainties in sea level rise and coastal flooding



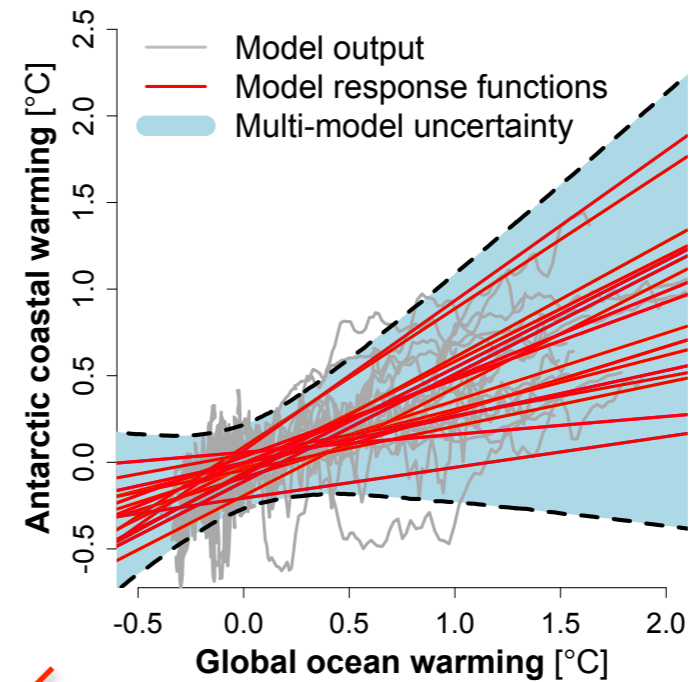
# Toy example: Antarctic sea level rise

## 1. Energy balance model emulator of CMIP5 global warming



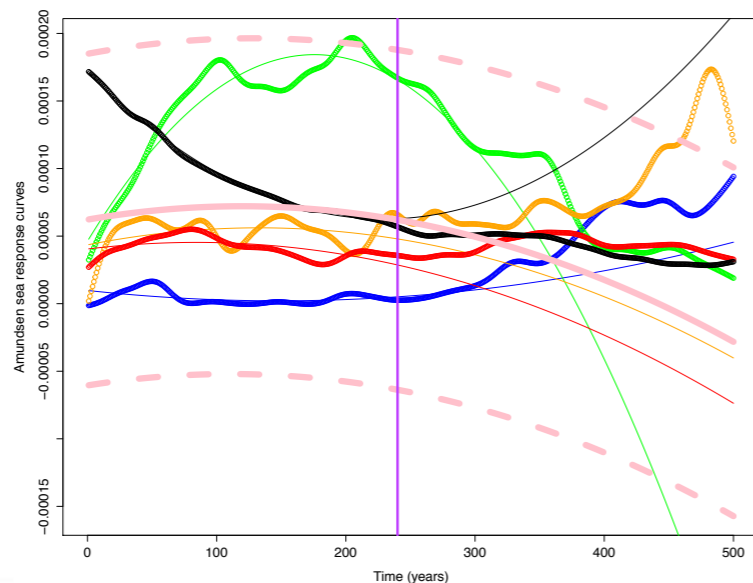
adapted from work by  
K. Kyzyurova; inspired  
by Levermann et al.  
(2014)

## 2. Regression-based downscaling of CMIP5 global ocean heat uptake to coastal Antarctic warming

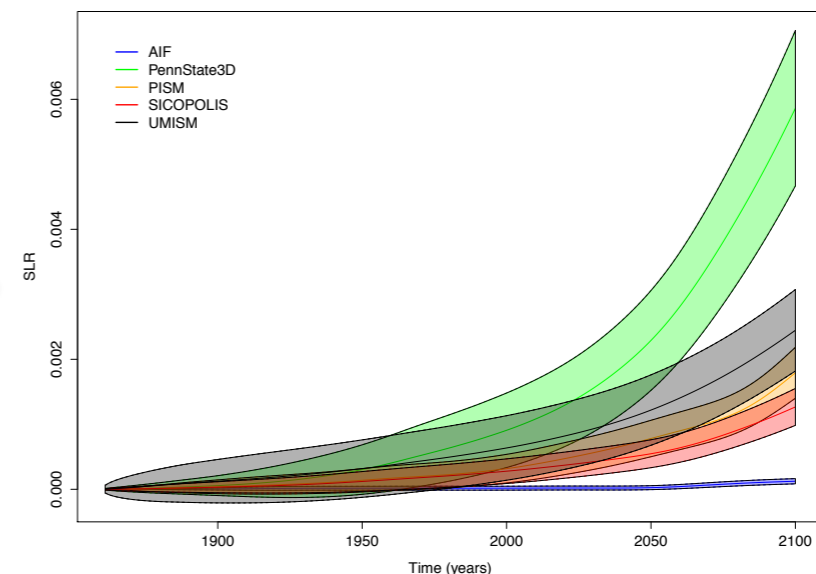


Little and Urban (2016)

## 3. Impulse response emulator of Antarctic land ice disintegration (from SeaRISE)



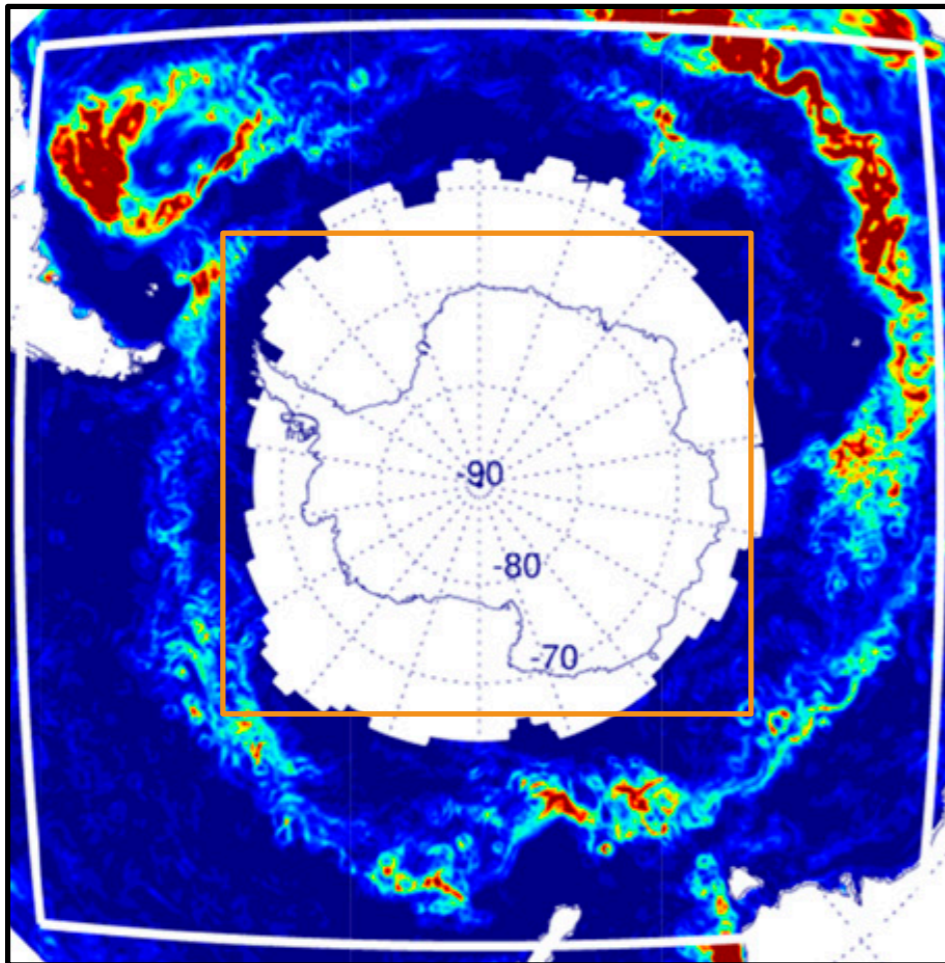
## 4. Probabilistic, multi-model Antarctic sea level rise projections



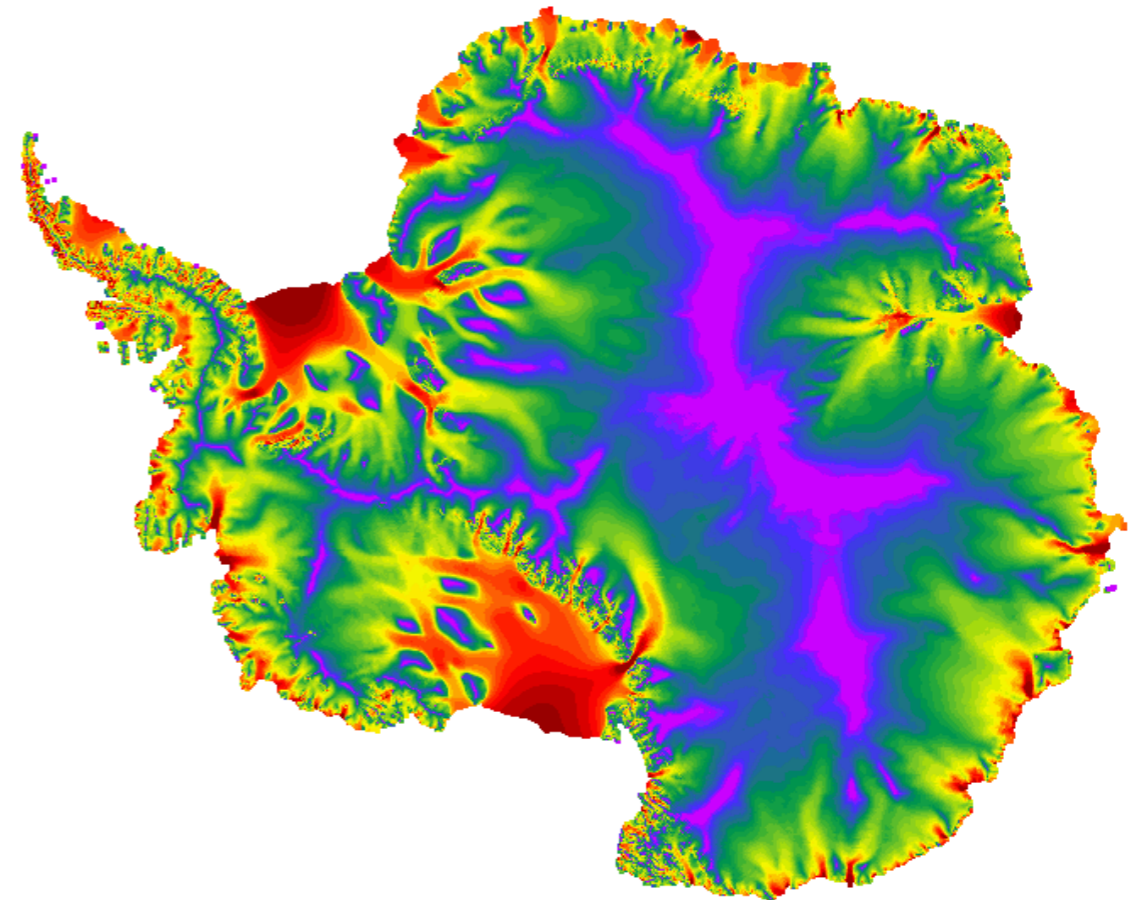


# Adding process fidelity: numerical model ensembles

ROMS ocean model @ 5 km



CISM land ice model @ 4 km  
(8 km shown here)



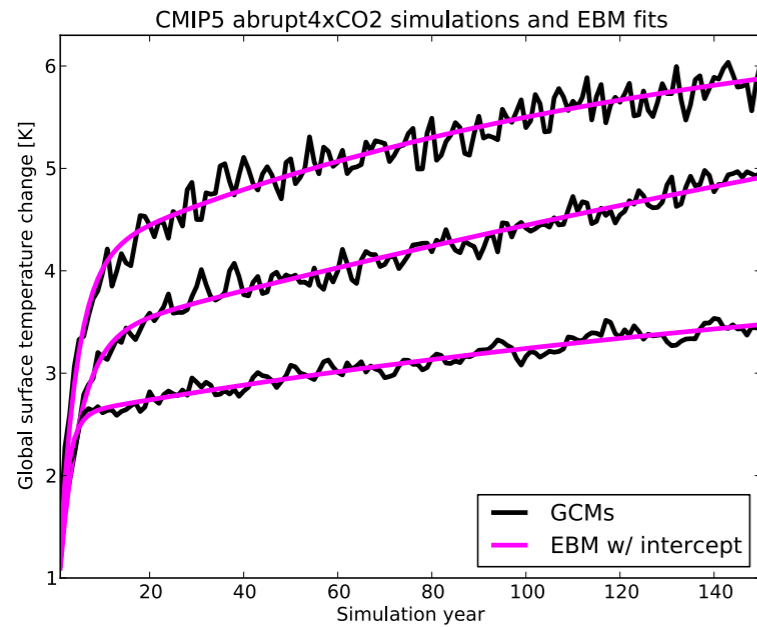
Ocean projections driven by CMIP5 multi-model atmosphere-ocean boundary conditions + reanalysis variability

Ice projections driven by assumed basin-specific basal melt trajectories

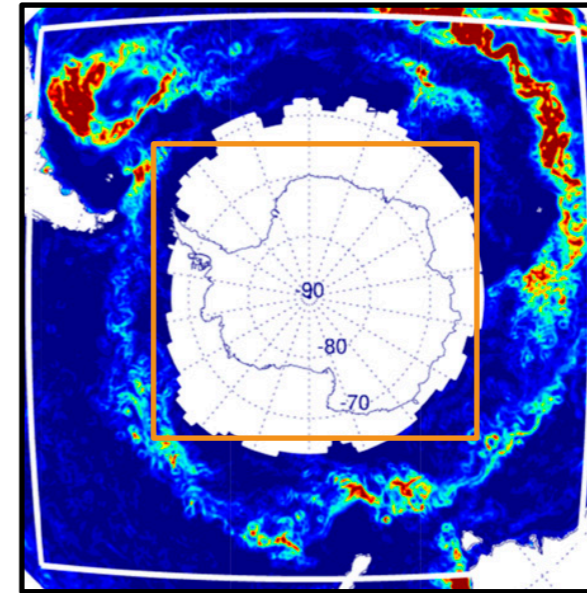


# Uncertainty propagation through reduced models and response functions, informed by numerical models

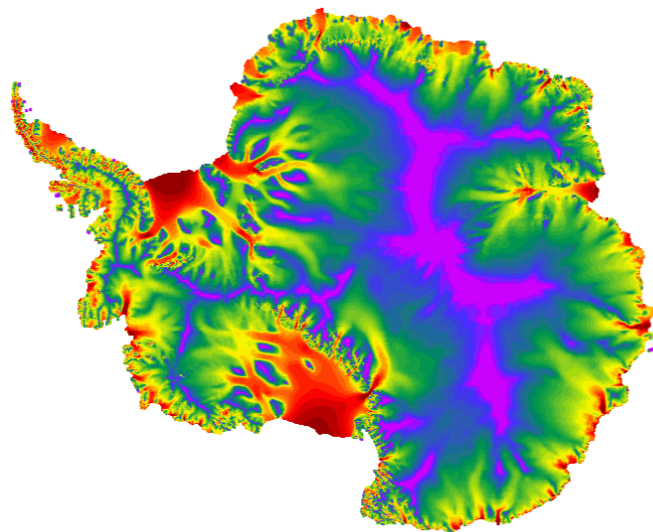
## 1. Energy balance model emulator of CMIP5 global warming



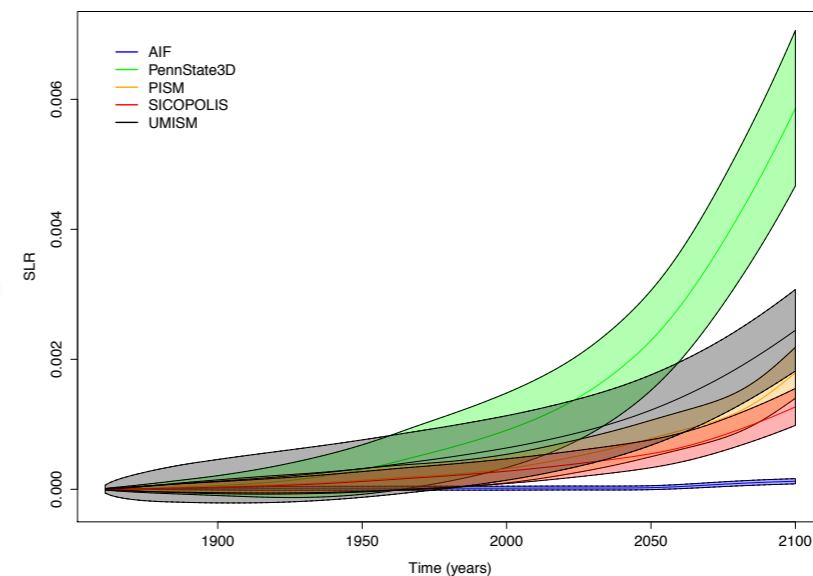
## 2. Emulate ROMS basal warming as a function of CMIP5 ocean warming



## 3. Emulate CISM discharge as a function of ROMS-derived basal melt rates



## 4. Probabilistic, multi-model Antarctic sea level rise projections



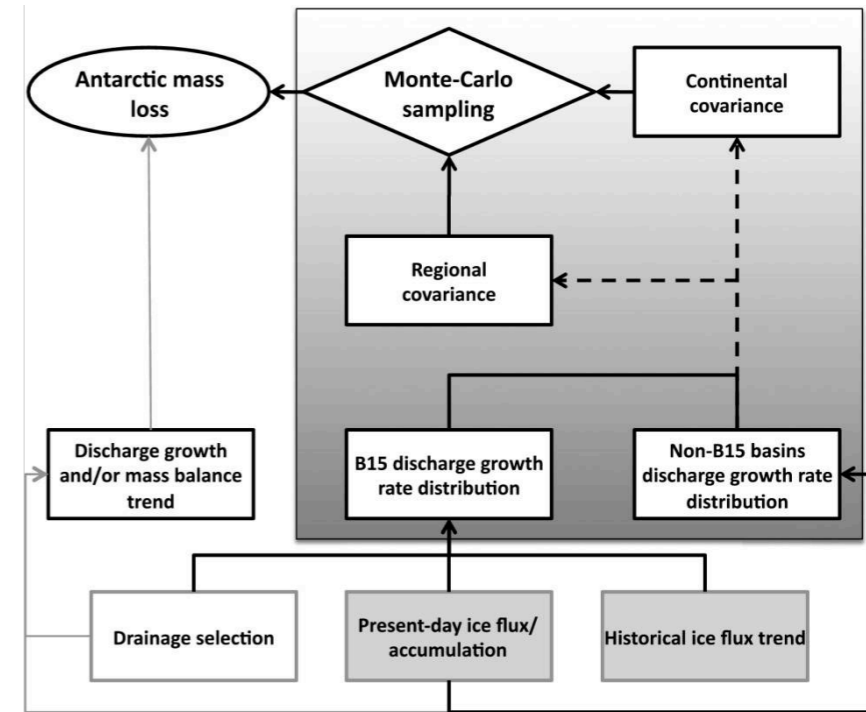
# Features of a modular UQ approach

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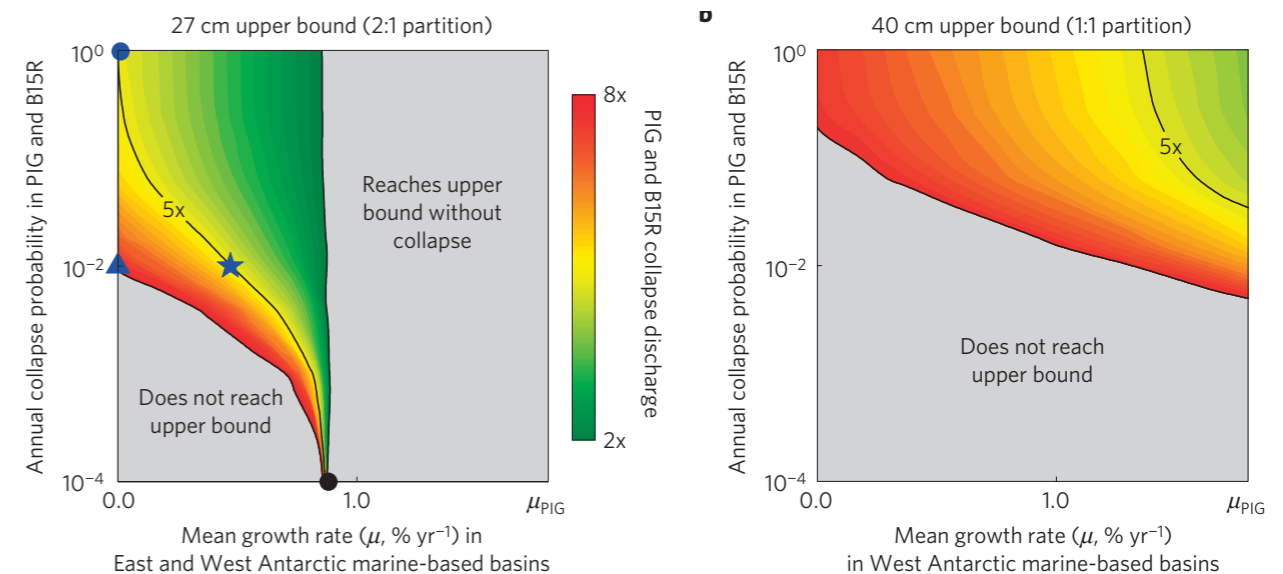
- Synthesis: response functions or “links” can be based on
  - high resolution coupled simulations
  - low resolution ensembles (e.g. LENS, CMIP)
  - standalone component models with prescribed forcing (e.g. CISM)
  - idealized process studies (CISM-MOM local shelf studies?)
  - global or local observations (can be process-level)
- Commission *new* simulations designed to probe specific process relationships
  - e.g. eddy-driven ocean heat transport to Antarctic ice shelves, and its dependence on large-scale climate drivers; ensembles of ice simulations under ranges of ocean forcing
- New climate scenarios that no single model produces
- Novel combinations of model structures (e.g. highest SLR results from fastest warming ocean + fastest melting ice)
- Sample “tail” scenarios outside the range of any model

# Goal: quantitative, transparent, traceable synthesis

- IPCC synthesis is “gold standard”, but limited
  - Hard to interrogate, change assumptions (expert judgment can be opaque)
  - Hard to add new information post-publication (science is moving target)
  - Stakeholders already moving on
- Can we devise a synthesis process that is more quantitative, transparent, and traceable (and “updatable”)?
  - Modular UQ 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/judgments
  - Allow experts to study, challenge, change assumptions; examine impact on conclusions



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





# RESERVED SLIDES

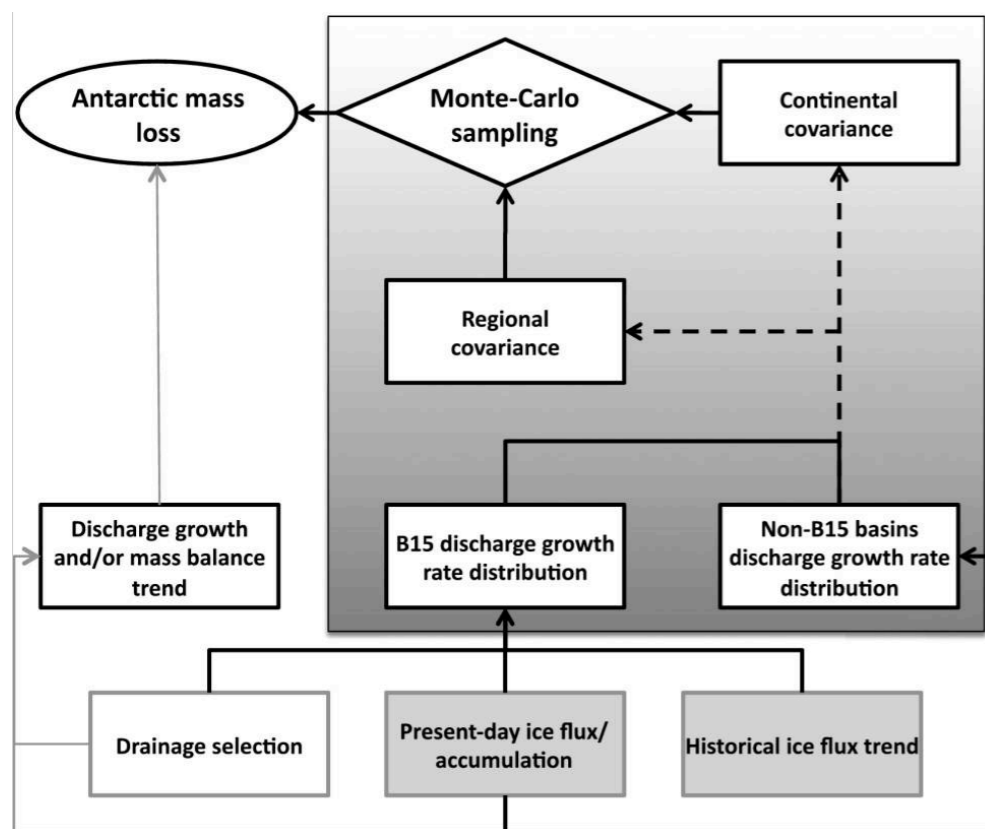
# Observations and questions

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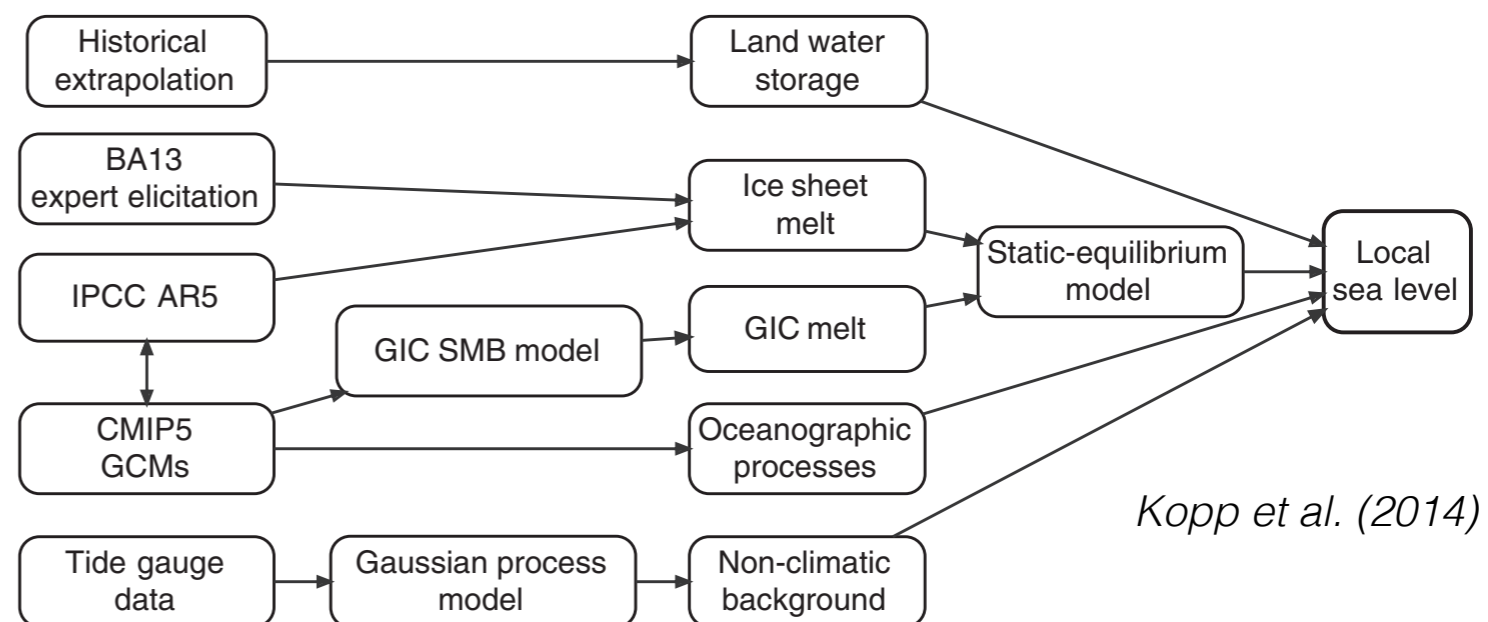
- More common than not: science studies don't influence decision makers except through large synthesis reports
- Synthesis reports can be opaque from a science perspective
  - Hard to interrogate and change assumptions
  - Hard to add new information post-publication
- Can we devise a synthesis process that is more quantitative, transparent, and traceable?
  - Would this lead to improved decision making down the line?
  - How can direct interaction with decision makers help?
- Science-focused studies improve process understanding, which should lead to improved projections, but how can we actually do this?
  - Can research be directed to be more useful for decision makers?

# Quantitative synthesis approaches for SLR uncertainties

- Move toward IPCC-style synthesis within a formal statistical framework for combining different information sources
- Goals: propagation of quantified uncertainties, transparency, traceability



*Little, Urban, Oppenheimer (2013)*



*Kopp et al. (2014)*

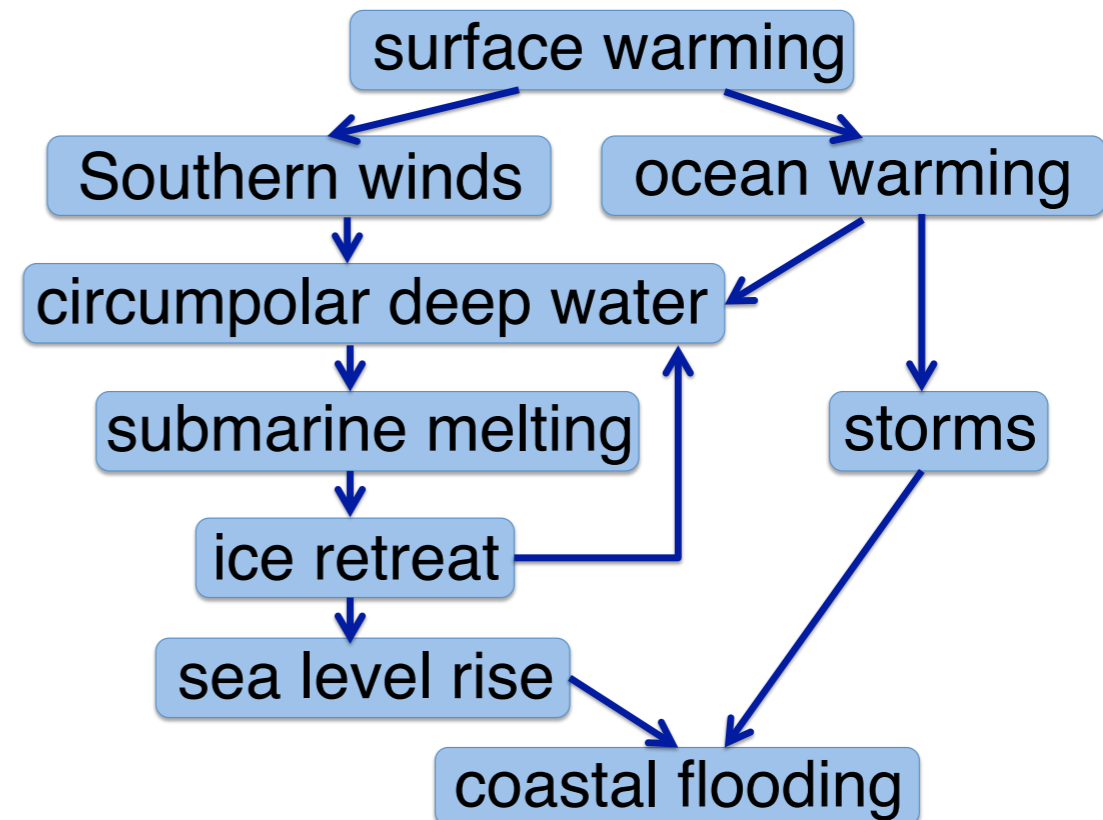
## Can we add:

- Targeted simulations to of neglected processes to improve information sources
- Expanded treatment of model structural uncertainties leading to extreme SLR
- Calibrated model-data fusion



# Modular approach to SLR uncertainty

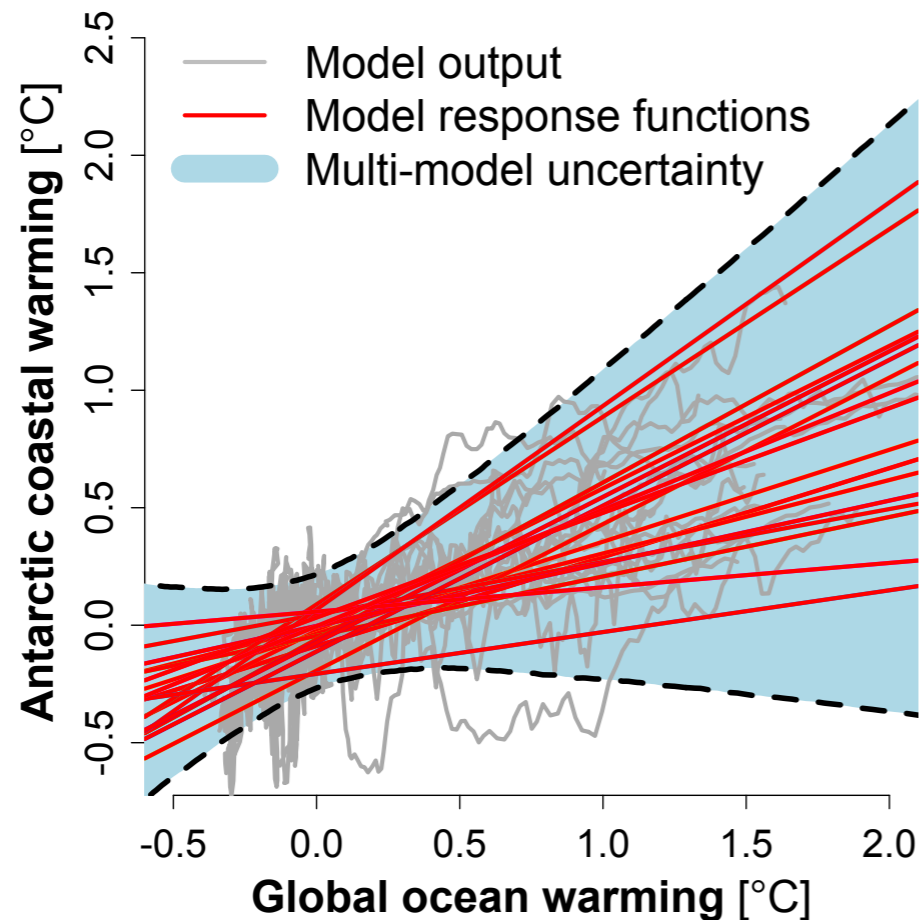
- Sea level rise and coastal impacts occur through a causal chain of processes
- Associate a “response function” to each link
- Propagate uncertainty through the network to predictions



Statistical network of  
response functions

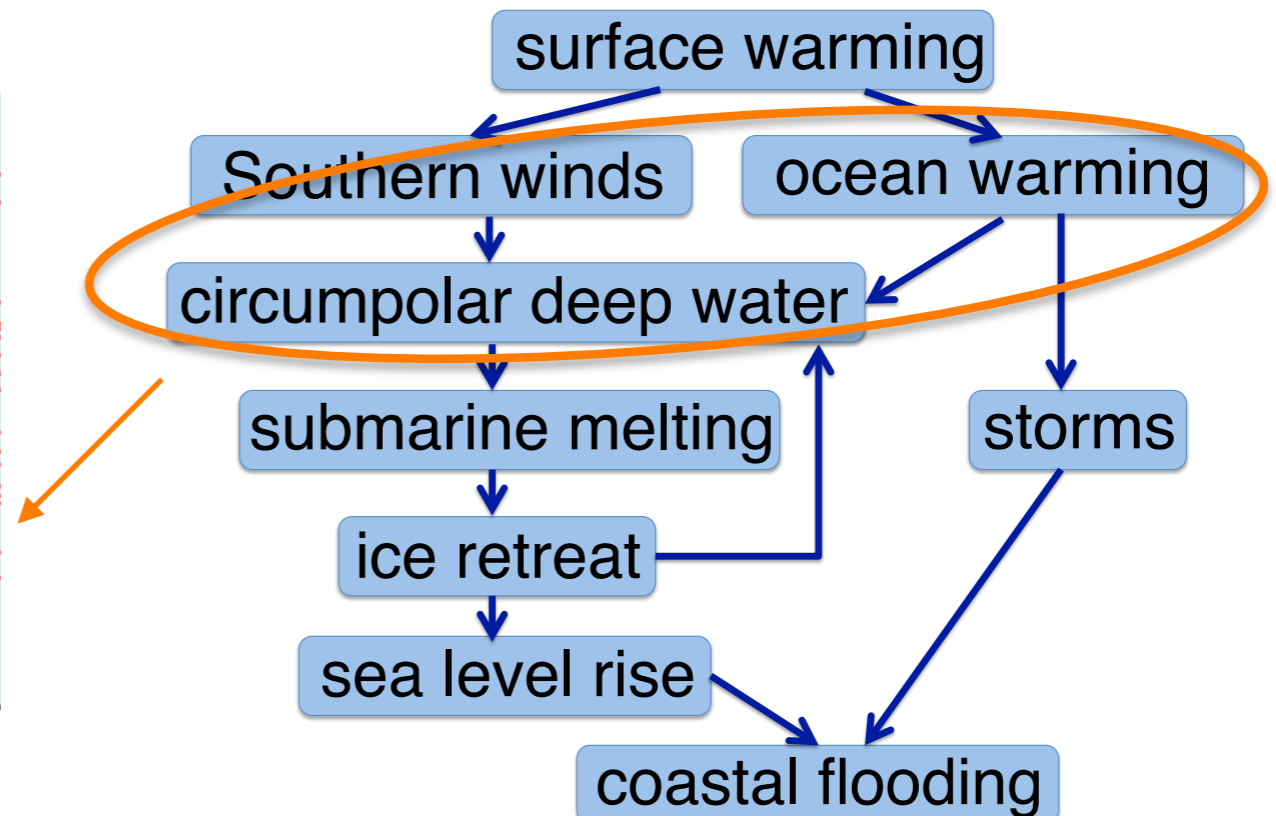
# Modular approach to SLR uncertainty

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## Individual response function

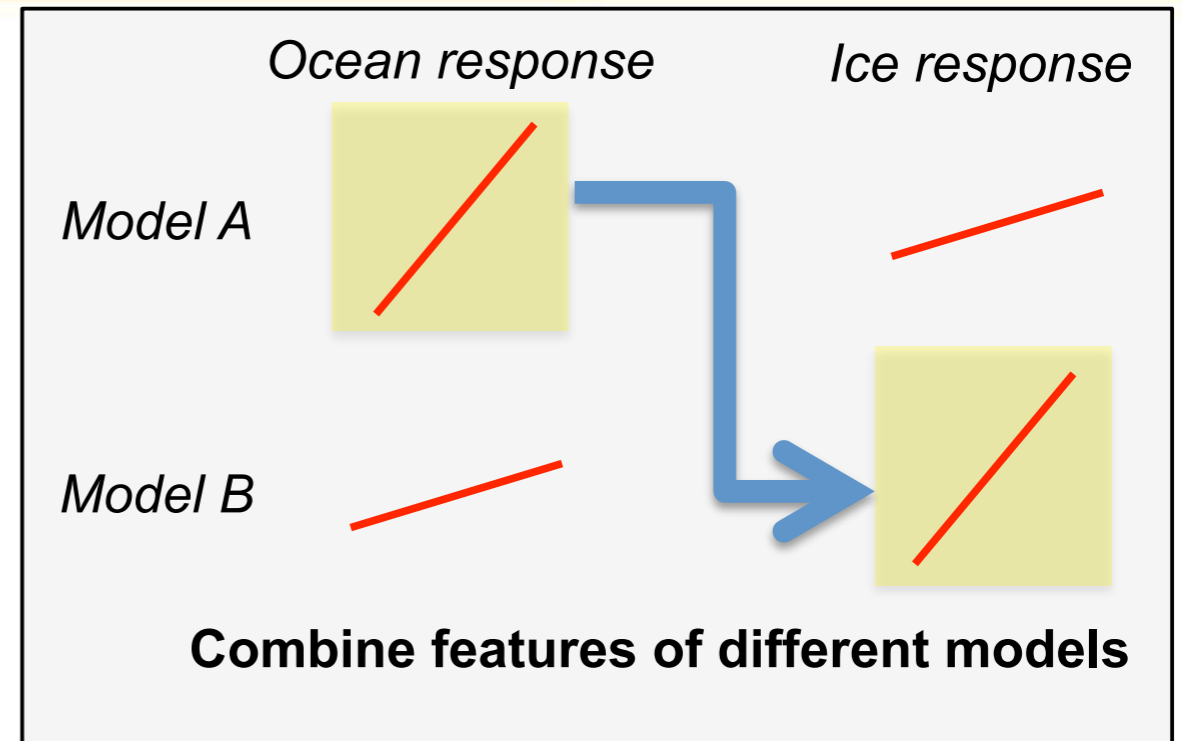
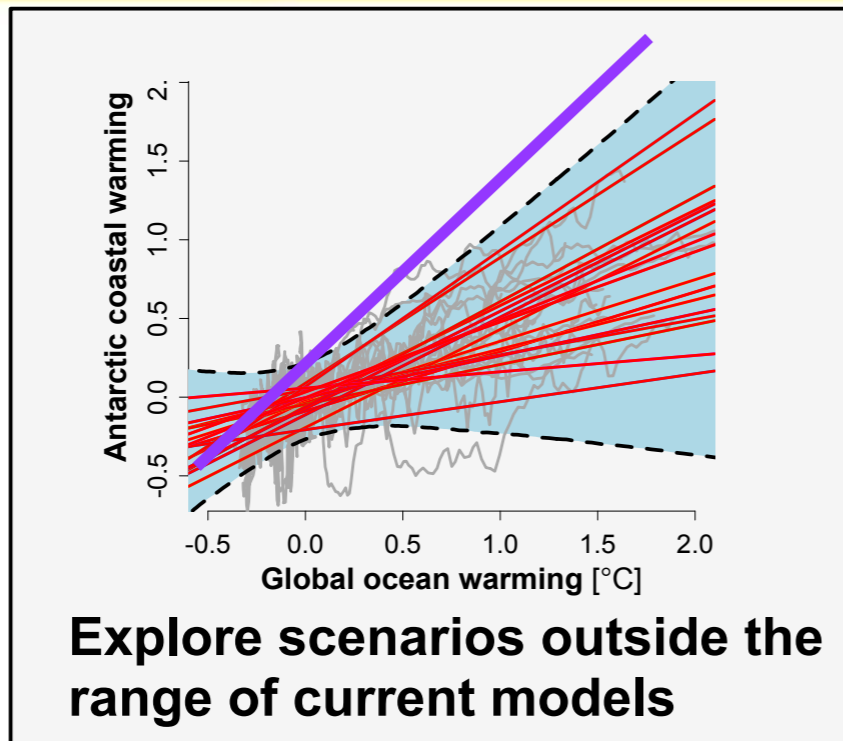
*(links global ocean warming to Southern Ocean warming; incorporates multi-model uncertainty)*



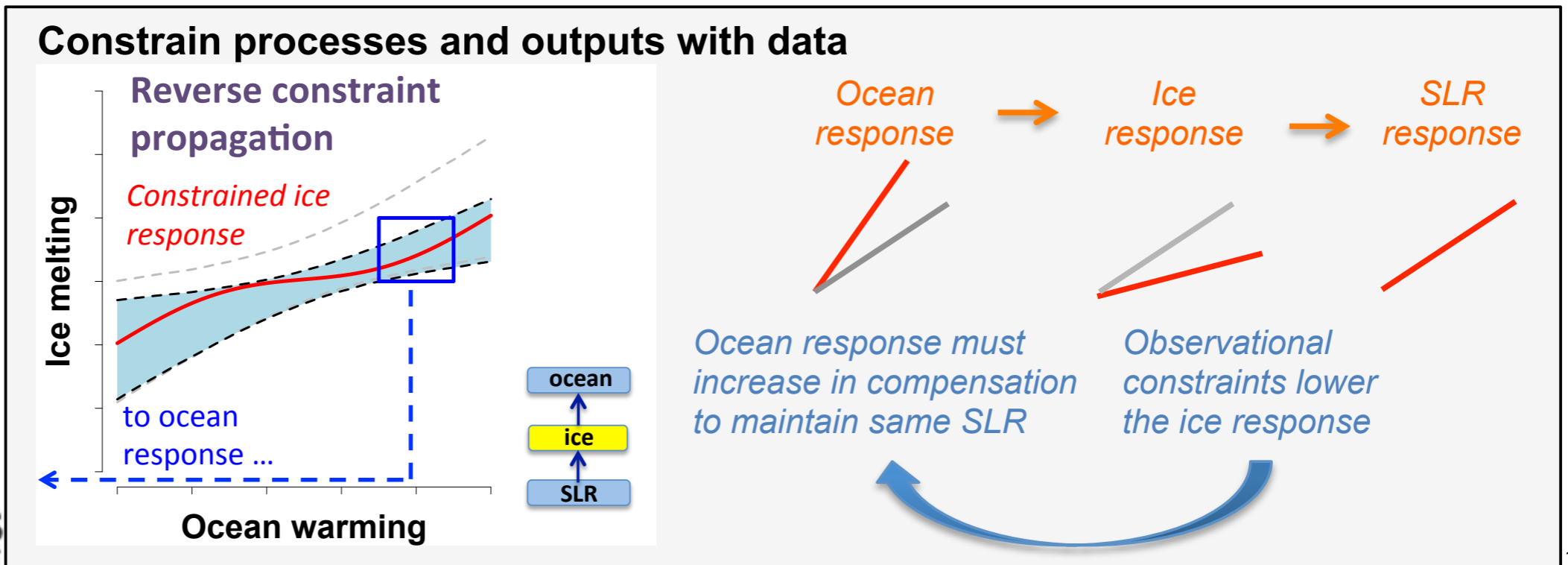
## Statistical network of response functions

# UQ process decomposition addresses both model overconfidence and underconfidence

Overconfidence:



Underconfidence:



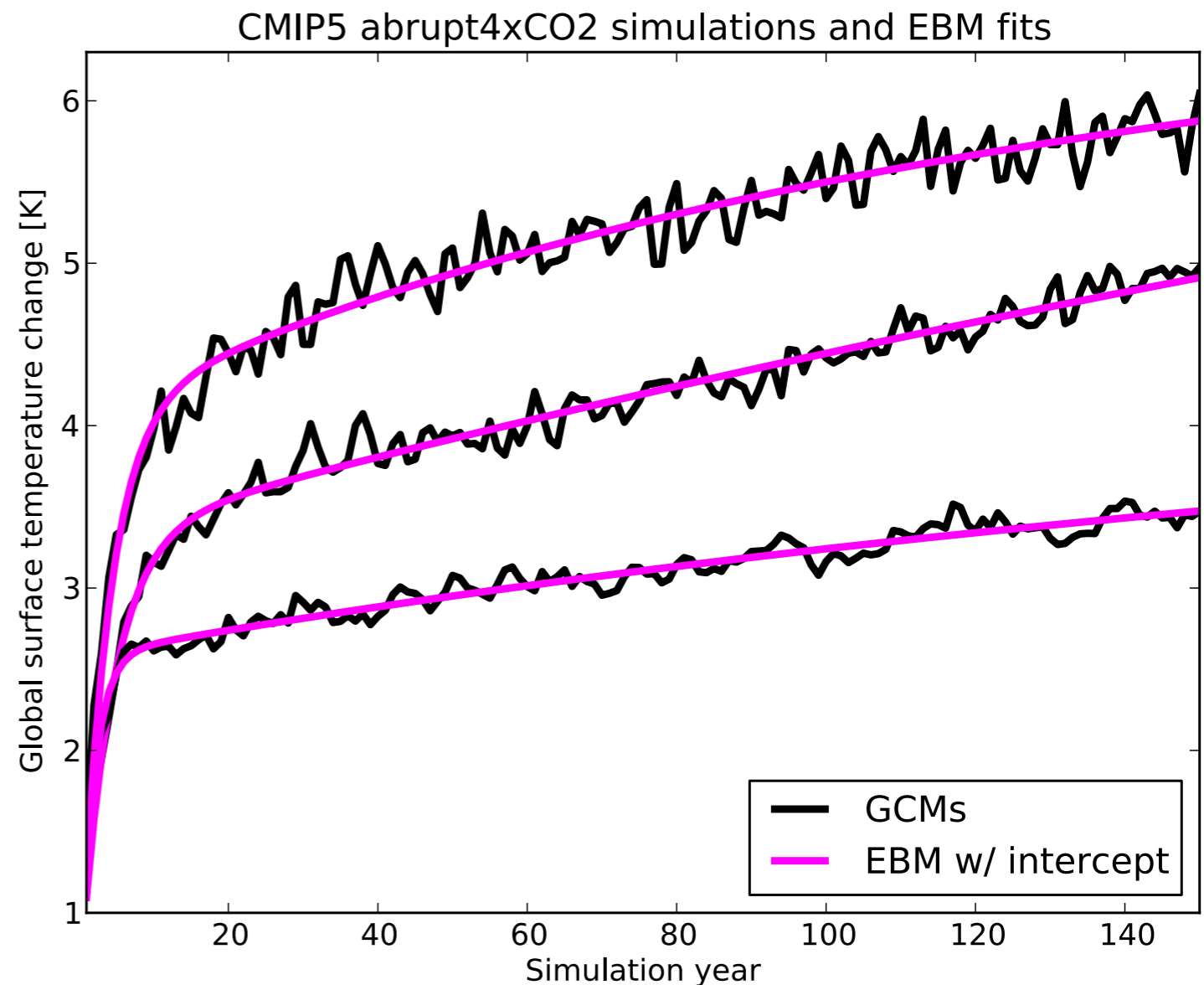


# Reduced models as multi-model emulators

- Reduced-order energy balance model (EBM) fits to complex Earth System Models (ESMs):

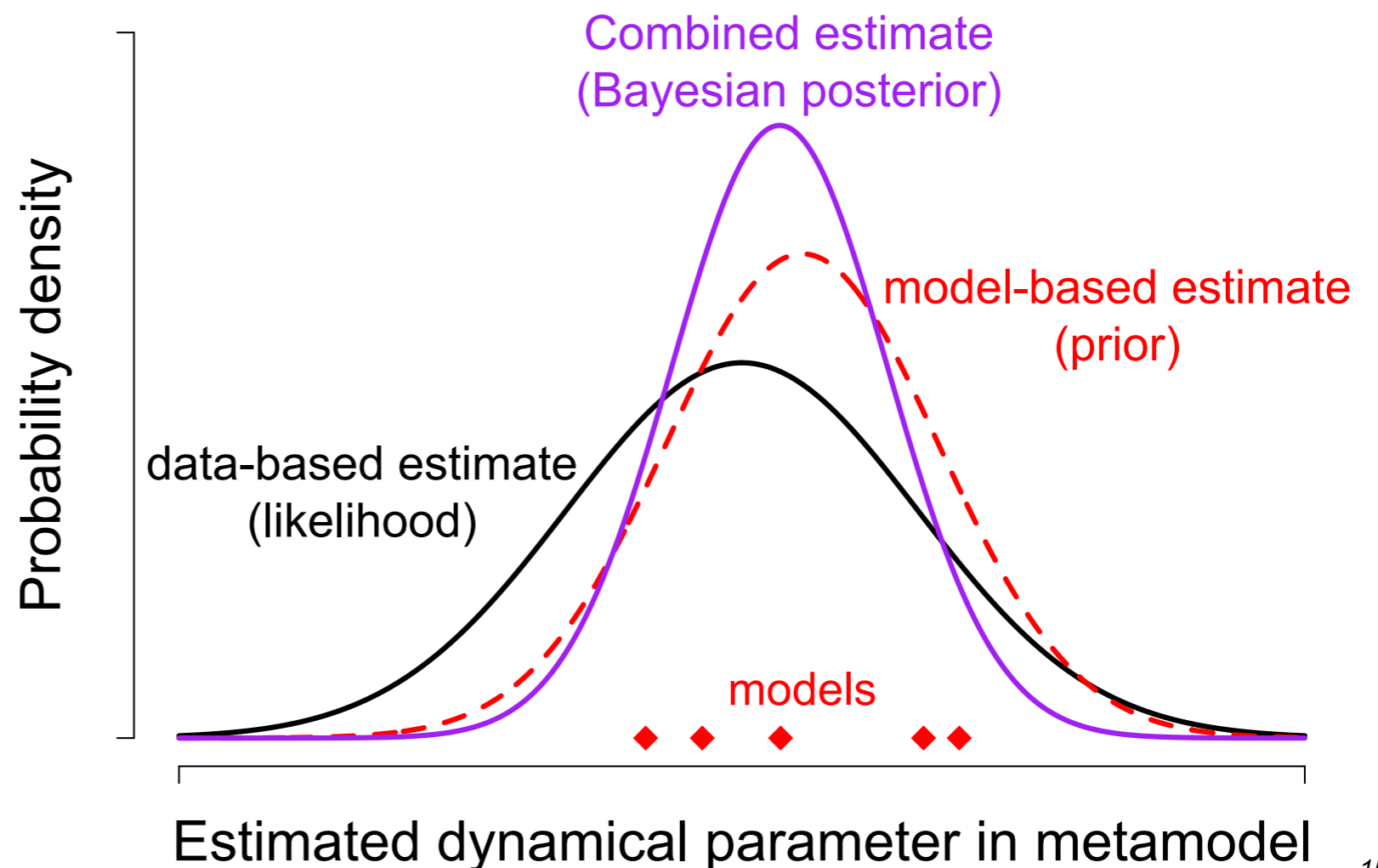
$$C_S \dot{T}_S = F - \lambda T_S - \gamma(T_S - T_D)$$

$$C_D \dot{T}_D = \gamma(T_S - T_D)$$

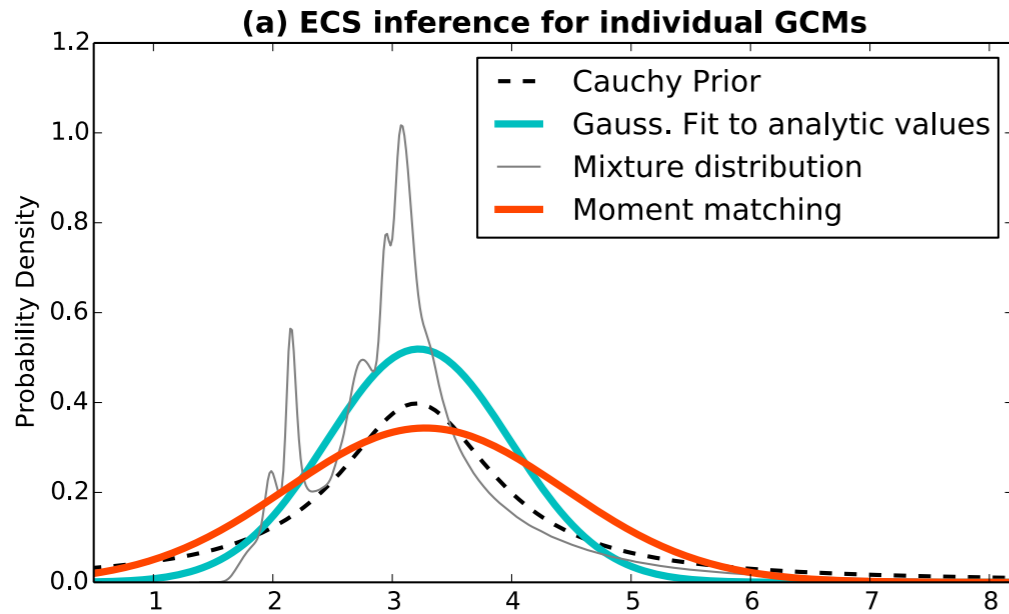


# “Model blending”: convert multi-model uncertainty to parameter uncertainty in a reduced model

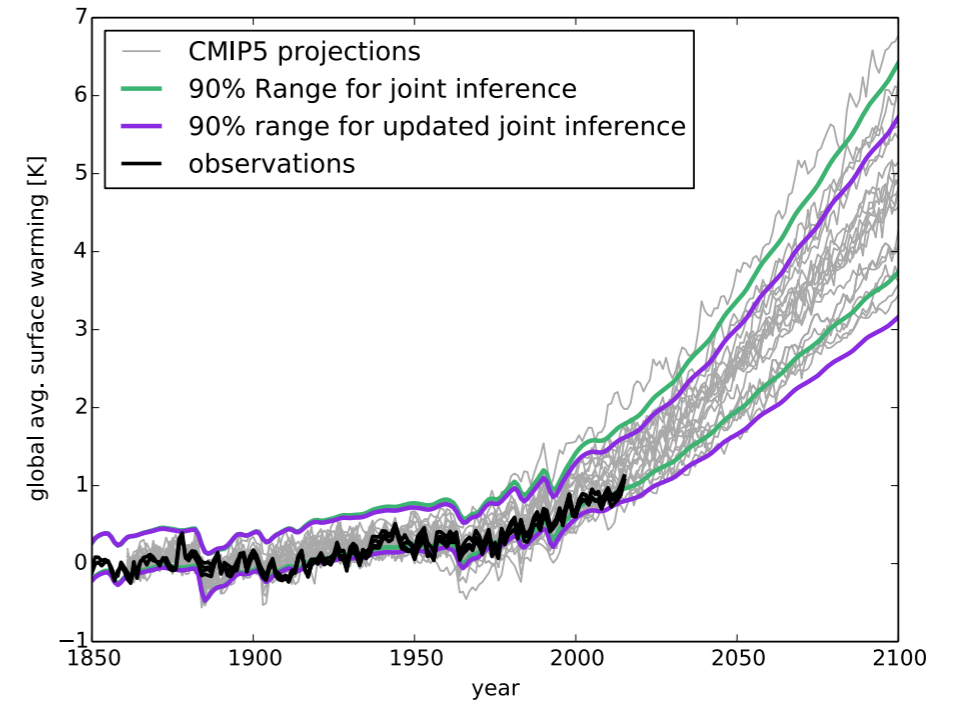
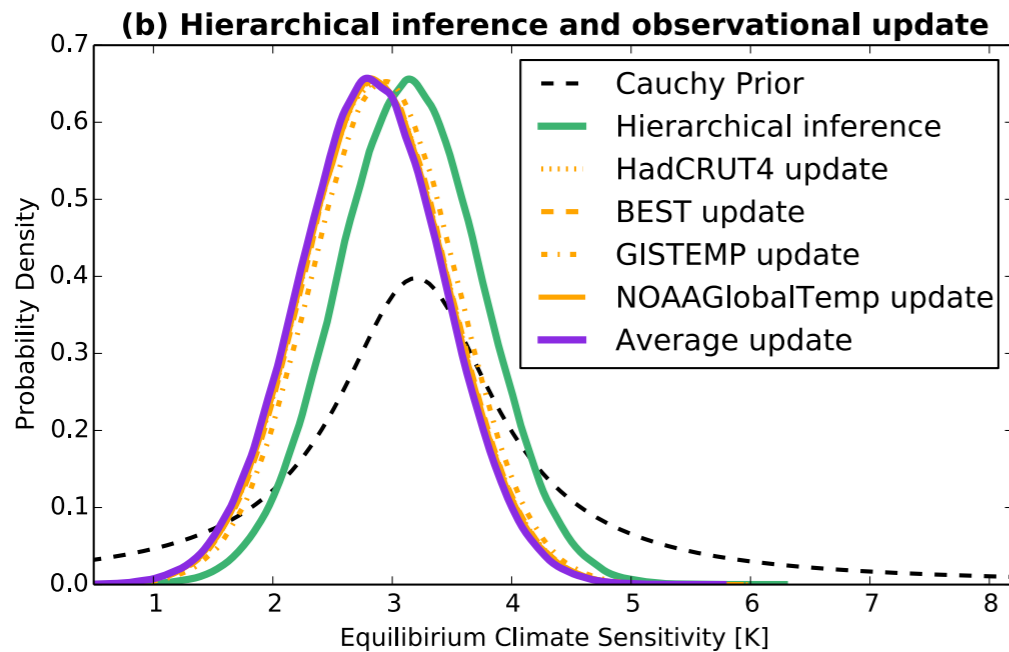
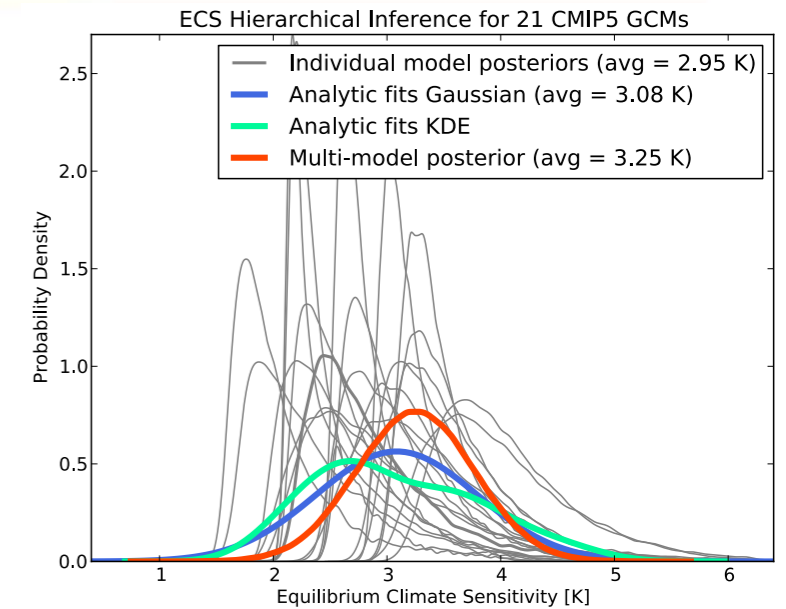
- Fit reduced-model parameters to each ESM
- Combine into single multi-model parameter distribution
- Update ESM-based prior with observational data to correct model biases



# Application: climate sensitivity



← Individual model inferences →

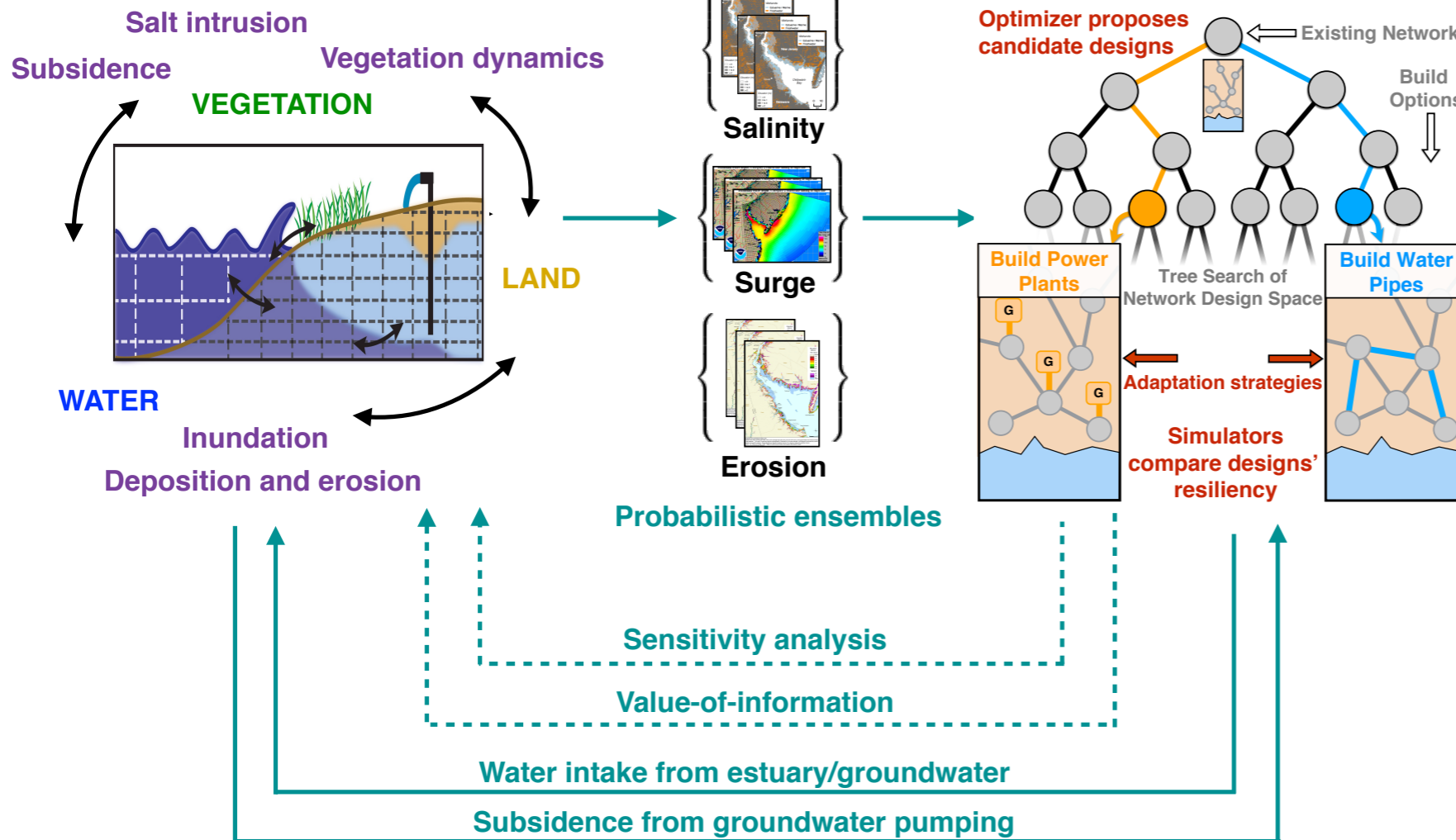


# Integrated coastal adaptation framework

## COASTAL PROCESS SCIENCE

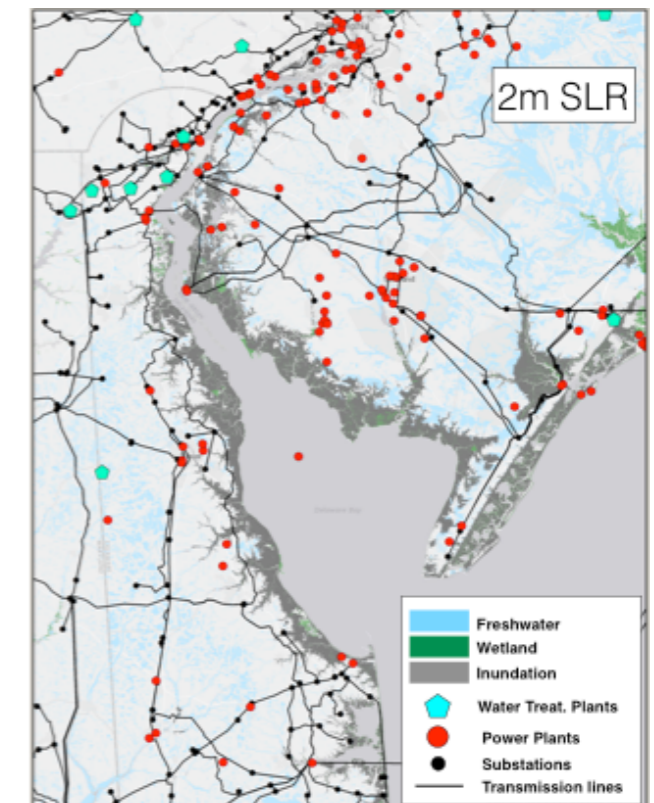
## INTEGRATIVE SCIENCE

## ADAPTATION SCIENCE



## Integrated natural-engineered systems modeling and risk management

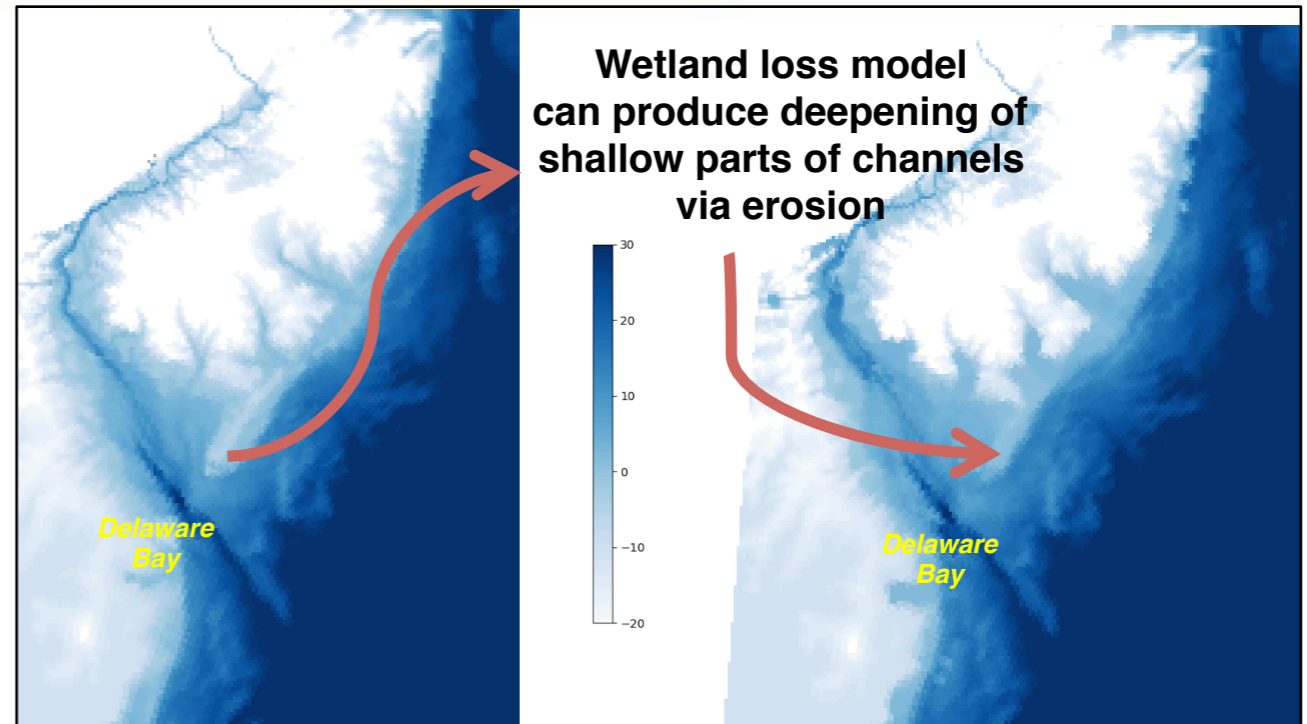
- Ocean-wetland-erosion-salt intrusion dynamics
- Realistic large-scale electricity-water interdependent network optimization
- Hierarchy of models for decision support
- Extensive sensitivity and uncertainty analysis
  - Input sensitivity analysis
  - Process sensitivity analysis
  - Probabilistic calibration & prediction
  - Adaptation sensitivity analysis
  - Value-of-information study





# Coastal evolution matters to adaptation

- SLR / wave action accelerates erosion
- Salt intrusion, storm damage, development can degrade wetland buffers
- Coastline changes increase susceptibility to storm surge
- Salt intrusion contaminates water supplies



- Erosion scenario changes number and location of damaged assets (relative to static coastline)

