Climate Change Risk Assessment

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Workshop on Uncertainty Quantification in Climate Modeling and Projection

2015 July 13-17

PENNSTATE 1855 SCRiM ICTP The Abdus Salam International Centre for Theoretical Physics

SCRiM

an NSF-sponsored research network for

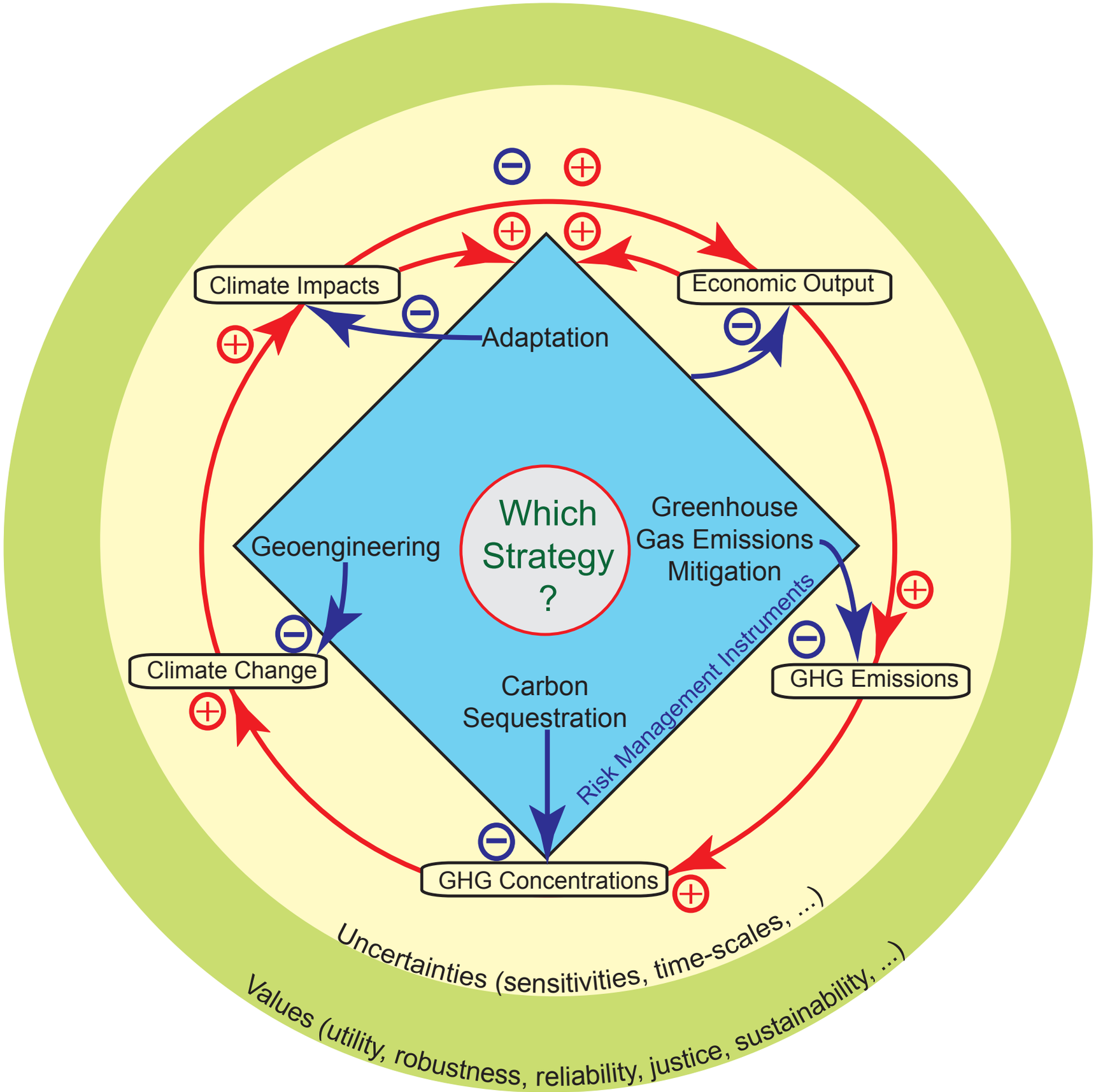
Sustainable Climate Risk Management

What are sustainable, scientifically sound, technologically feasible, economically efficient, and ethically defensible strategies for managing the risks associated with climate change?

http://scrimhub.org

Assessing climate risk management strategies requires the analysis of complex systems with nontrivial interactions and emerging properties.

What are challenges?



Uncertainty Quantification

Bayesian data-model fusion
model emulation
parameter estimation

Earth System Modeling & Analysis

simple climate models, ice sheet models, GCMs, Earth system models

Computational Methods & Cyber Tools

high-performance computation, sensitivity analysis, optimization

Our workshop has focused on these three issues with attention being given to these other parts of the decision making process.

Coupled Ethical-Epistemic Analysis

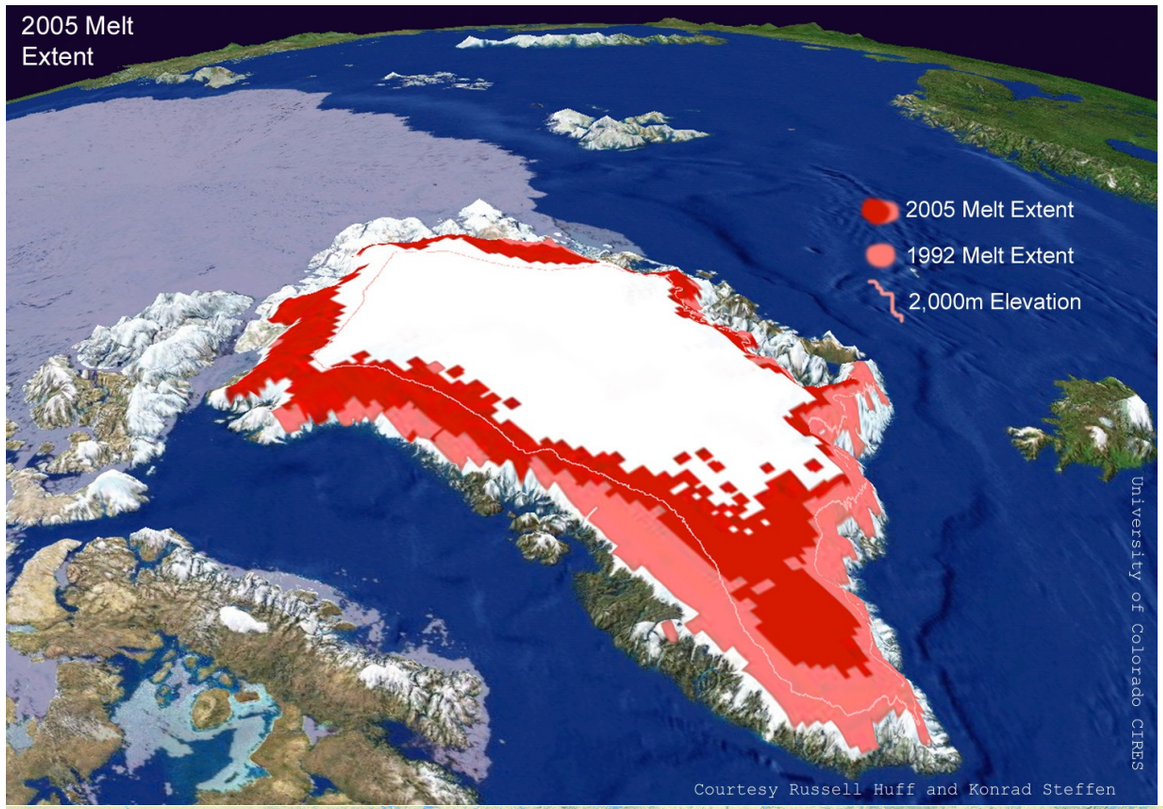
ethical analysis, justice, value judgments in science and society

Stakeholders & Decisionmakers

objectives, preferences, constraints, mental models

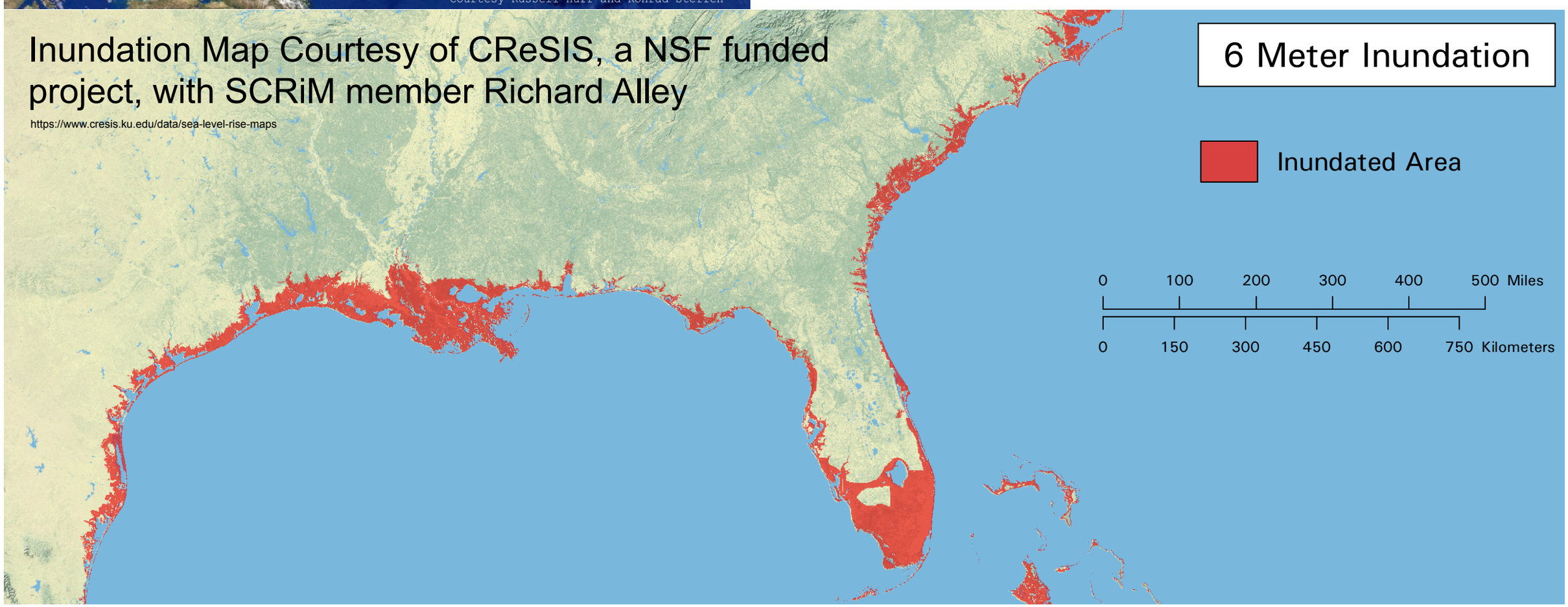
Research Interactions

provides INPUT to — provides METHODS for — provides INSIGHTS for refinement

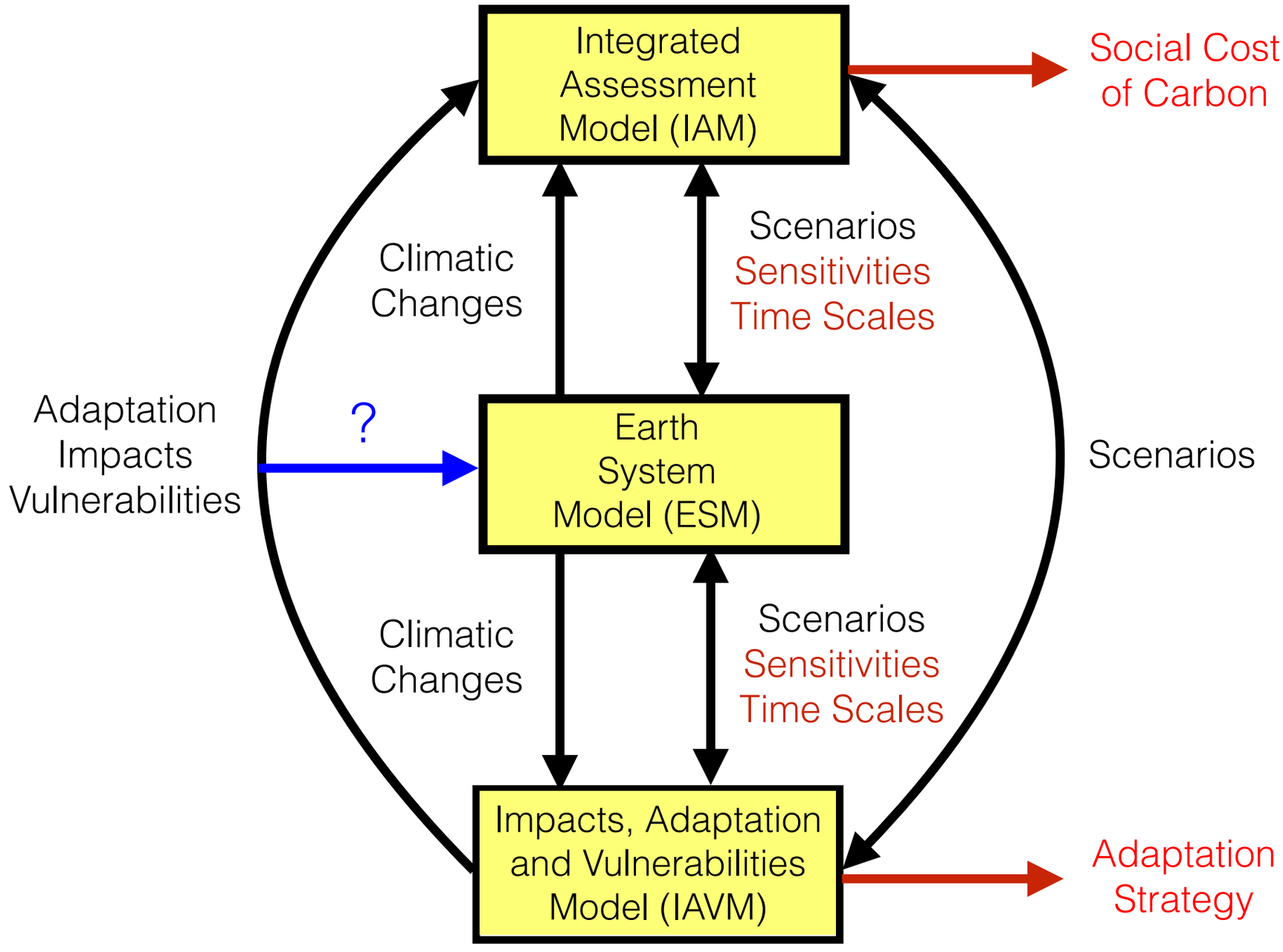


The Greenland Ice Sheet (GIS) is melting. A GIS disintegration could eventually raise the global mean sea level by roughly seven meters.

So what?



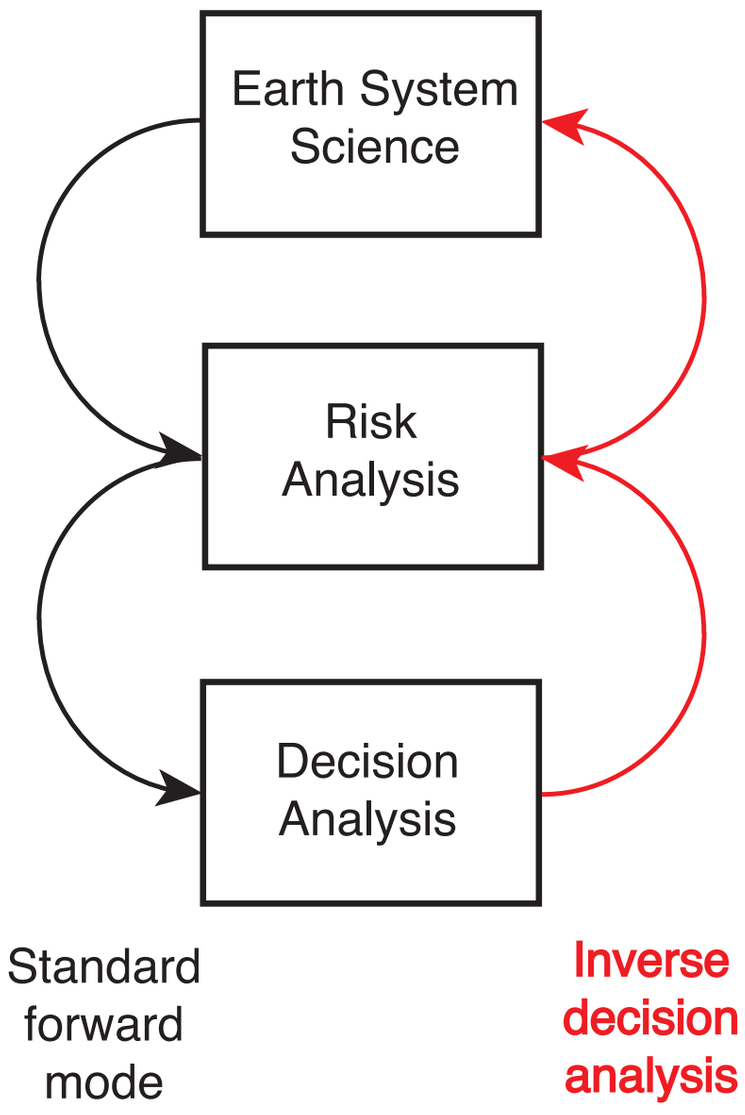
Analyzing climate risk management strategies requires a **tight and bidirectional linking** of disciplines and models.

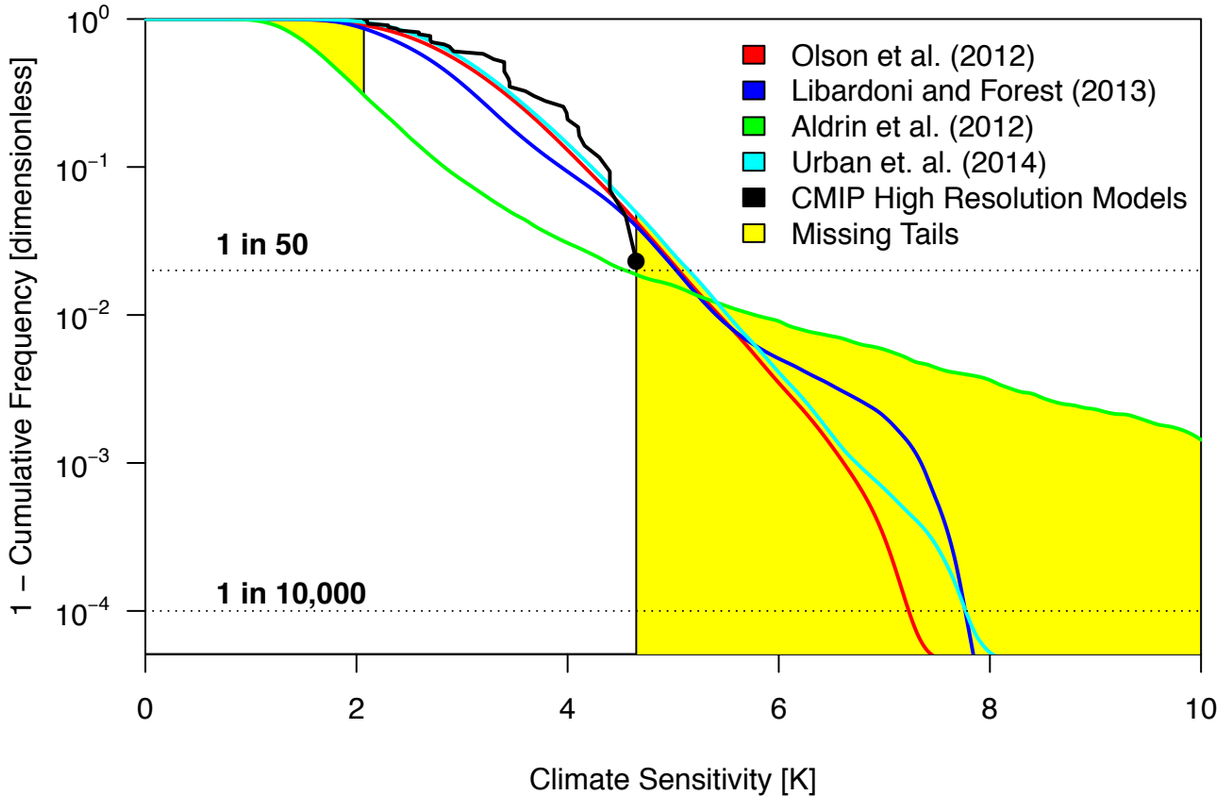


Keller et al (in prep)

How can we achieve these linkages?

Inverse decision analysis can point to promising and decision-relevant research directions





- Which uncertainties matter the most for decision making?
- What constrains the fat tail of climate sensitivity?
- How fast can the Greenland Ice Sheet disintegrate?

This brings us back to some of the tools and techniques being discussed here…

Fundamental uncertainties exist for projections of future climate

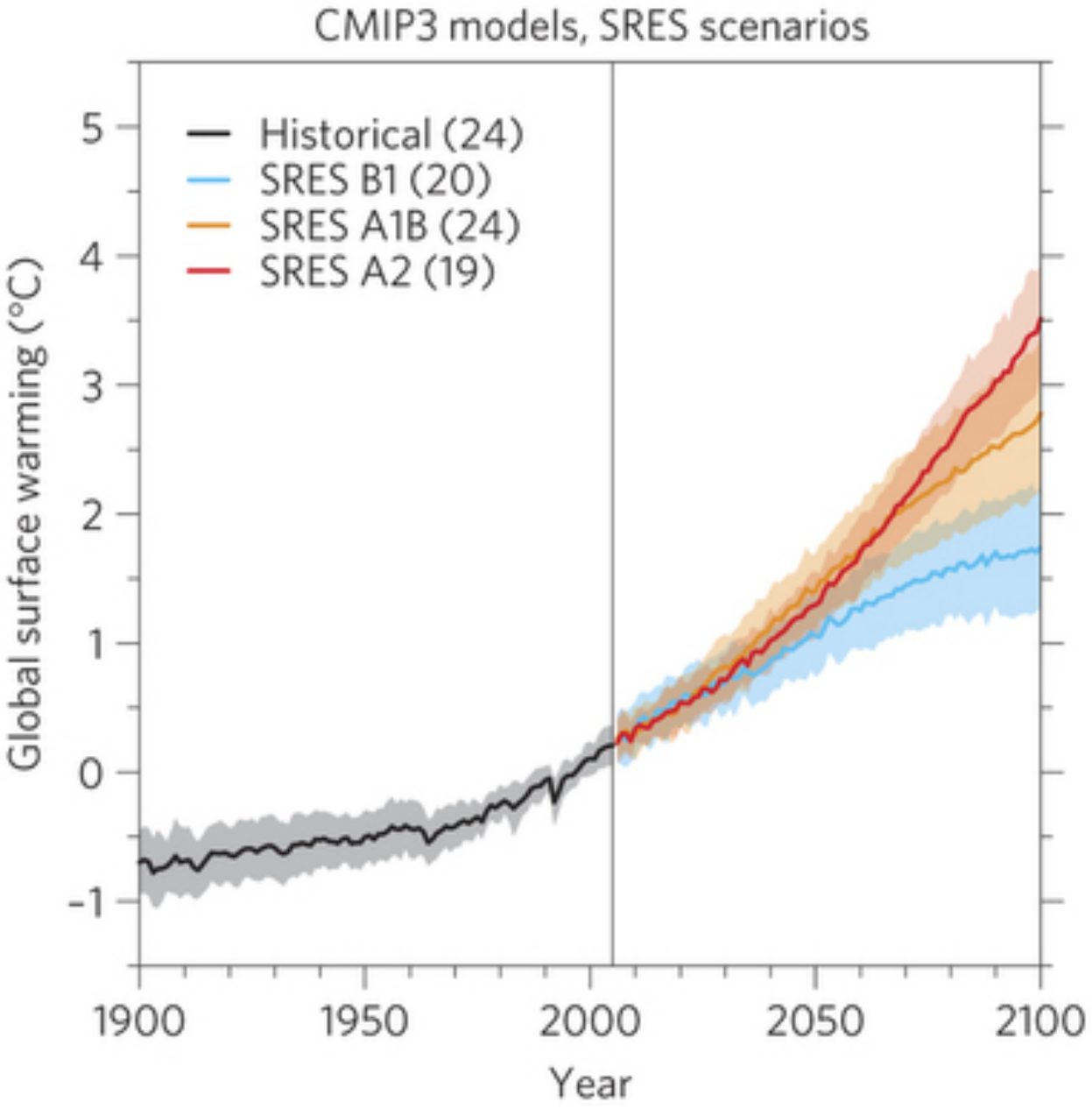
The uncertainties fall into a few broad categories:

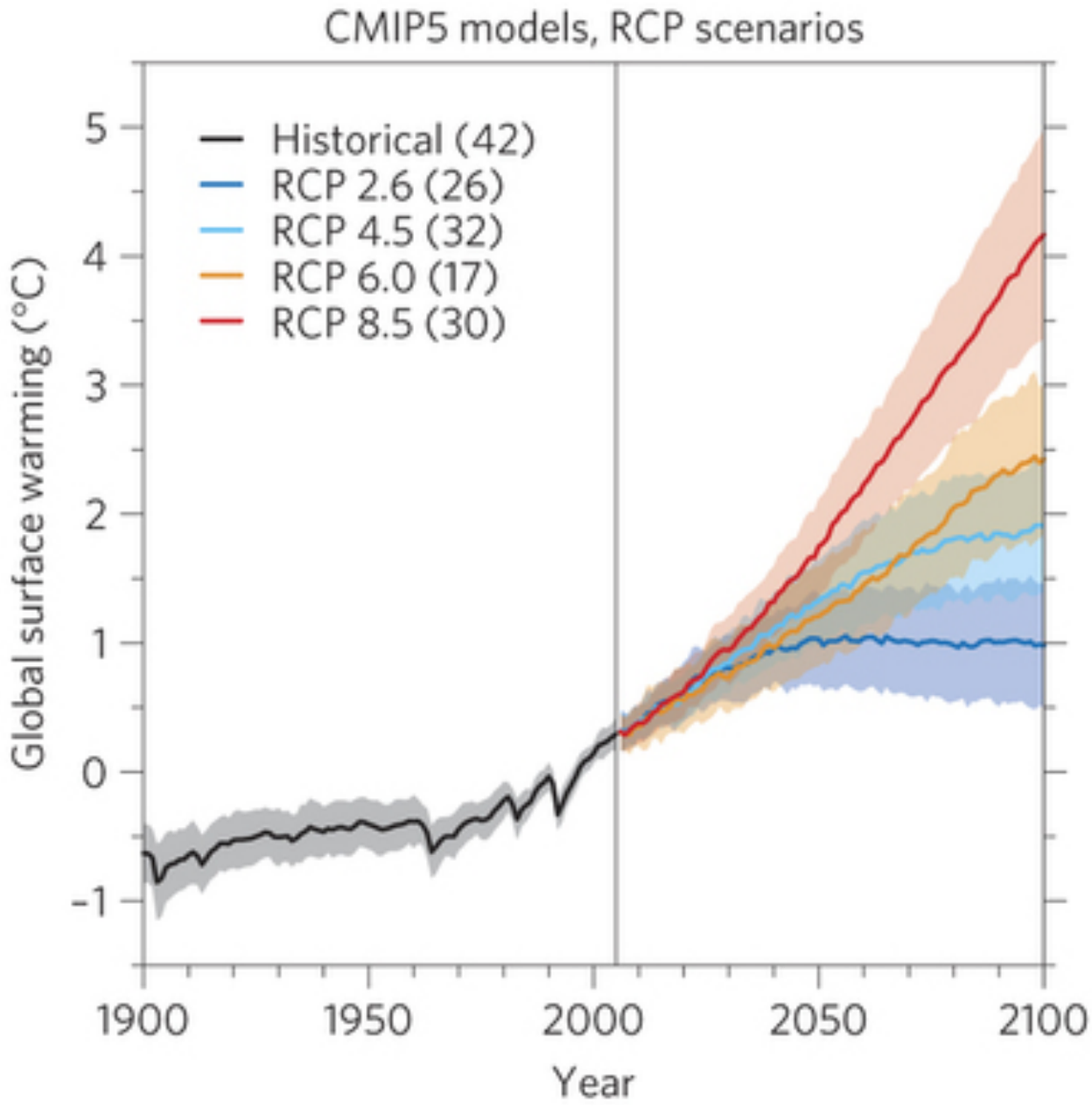
- observational uncertainty
- forcing or scenario uncertainty
- model uncertainty ⟹ structural, parametric (i.e., right physics, right settings)
- natural/internal variability

Goals

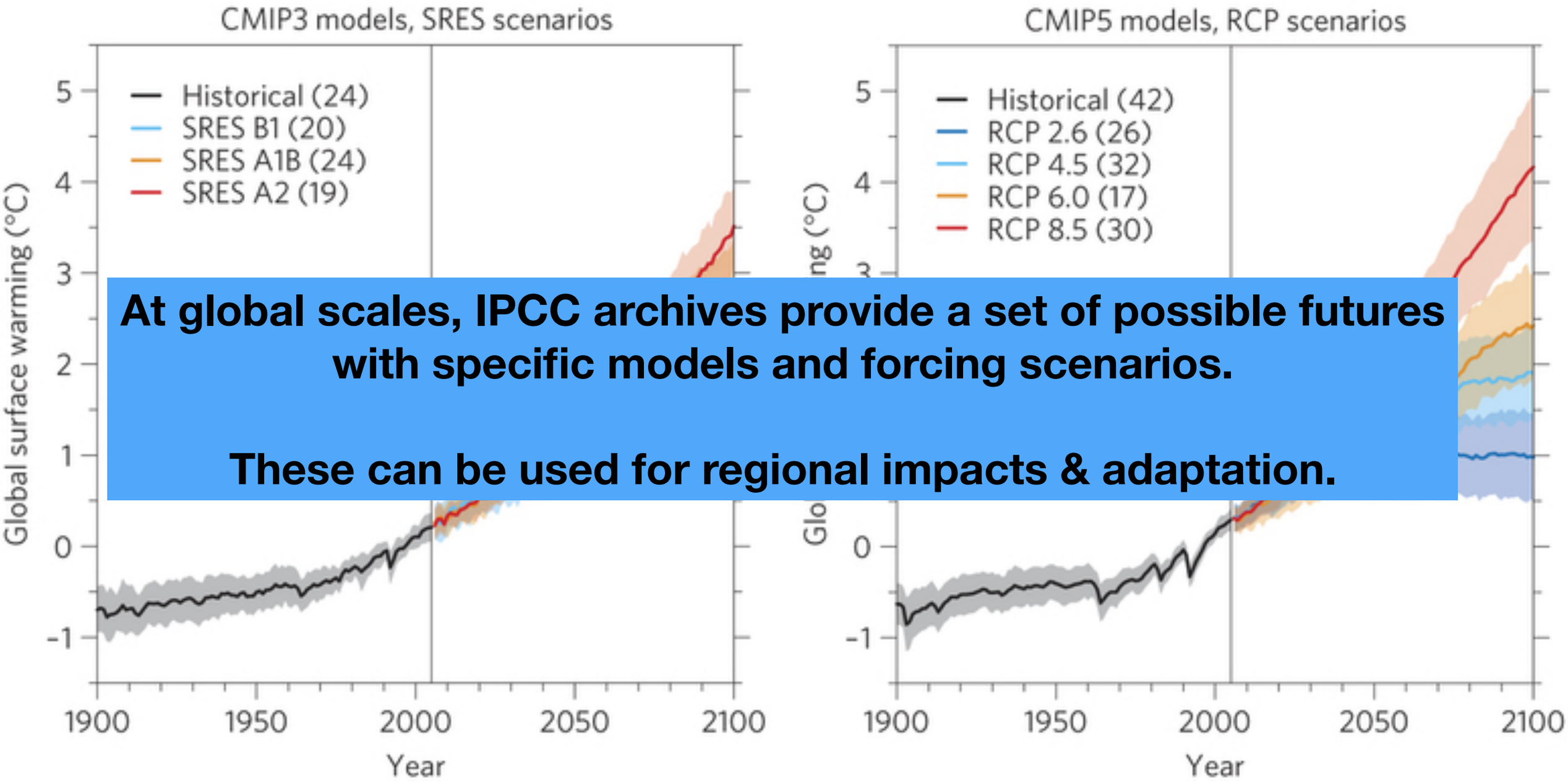
1. Can we separate uncertainties between Global v. Regional response?
2. How do we compare ensemble approaches? MME v. PPE v. ICE
3. How does structural uncertainty in regional changes assessed?

global mean temperature projections in CMIP3 and CMIP5





global mean temperature projections in CMIP3 and CMIP5

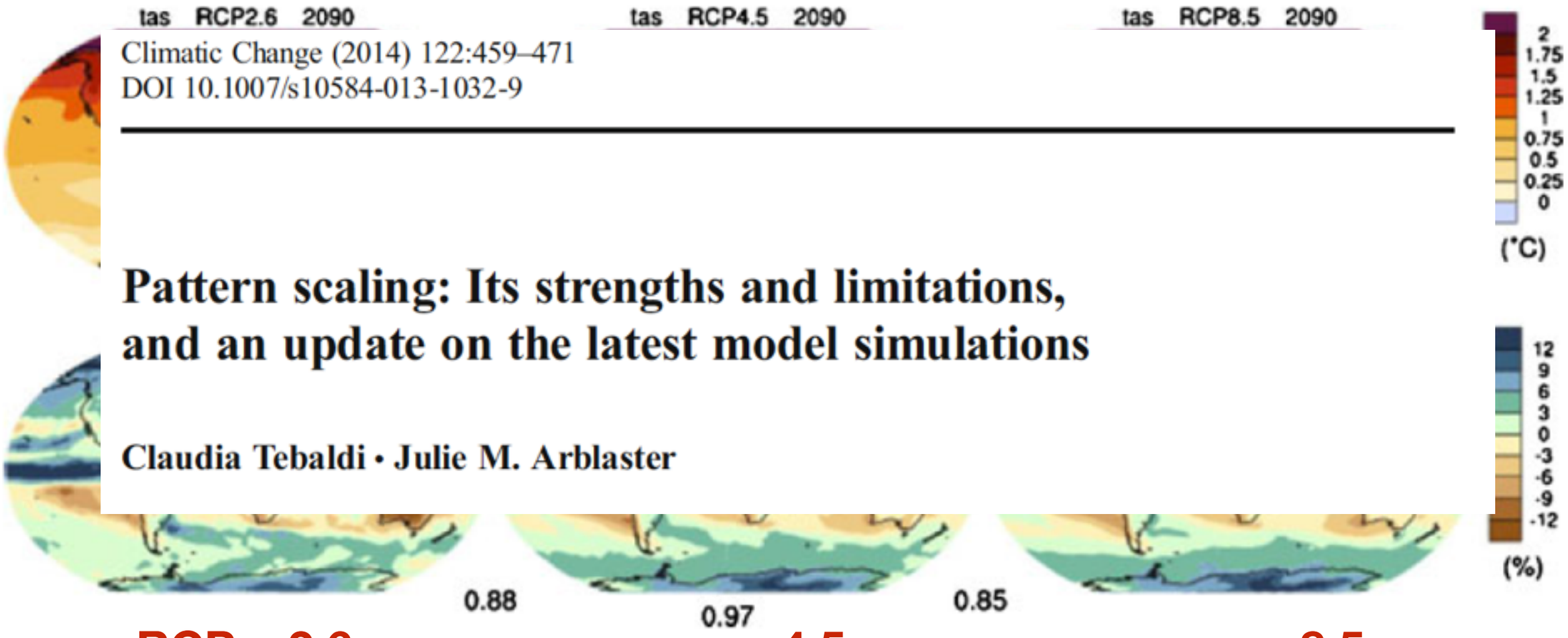


At global scales, IPCC archives provide a set of possible futures with specific models and forcing scenarios.

These can be used for regional impacts & adaptation.

The Pattern Scaling approach: A Method for Regional Model Predictions

$$P(x, y, z, t) = T(t)p(x, y, z)$$



Climatic Change (2014) 122:459–471
DOI 10.1007/s10584-013-1032-9

Pattern scaling: Its strengths and limitations, and an update on the latest model simulations

Claudia Tebaldi • Julie M. Arblaster

Fig. 1 Patterns of Temperature (*top*) and Precipitation (*bottom*) changes according to three RCPs (we exclude 6.0 because only a small number of models ran it). The numbers between adjacent maps show the pattern correlation between the two maps. The *lower number* in the center shows the pattern correlation between the first and third map

Tebaldi & Arblaster (2014, Climatic Change)

The Problem: Model Predictions have multiple sources of uncertainty…

- Epistemic uncertainty: getting the model right (the right model physics & right structure)

Example Work at Penn State:

Developing **Global Teleconnection Operators (GTOs)** to estimate structural uncertainty in regional response to global Sea Surface Temperature patterns

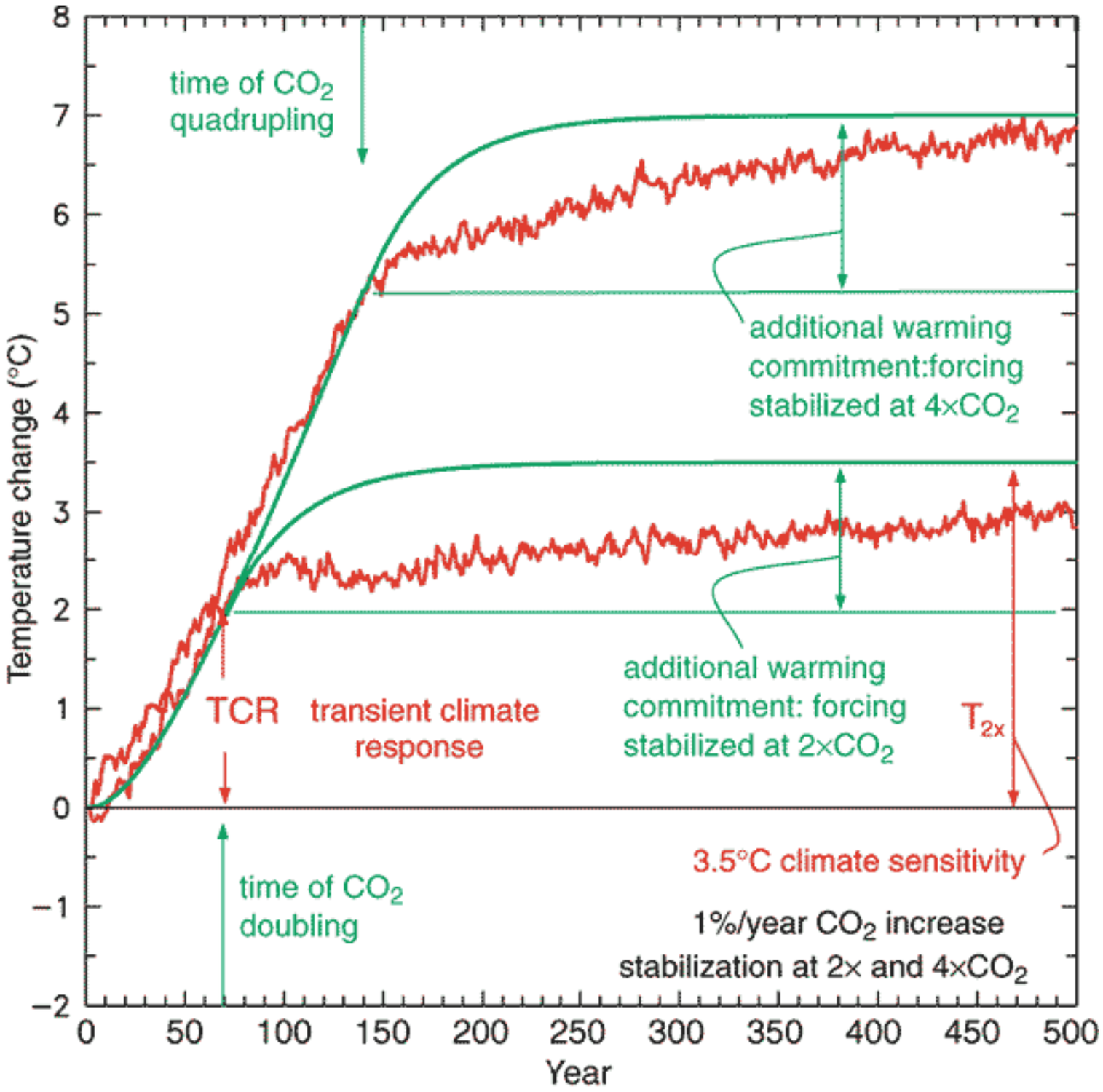
Li, Forest, & Barsugli (2012, J. Geophys. Res.)
Comparing two methods to estimate the sensitivity of regional climate simulations to tropical SST anomalies

Tsai, Forest, & Wagener (2014, Clim. Dynamics)
Estimating the regional climate responses over river basins to changes in tropical sea surface temperature patterns

What matters for long-term climate prediction?

- **Controls on:**
  - Long-term warming
  - Delay by ocean
  - Net forcing
- **Uncertainties in:**
  - Climate Sensitivity
  - Rate of Ocean Heat Uptake
  - Forcing by: Aerosols, Carbon-cycle, Land-use, Natural GHG Emissions, etc.

Climate Sensitivity is the equilibrium response of the climate to a constant forcing



Green: EBM response

Red: GFDL R15a response

T_{2x} = ECS = Equilibrium Climate Sensitivity

TCR = Transient Climate Response

Figure 9.1 from IPCC AR3 (2001)

Major Climate Projection Uncertainties

Consider the energy balance equation for the change in global-mean surface temperature (ΔT) from equilibrium:

$$c_p \frac{d\Delta T(t)}{dt} = F(t) - \lambda \Delta T(t) - \Phi_o(K_v)$$

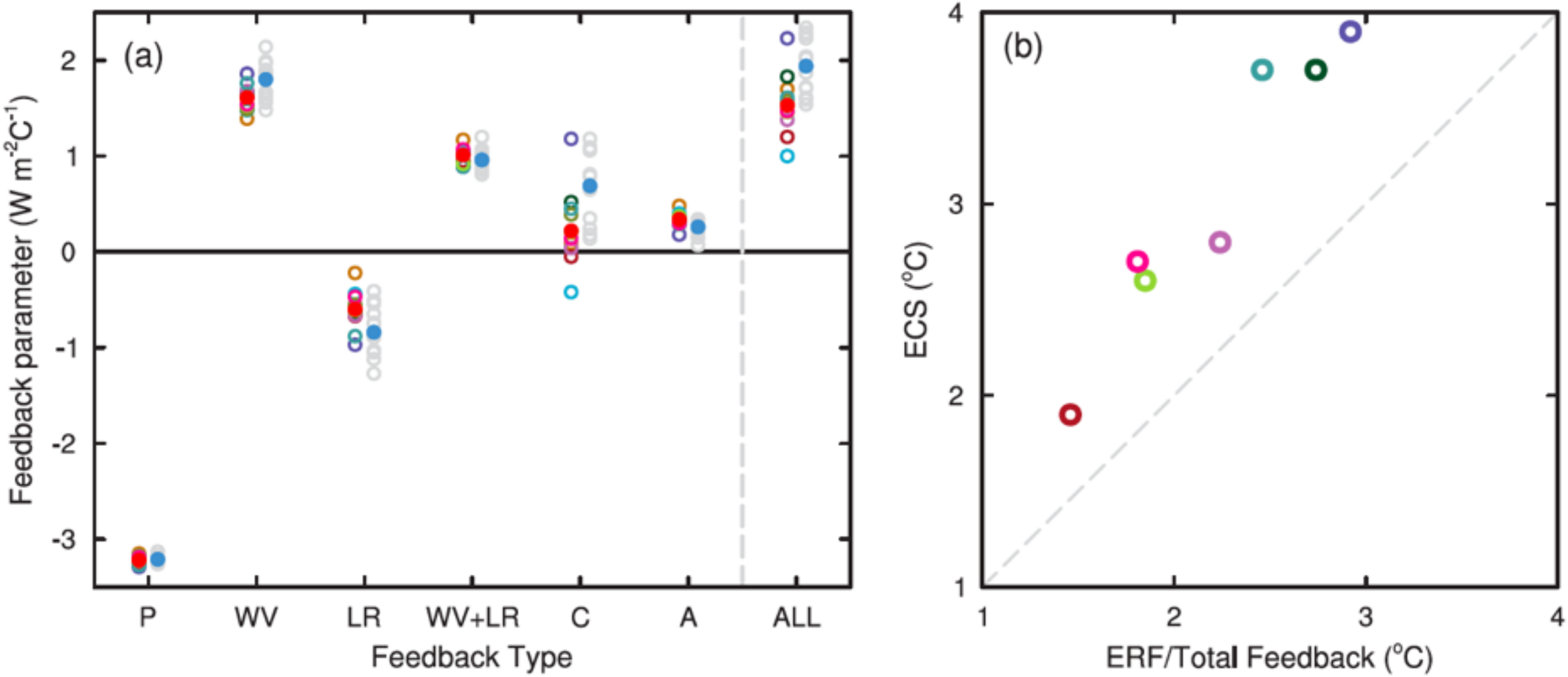
Change in global mean heat content	Future Forcings	Net Feedbacks $\lambda = 1/S$	Flux of heat into deep-ocean

Conceptually: This is a good framework for organizing where the uncertainty exists.

In practice: For state-of-the-art models, each uncertainty is an aggregate quantity and cannot be identified with any one specific model component or process.

Uncertainty in Atmospheric Model Feedbacks (IPCC WG1 AR5 Figure 9.43)

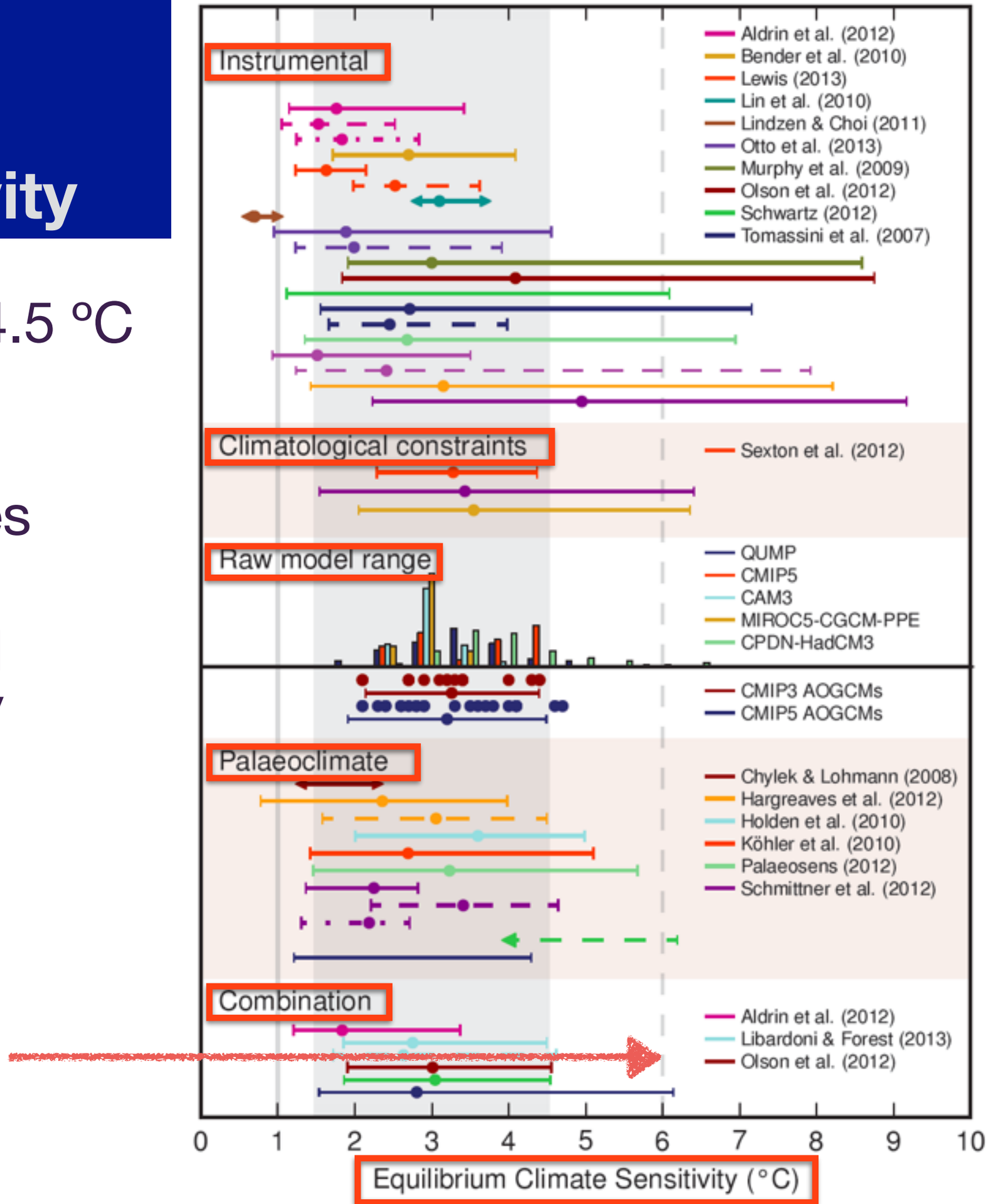
- Uncertainty in **P**lanck, **W**ater **V**apor, **L**apse **R**ate, **C**loud, **A**lbedo, and **ALL** Combined

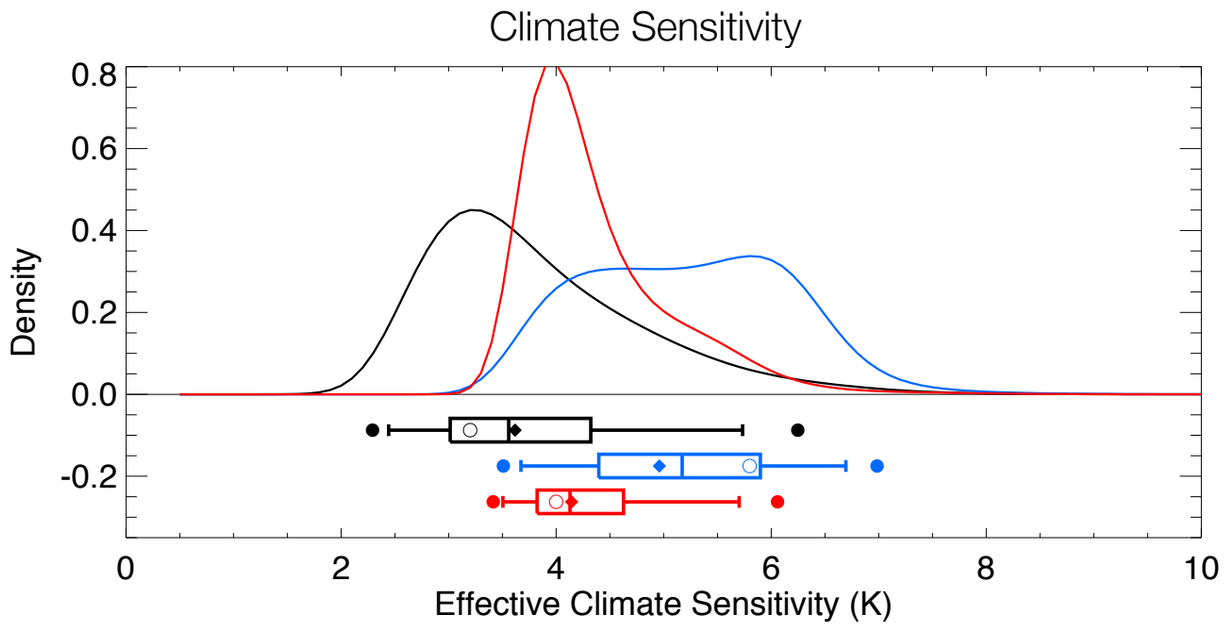


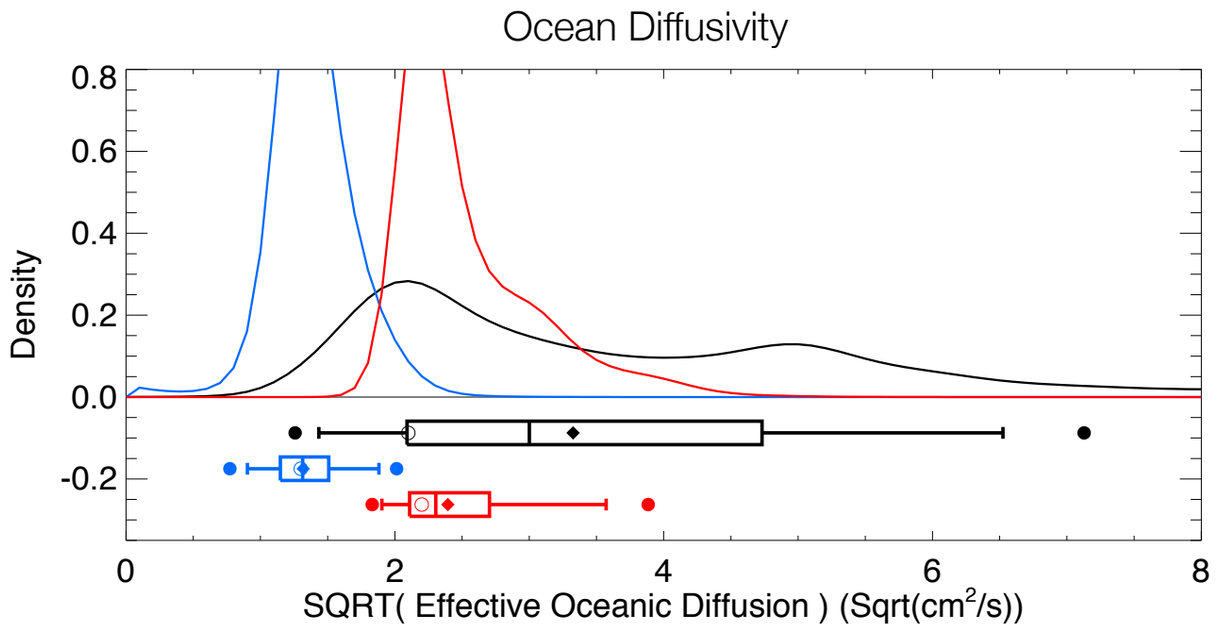
Uncertainty in Equilibrium Climate Sensitivity

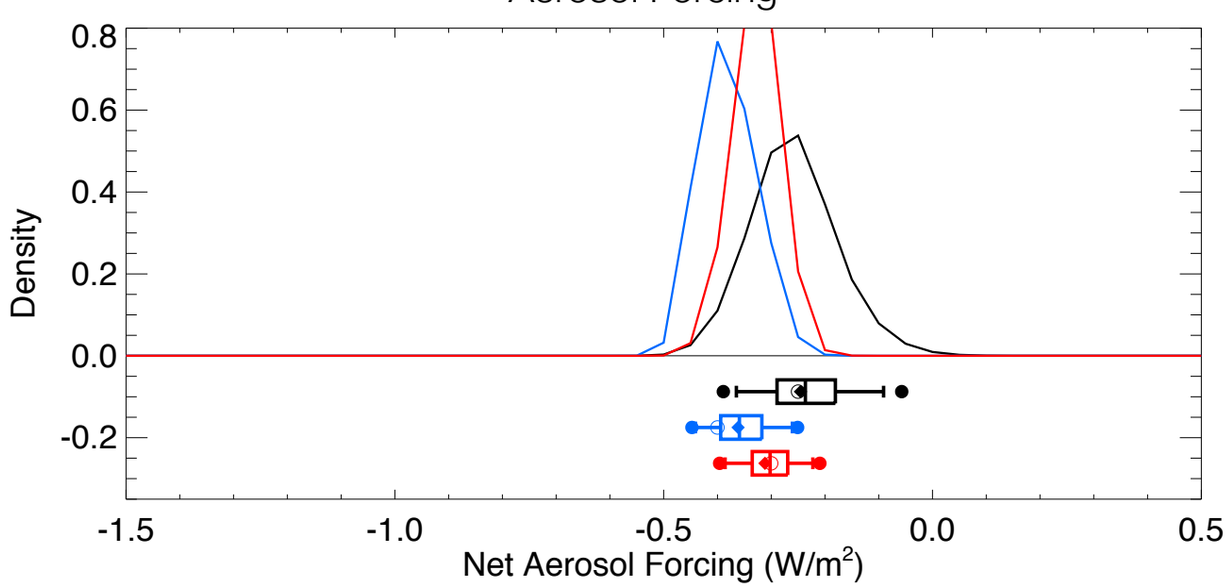
- IPCC Range: 1.5-4.5 ºC
- Box 12.2 Figure 1
- Multiple approaches based on different methodologies and observational data/ proxies.

Work by our groups:









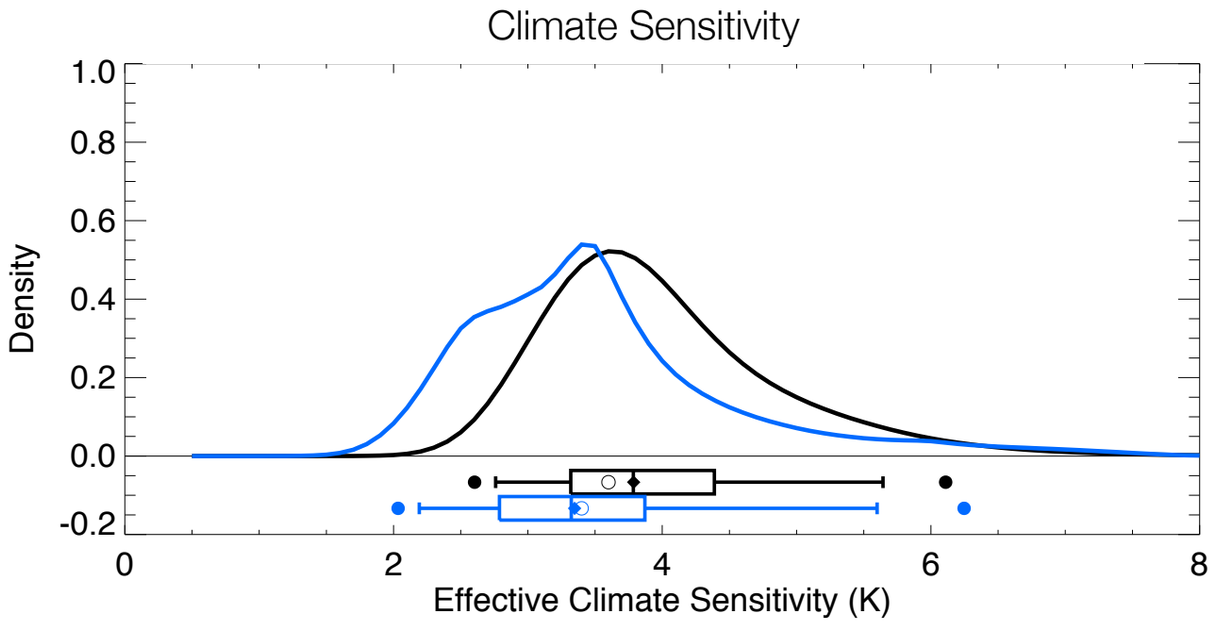
- **How are the marginal PDFs impacted?**

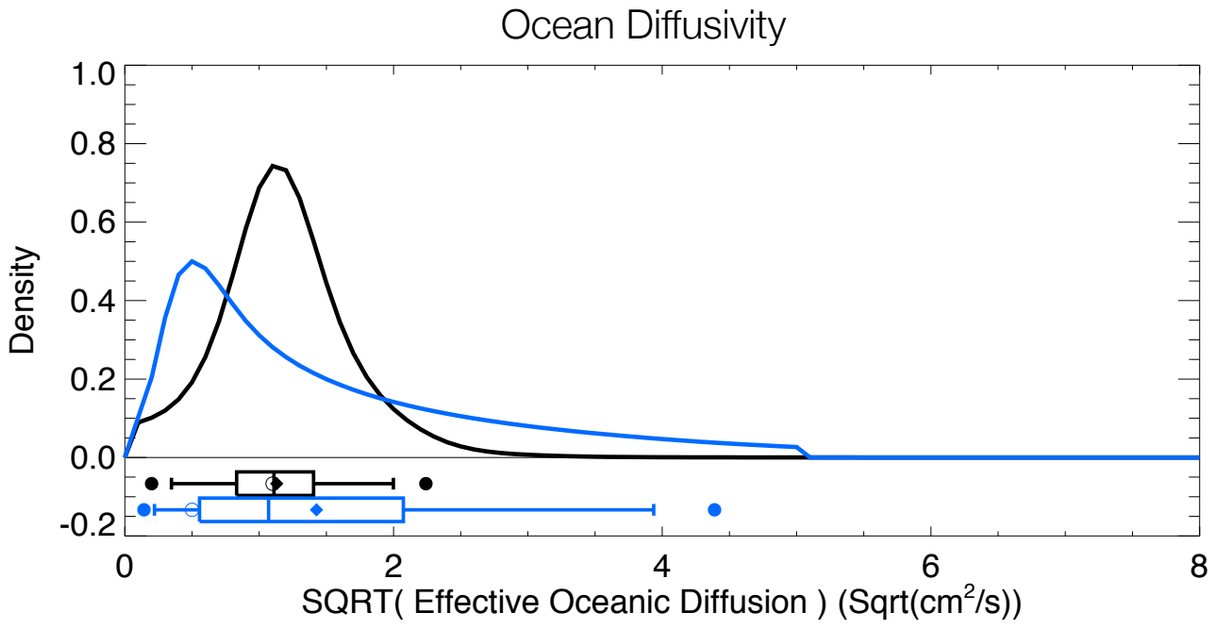
- **Extending model diagnostics with the new model**

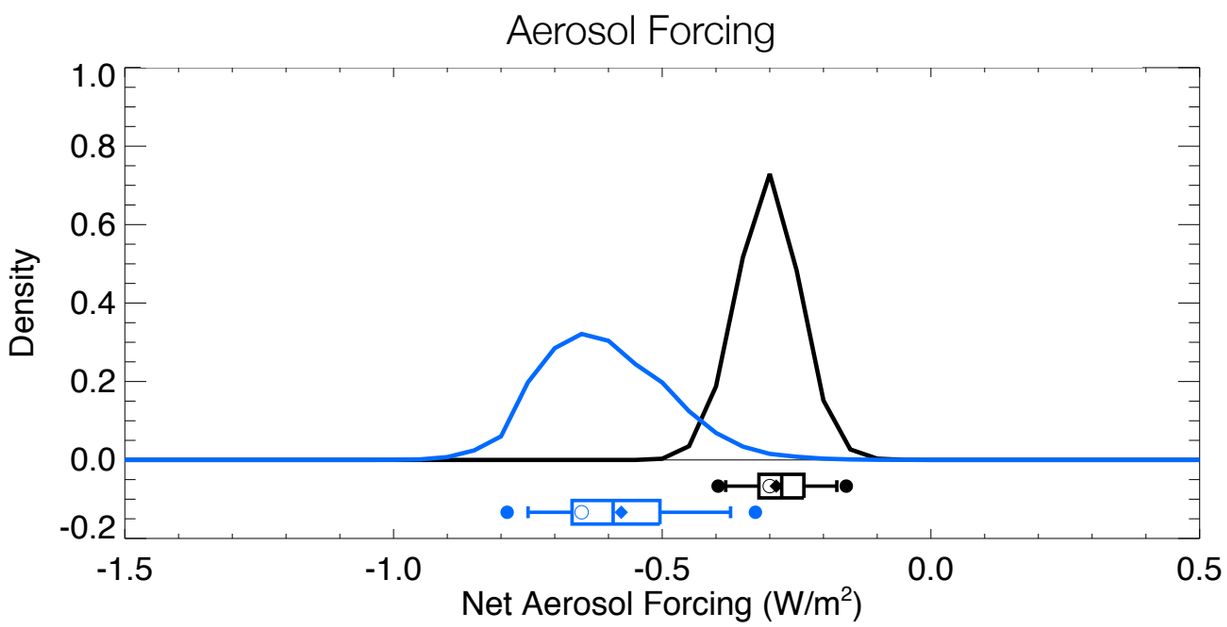
All Diagnostics start in 1941

Diagnostics end in 1990
Diagnostics end in 2000
Diagnostics end in 2010

Libardoni, Forest, & Sokolov (In prep)







- **How are the marginal PDFs impacted?**
- **Changing the model and forcings**

New Model (MESM)
Old Model (IGSM)
(Libardoni & Forest, 2013)

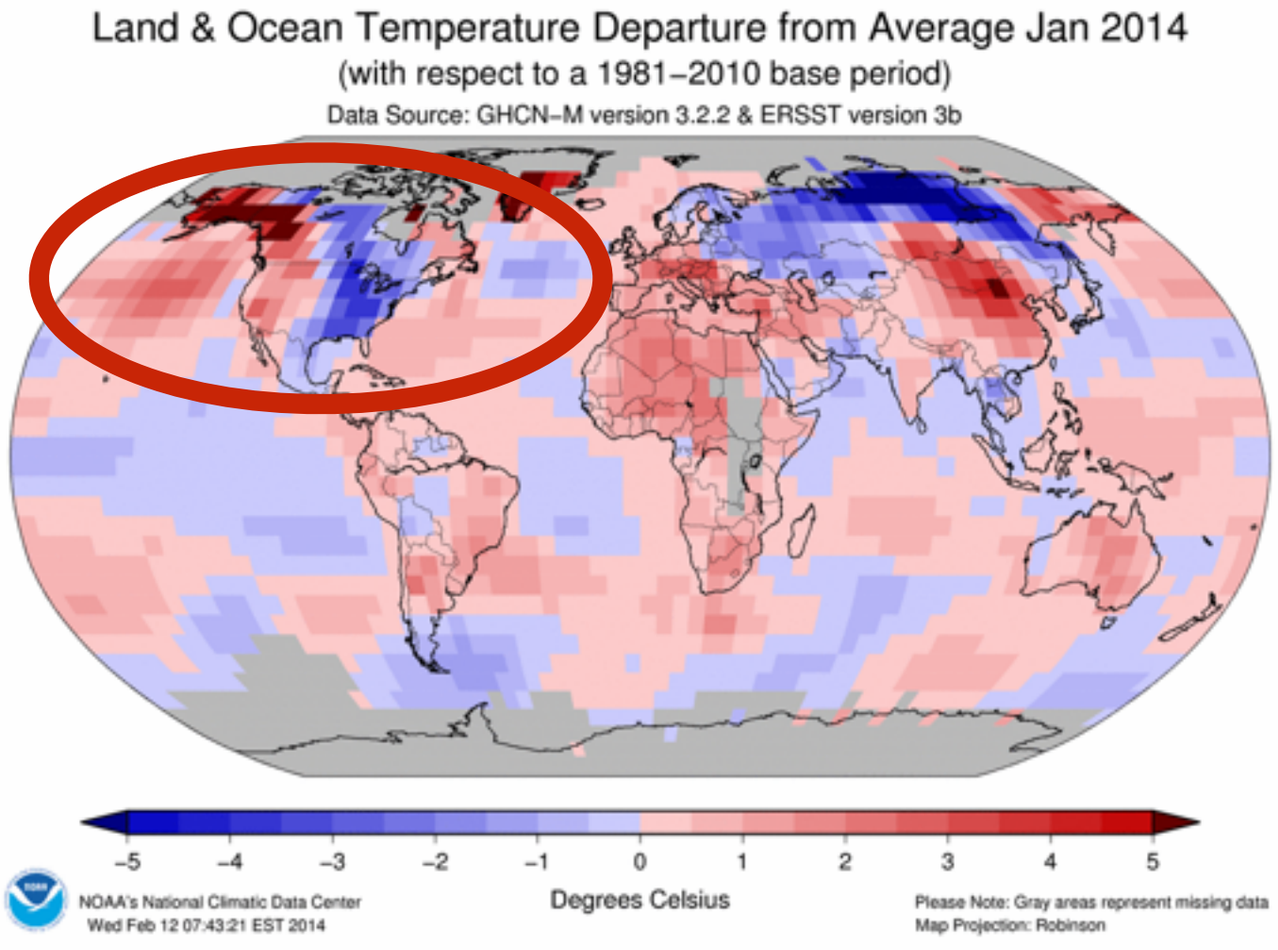
Both use Same Diagnostics

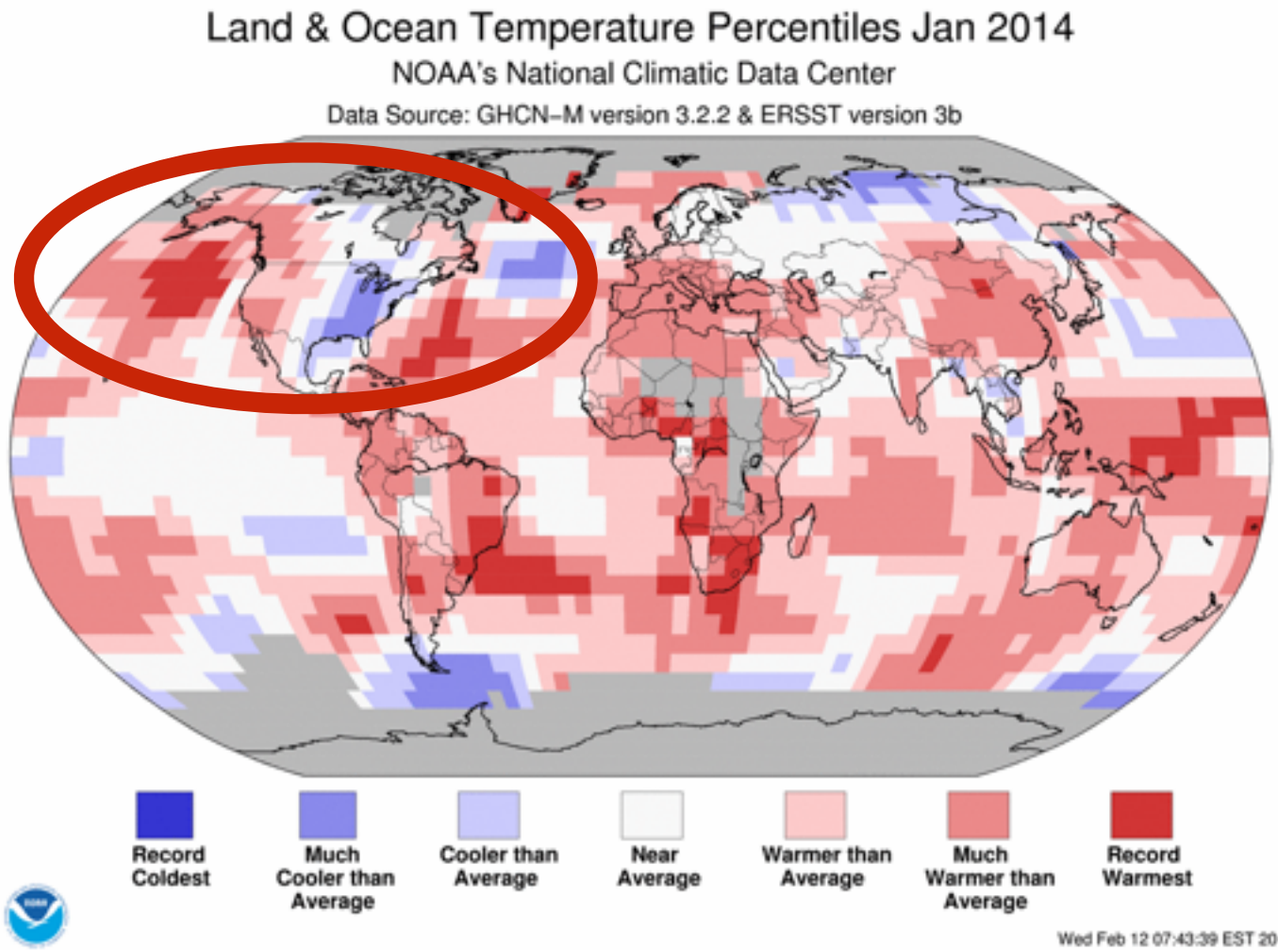
Libardoni, Forest, & Sokolov (In prep)

So this begins to address global scale uncertainties…

- How do we start assessing uncertainties at regional scales?

What are Drivers of Regional Extremes? Example: Polar Vortex in January 2014





SST patterns are a primary driver with land surface and sea-ice potentially being as important.

Implies that regional changes require better estimates of ocean variability.

Can we quantify structural uncertainty in model response at *regional scales*?

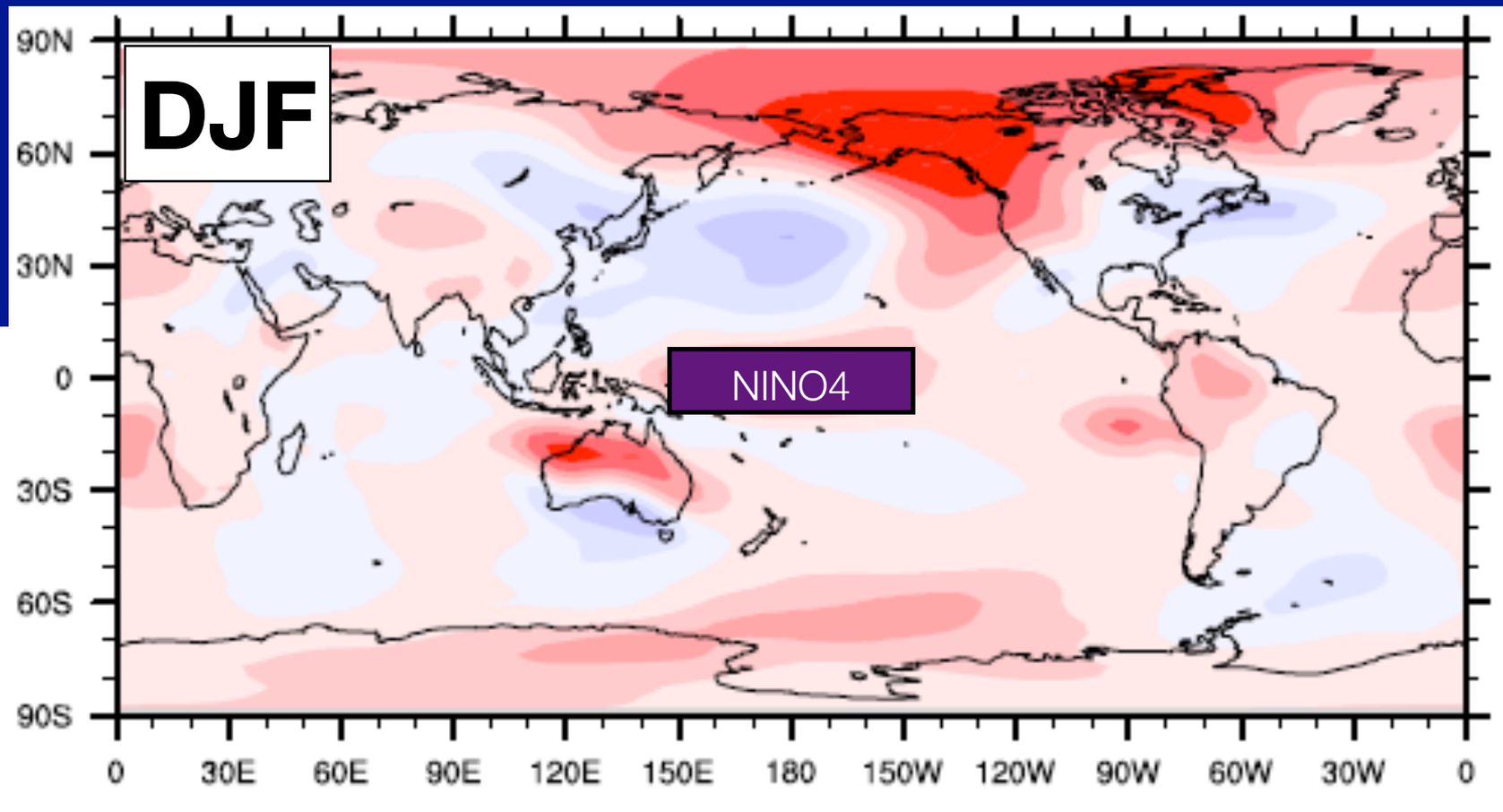
- Alternatively, how can we go beyond the IPCC/CMIP multi-model ensemble to assess climate risk?

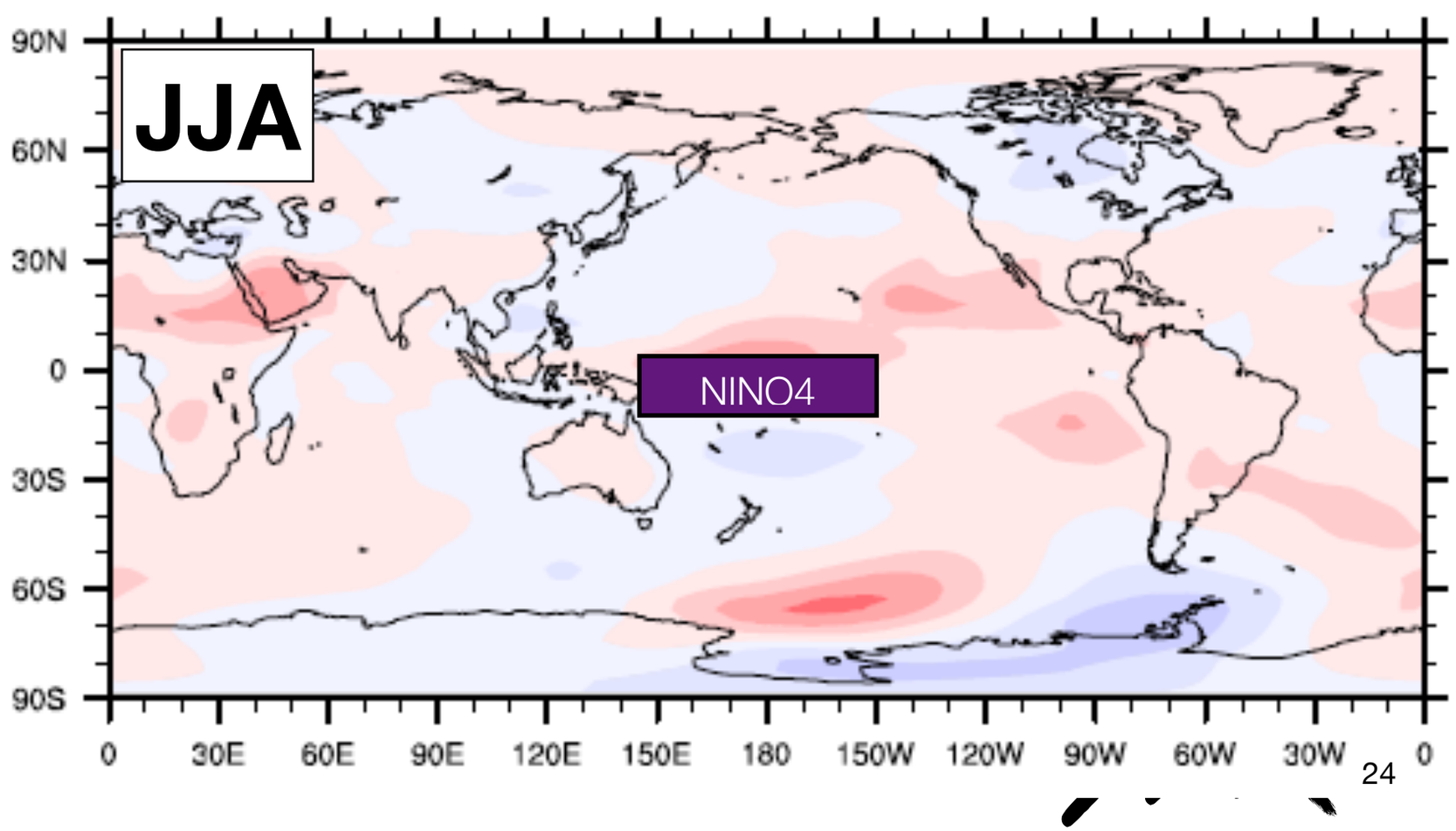
- How: Create ***idealized*** experiments with “known” forcings to provide metrics (or framework) for comparing model response *at regional scales*

- Purpose: Estimate the teleconnection response that ***adds*** to the mean climate response pattern.
  - *NB:* According to the physics community, teleconnections are second-order cumulant stats.

Example: Teleconnection

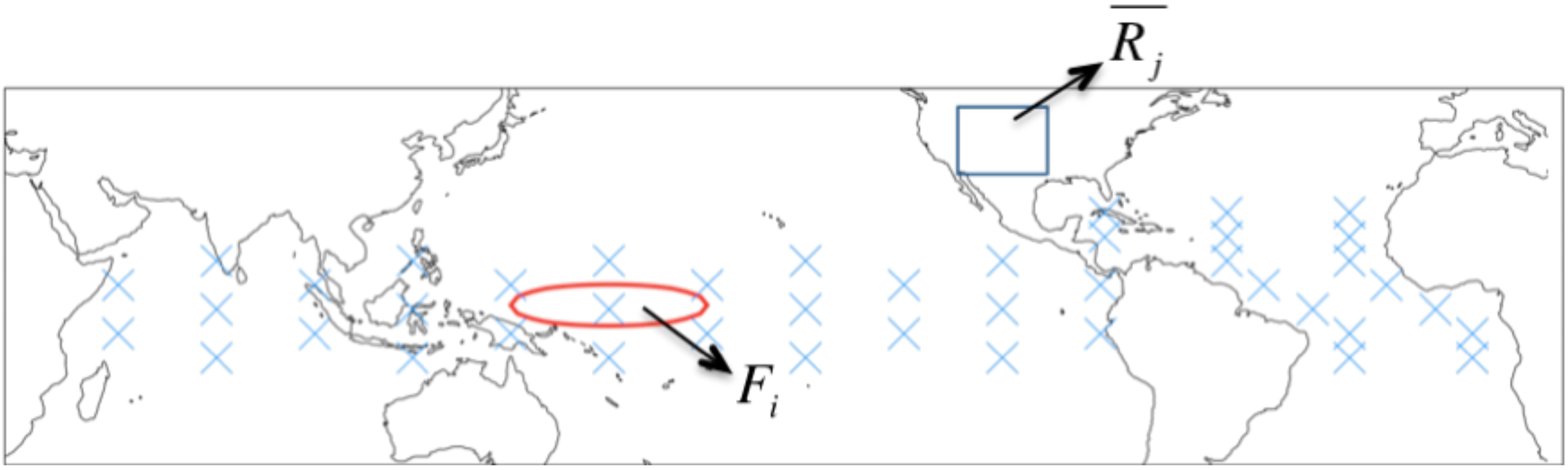
- Response to Nino4
- Seasonal Mean Temperature on 850hPa surface





Global Teleconnection Operator: GTO

Estimate the ensemble-mean response, R_j, to the ΔSST forcing, F_i



Estimate **Global Teleconnection Operator, K_{ij},** from:

$$\overline{R_j} = K_{ij} \cdot F_i + \varepsilon$$

Repeat this estimate for all SST anomaly locations in tropics

Patch Method: Barsugli and Sardeshmukh (2002, J. Climate)

Random Patch Method: Li, Forest, & Barsugli (2012, JGR-A)

GTO Experiments
(X = complete, O = in progress)

	Models					
Resolution	NCAR CAM				GFDL AM2	HadAM3 (CPDN)
	CAM3.1	CAM3.5	CAM4	CAM5		
T31				X		
T42	X					
T85	X					
FV0.9x1.25				X		
FV1.9x2.5	X	X	X	X	X*	O*
FV4x5				X		
HOMME_N30				X		

NOTE1: Ensemble size with n=400 is typically sufficient.

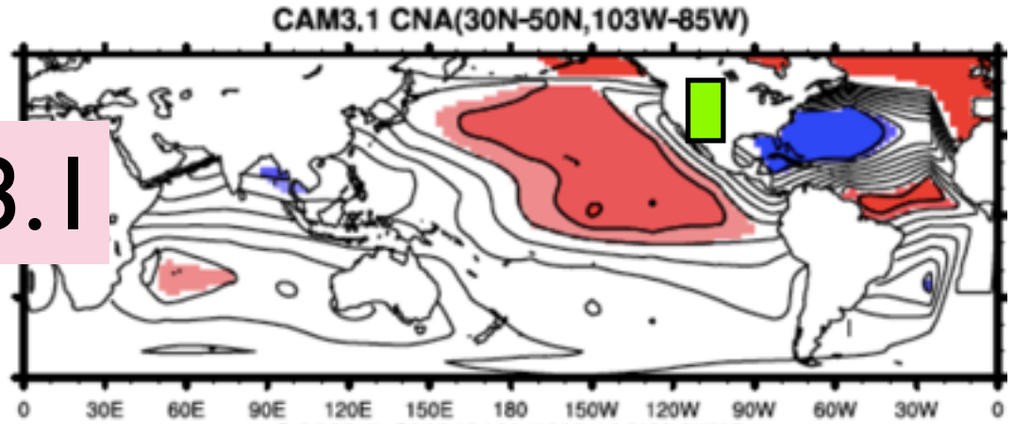
*GFDL AM2 (2.0x2.5), HadAM3 (2.5x3.75)

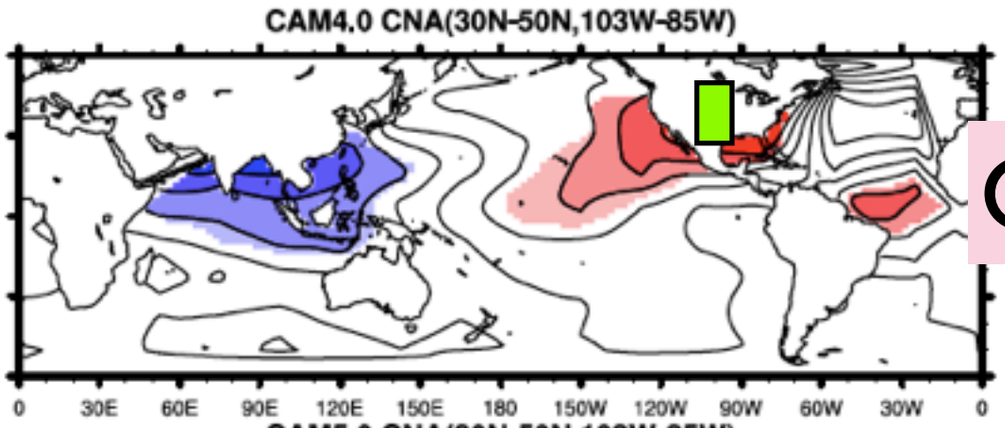
NOTE2: GTO for HadAM3: a new Climate*Prediction*.net experiment, >10k simulations

Testing for Structural Uncertainty
GTO: Sensitivity Maps (K_{ij})

Comparing Physics

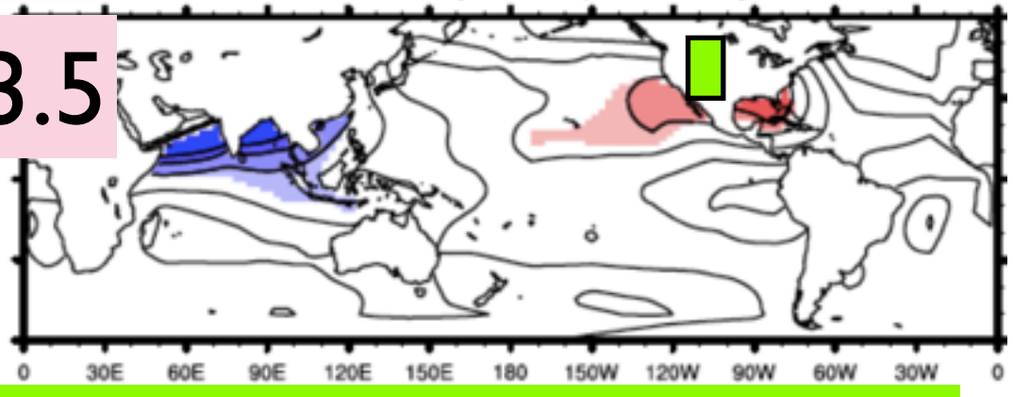
CAM3.1

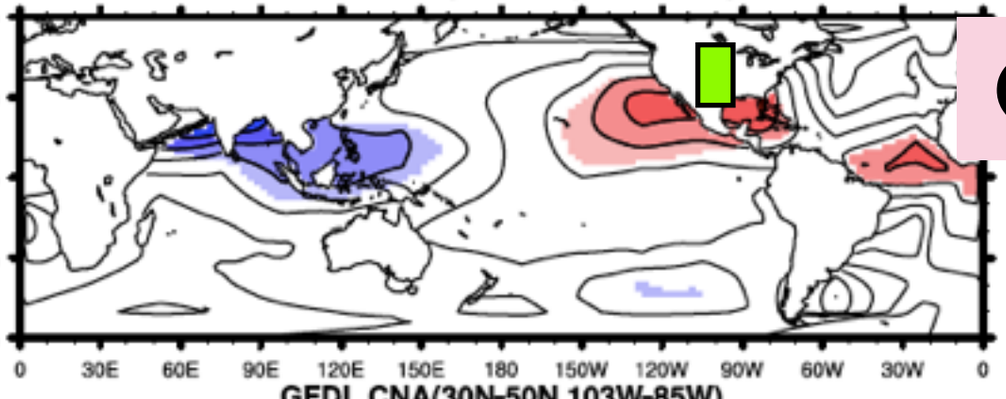




CAM4

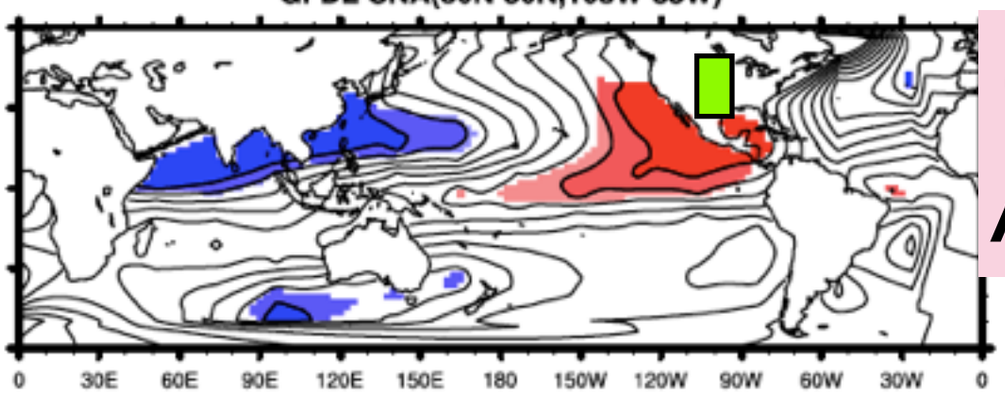
CAM3.5





CAM5

R_j: Central North America Midwest Agriculture JJA Precip



GFDL AM2.1

All use FV1.9x2.5

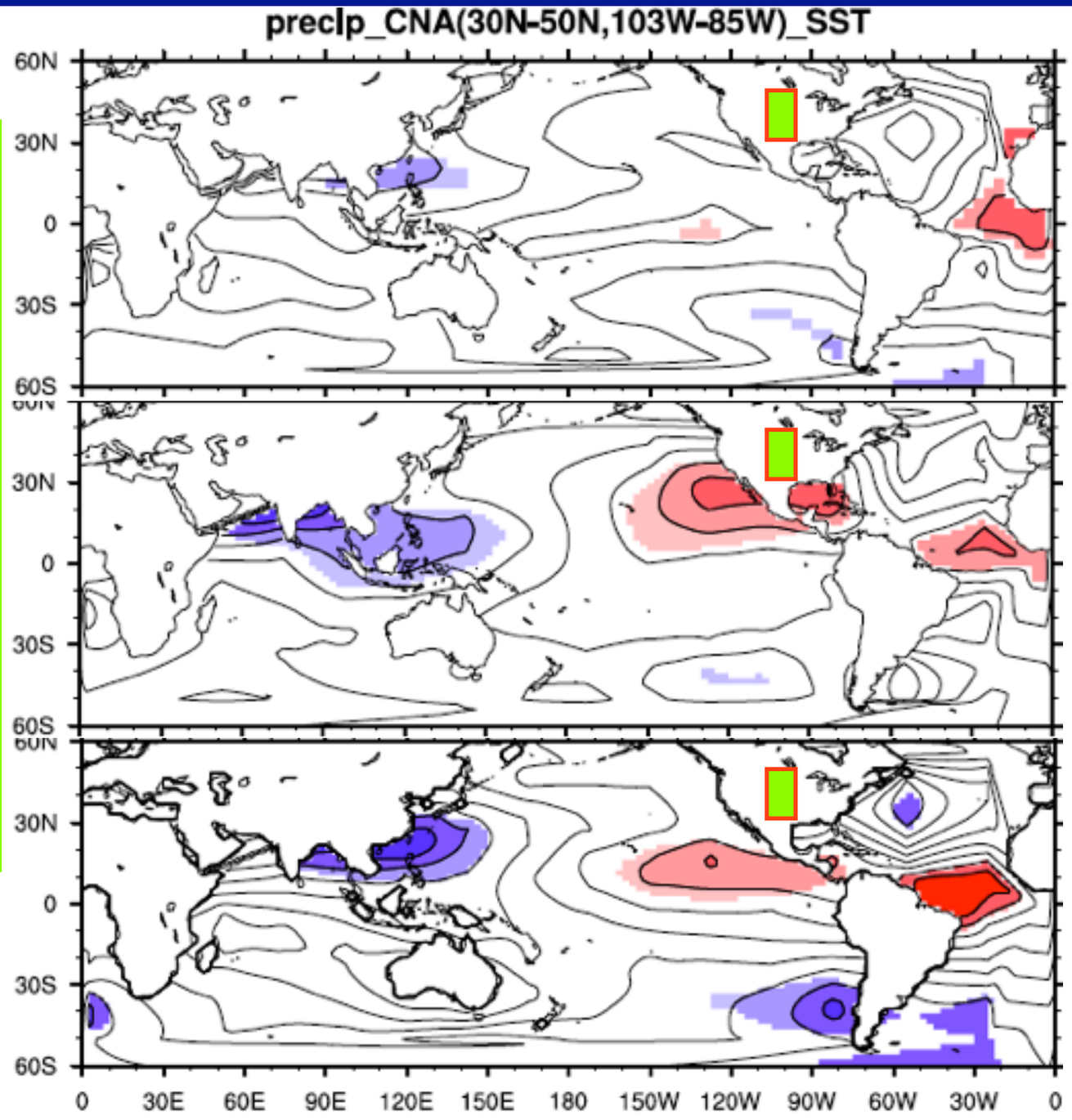
Testing for Structural Uncertainty
GTO: Sensitivity Maps (K_{ij})

Comparing DyCore

R_j: Central North America

Midwest Agriculture

JJA Precip



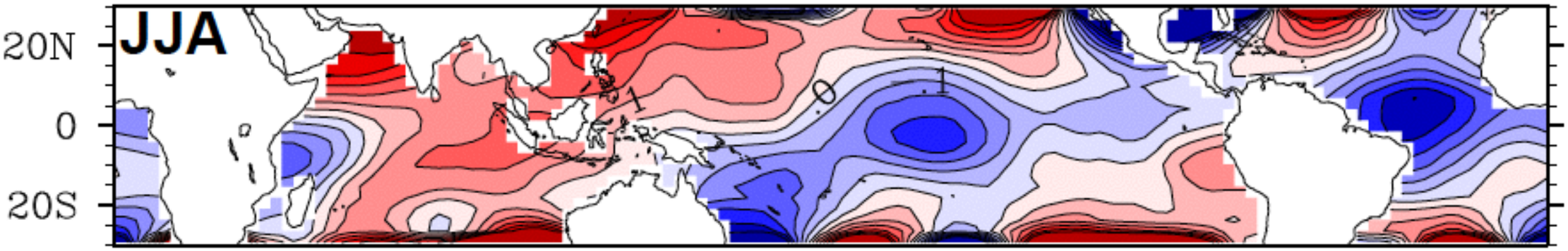
CAM5
T31

CAM5
FV1.9x2.5

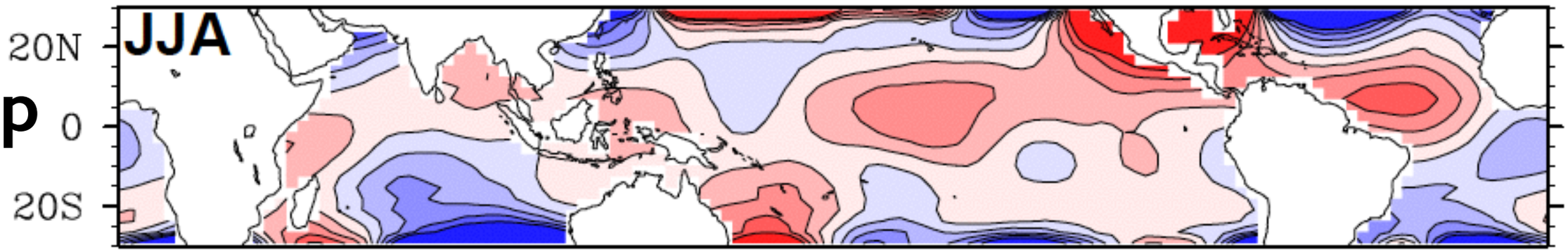
CAM5
HOMME
ne30

Application to Mississippi River Basin (JJA)

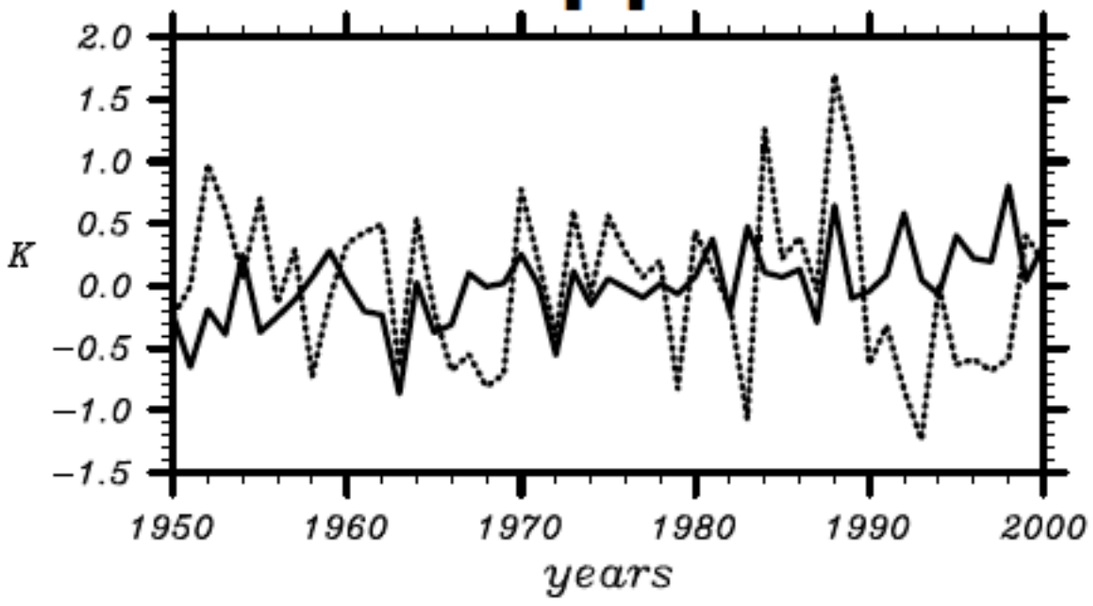
T850



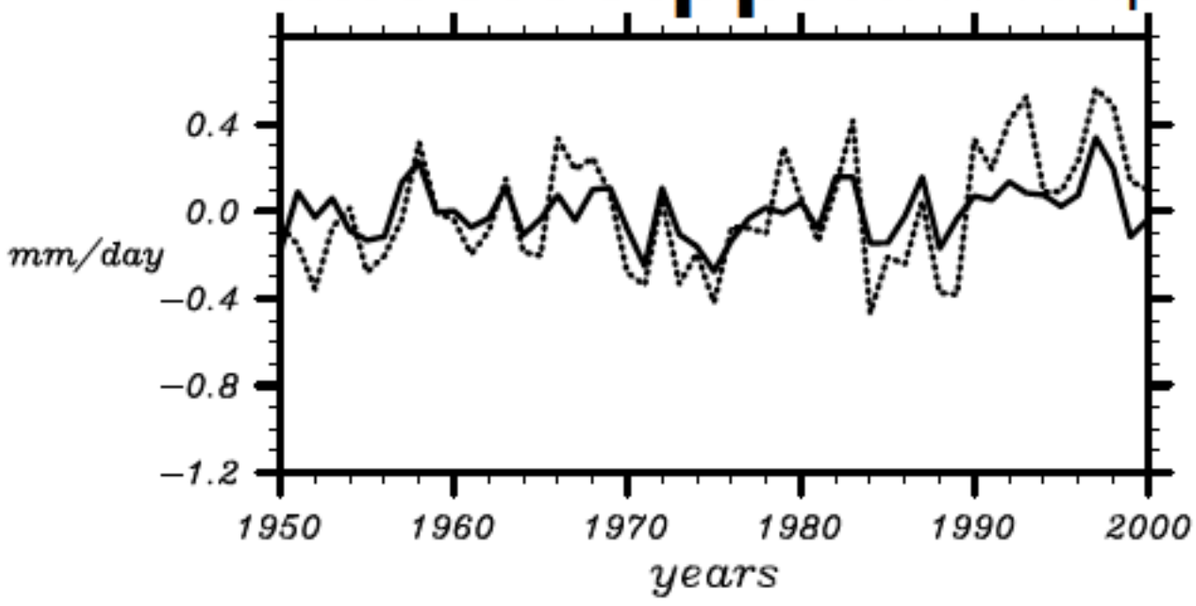
Precip



(c) **Mississippi** JJA T850



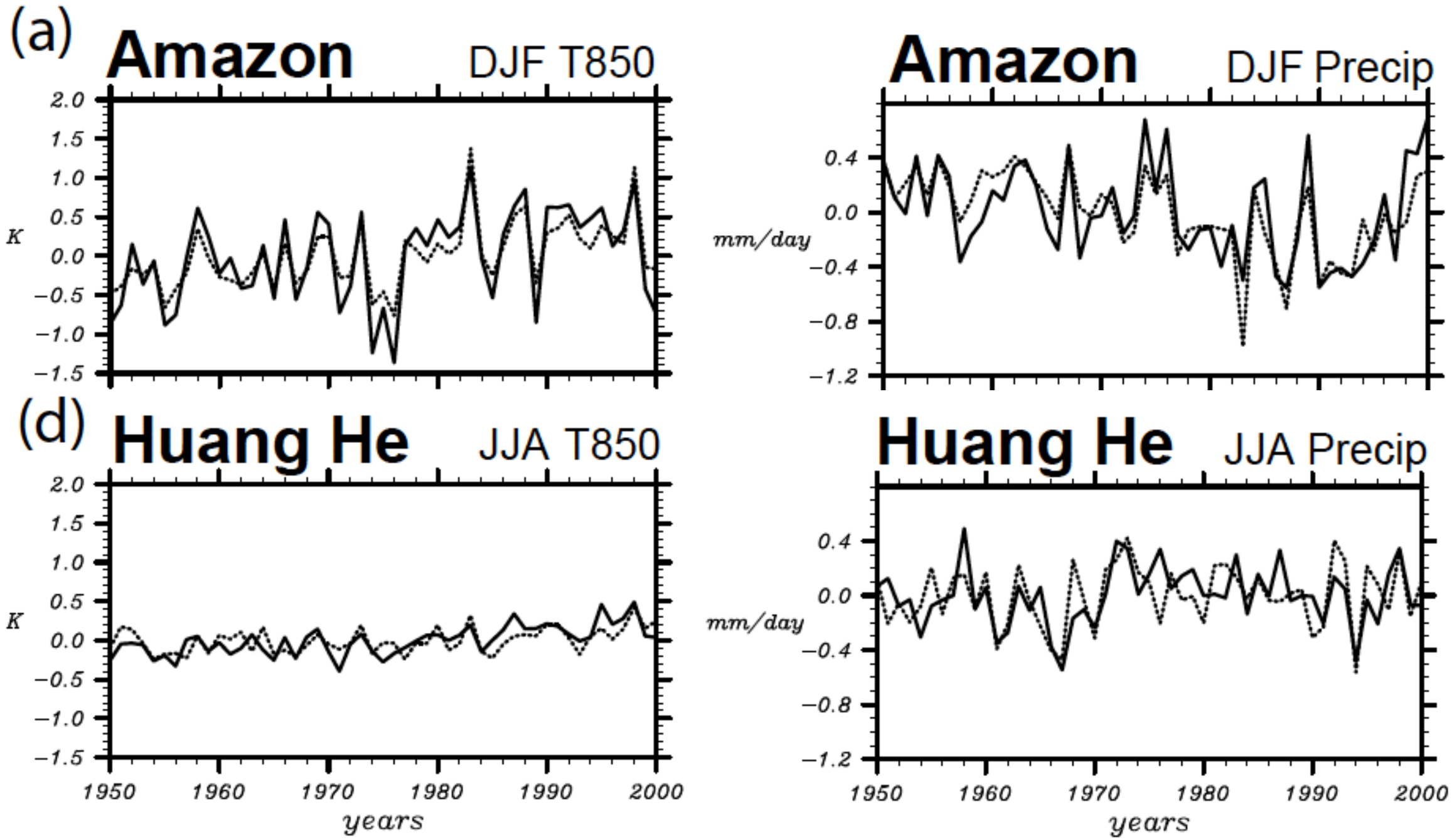
Mississippi JJA Precip



Work by Judy Tsai (PSU) and Thorsten Wagener (Bristol)

Application to Amazon River and Huang He

Reconstruct T and Precipitation based on Green's function response to observed SST: $R(t) = K_{ij} * SST(t, x_i)$



Work by Judy Tsai (PSU) and Thorsten Wagener (Bristol)

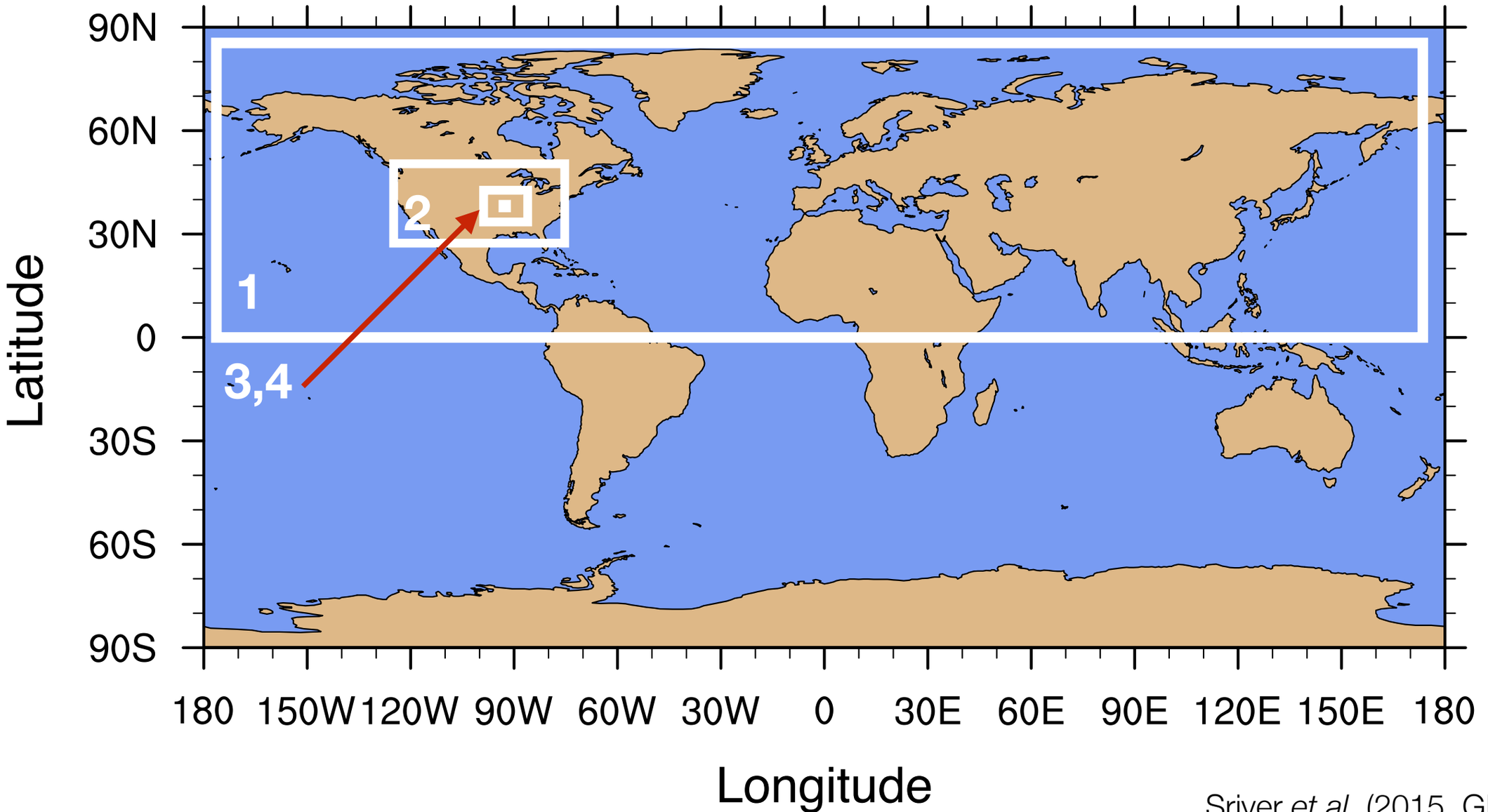
Running CESM ensembles for decision relevant problems

Goal: To add additional information on initial condition uncertainties

Running CESM ensembles for decision relevant problems

Goal: To add additional information on initial condition uncertainties

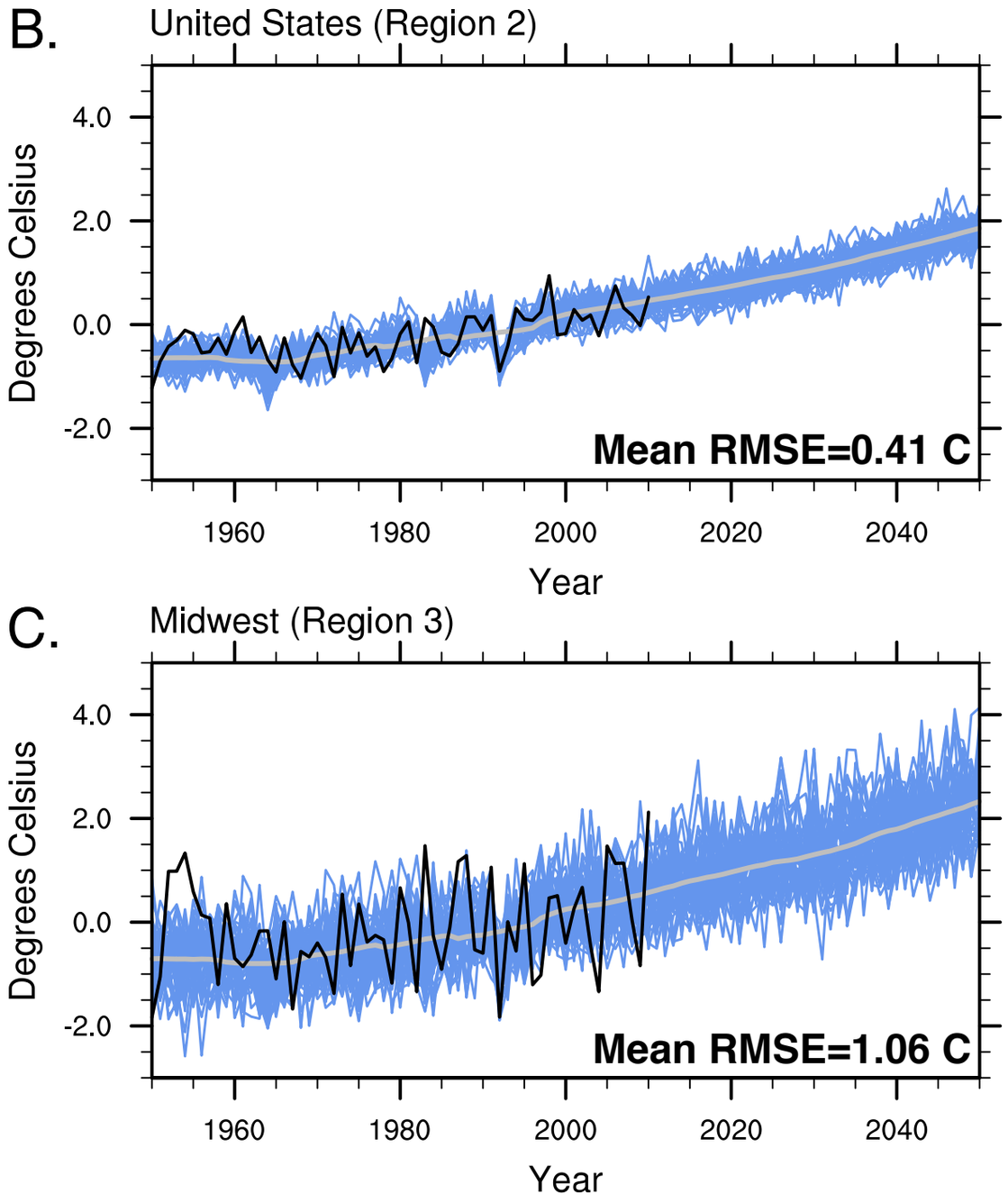
Focus on representing climate information at regional scales



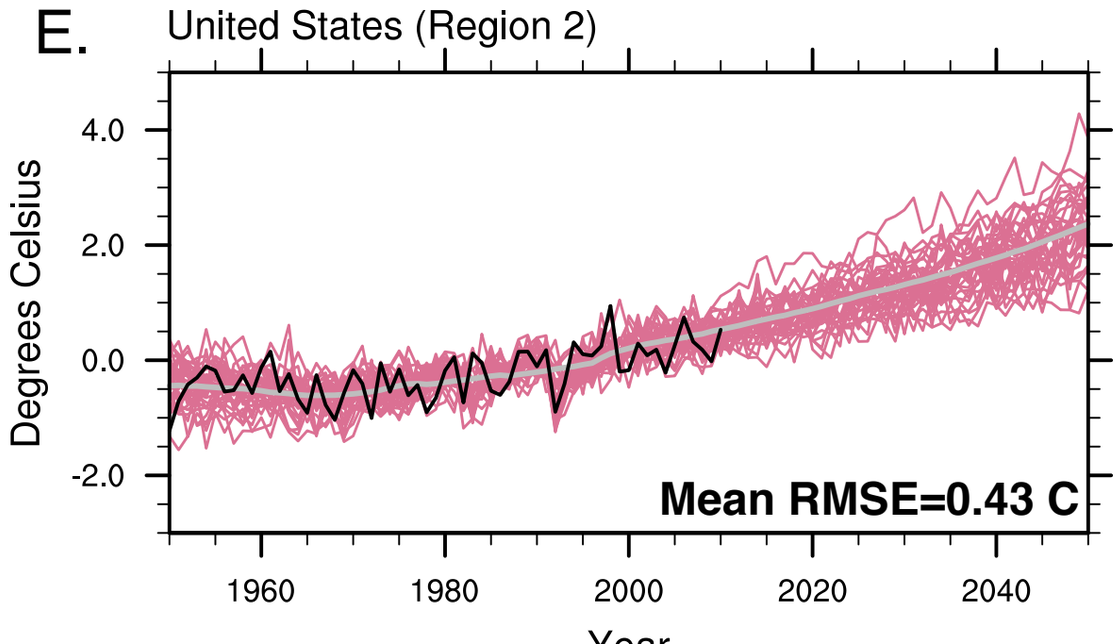
Sriver *et al.* (2015, GRL)

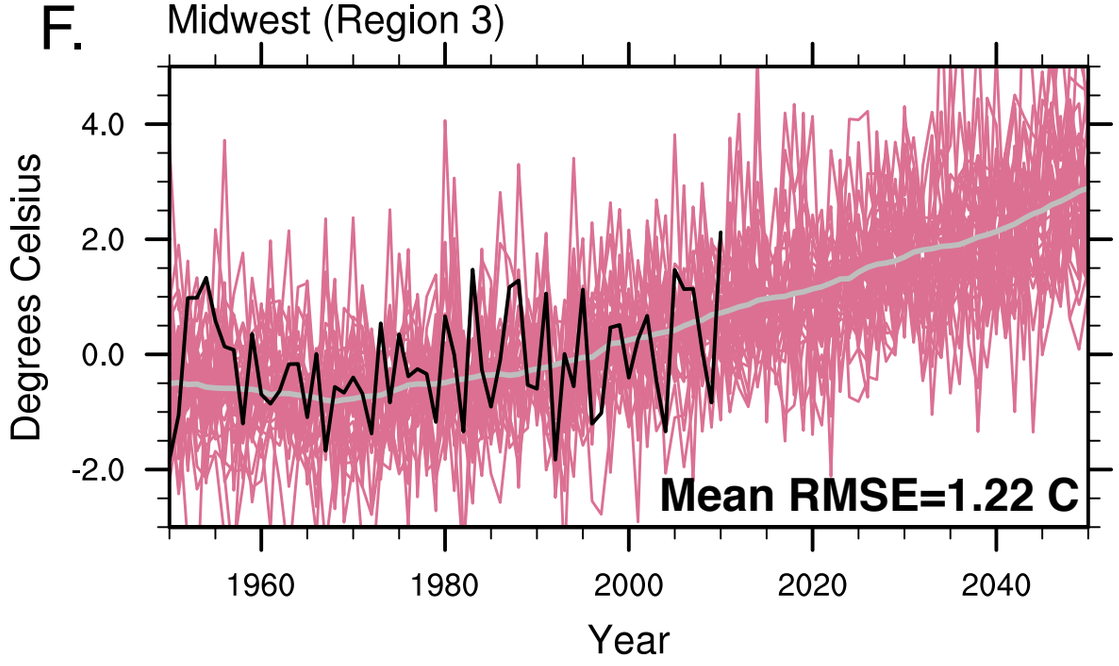
Running CESM ensembles for decision relevant problems

PSU CESM Ensemble



IPCC CMIP5





1. 50 Member Initial Condition Ensemble: 1850-2100
2. Based on unique initial condition from 5000 yr control
3. Total Simulation years: 17,500 (150 h

Sriver *et al.* (2015, GRL)

there are fundamental uncertainties about projections of future climate

The uncertainties fall into a few broad categories:

- observational uncertainty
- forcing or scenario uncertainty
- model uncertainty ⟹ structural, parametric
- natural/internal variability

The magnitudes of the projection uncertainties vary in space and time; smaller spatial and temporal scales ⟹ greater uncertainties.

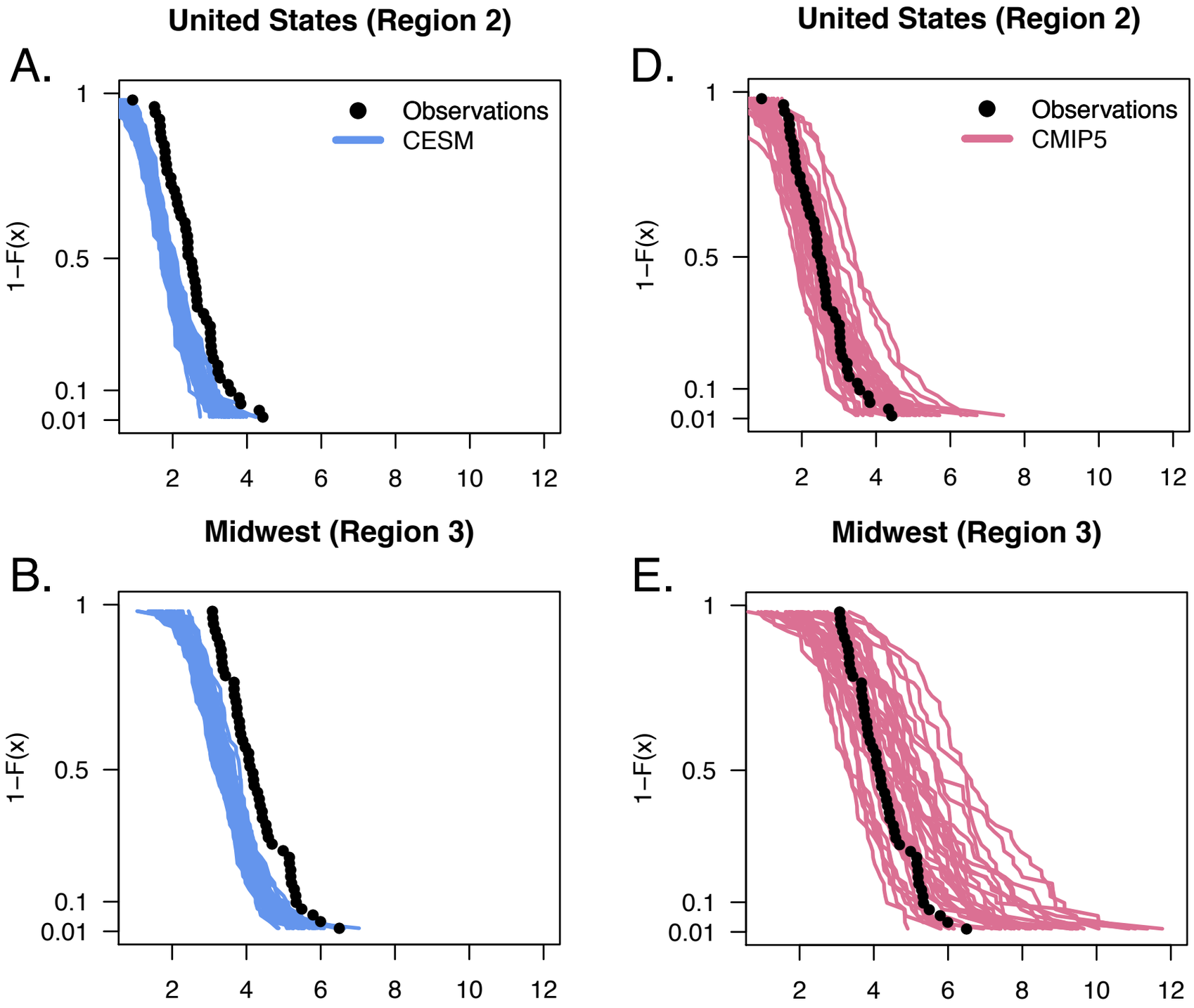
Climate projections may also exhibit systematic biases.

Failing to account for biases and the full range of uncertainties can lead to overconfident (and unhelpful) projections.

We are working to incorporate all these into decision-making frameworks

Next: How do we assess uncertainty at regional scales directly?

Running CESM ensembles for decision relevant problems



Survival Function for Summer block maxima of daily surface temperature anomalies (1956-2005) for the CESM and CMIP5 models.

Sriver *et al.* (2015, GRL)

Summary

Goals

1. Can we separate uncertainties between Global v. Regional response?

— Pattern scaling approaches suggest yes but formal assessment is needed.

2. How do we compare ensemble approaches? MME v. PPE v. ICE

— Multiple estimates with similar results. Does each have a place?

3. How does structural uncertainty in regional changes assessed?

— Proposing metrics for this uncertainty is difficult.

— Teleconnections (aka second-order cumulant statistics) are one option.

— The GTO estimates the first-order linear response to SST patterns and can be used for emulations.

Thank you!
mailto:ceforest@psu.edu

Questions?