Analyzing climate impacts using a low resolution CESM ensemble

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Climate impacts/damages closely linked to extreme (low probability) events

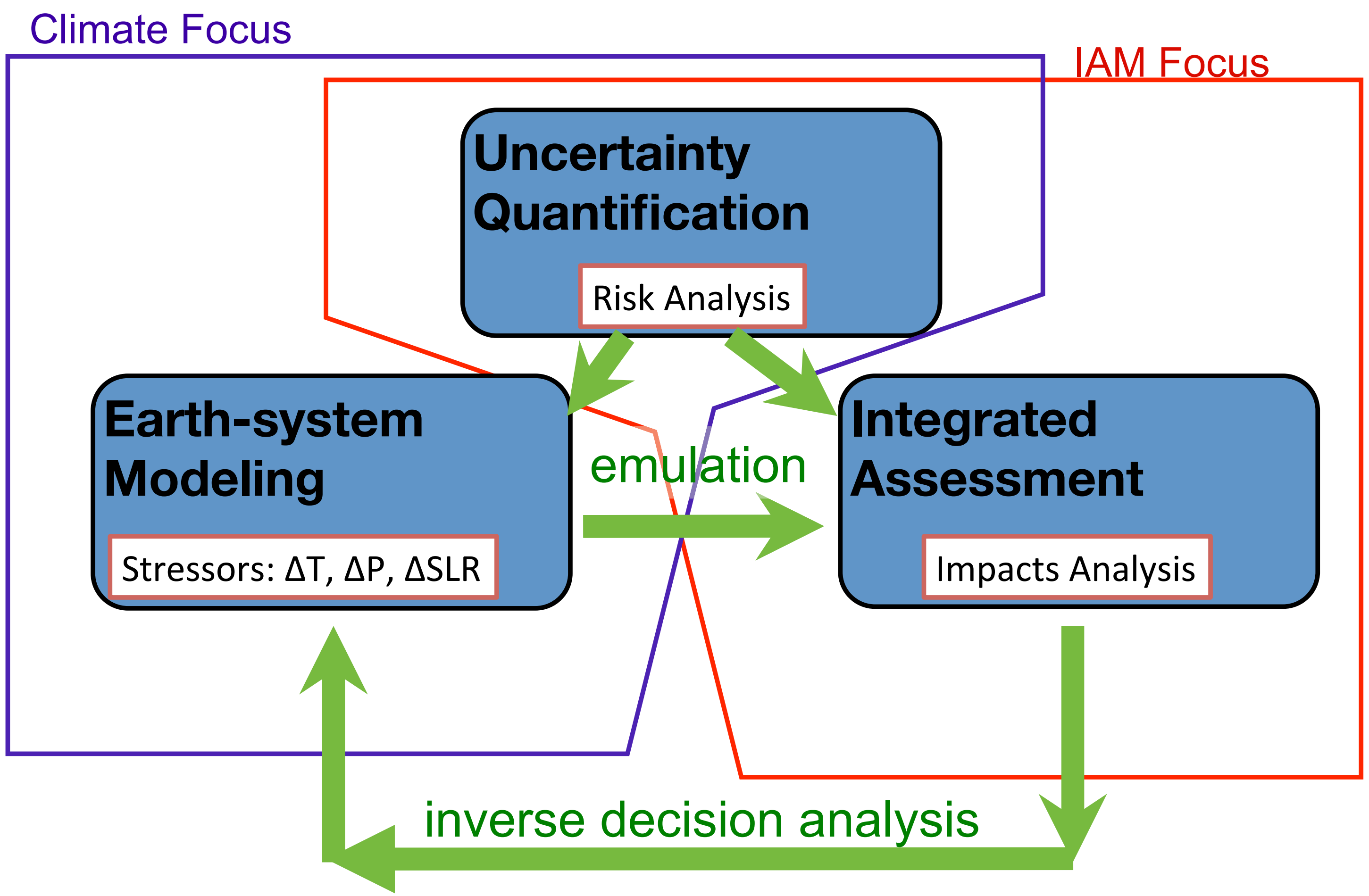
source: AP/Seth Perlman

source: NOAA

Earth system models typically geared toward estimating the most likely outcome

Can we formulate a self-consistent Earth system modeling approach that captures the maximum likelihood (climate mean) and tail area behavior (climate extremes)?

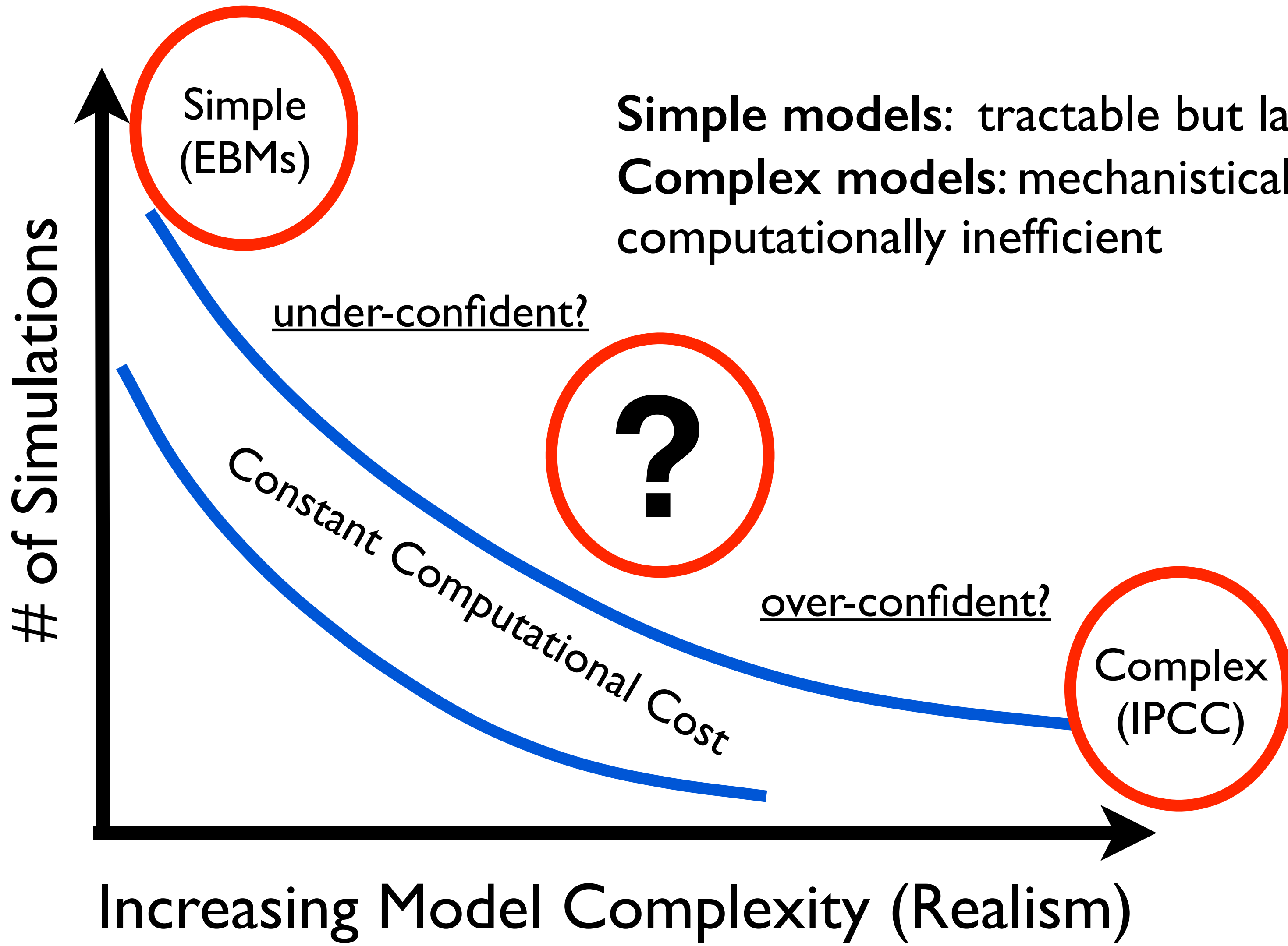
Uncertainty Quantification provides an important link between Earth-system modeling and Integrated Assessment, Risk Analysis and Impacts Analysis



Questions:

1. What uncertainties are important (decision-relevant)?
2. What drives the uncertainties?
3. How do the uncertainties affect climate metrics related to impacts?

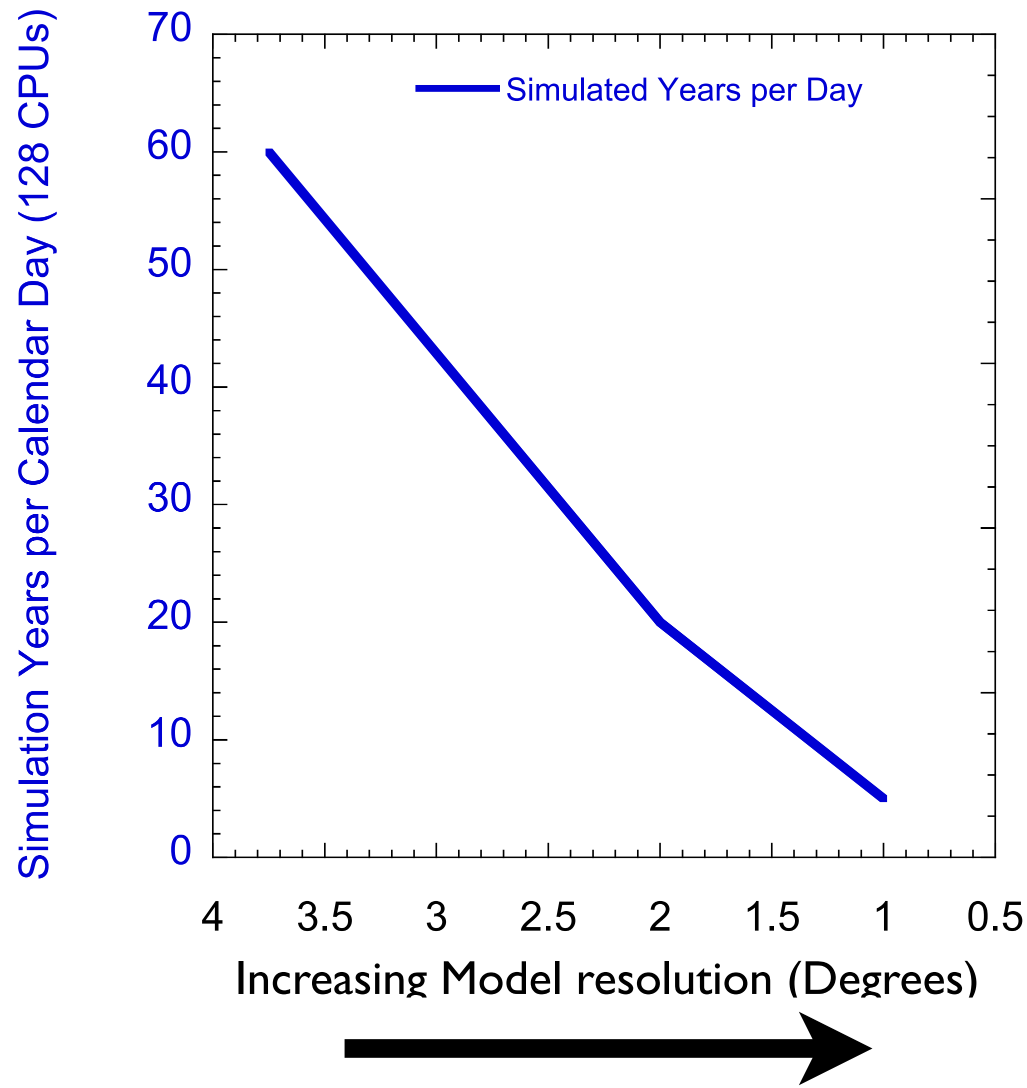
Tradeoff between model realism and computational tractability



Simple models: tractable but lack realism
Complex models: mechanistically sound but computationally inefficient

- Integrated Assessment requires probabilistic predictions with full treatment of uncertainty
- How do we achieve this given the tradeoffs between realism and tractability?

Example: Computational trade-off in CESM



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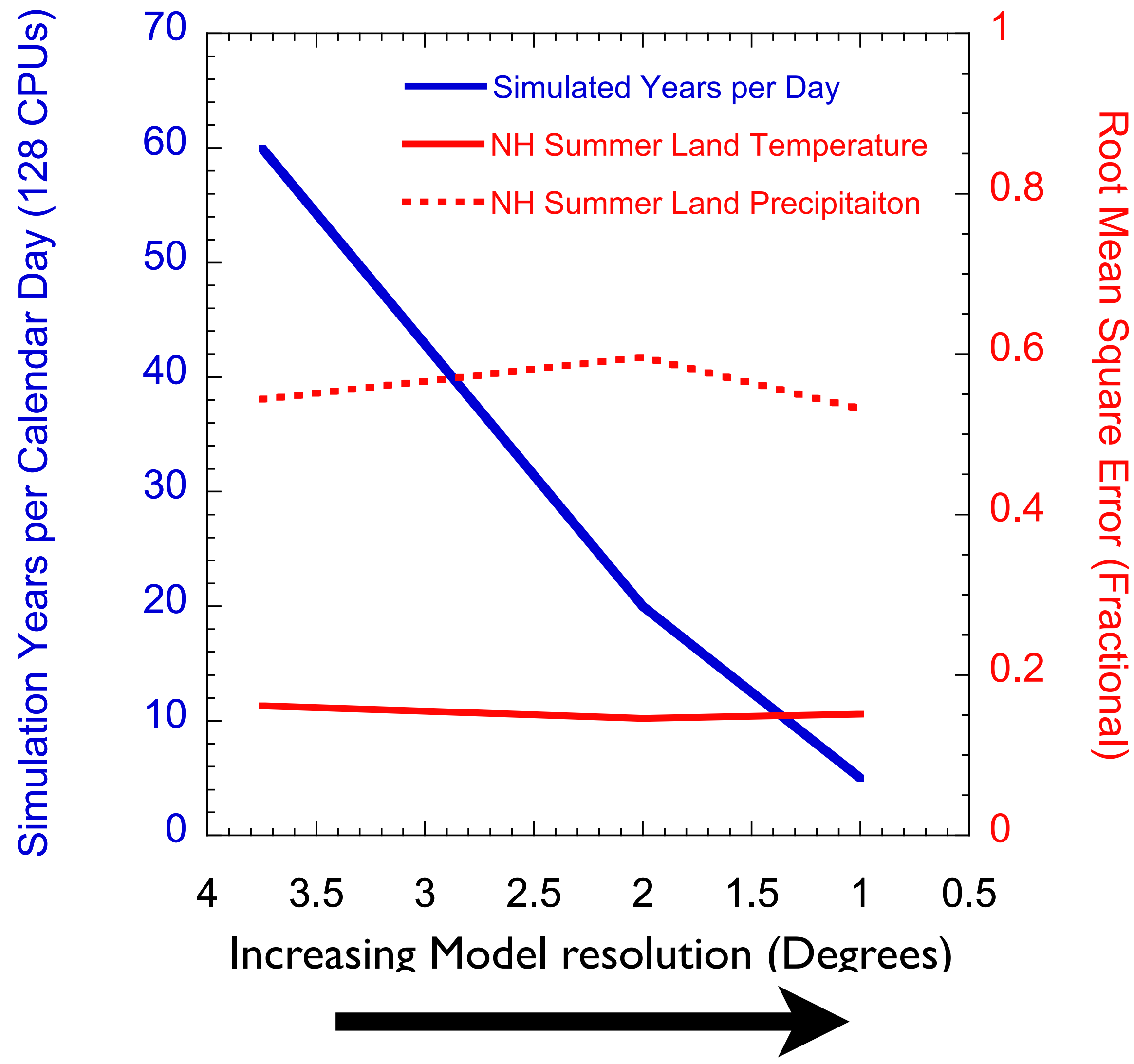
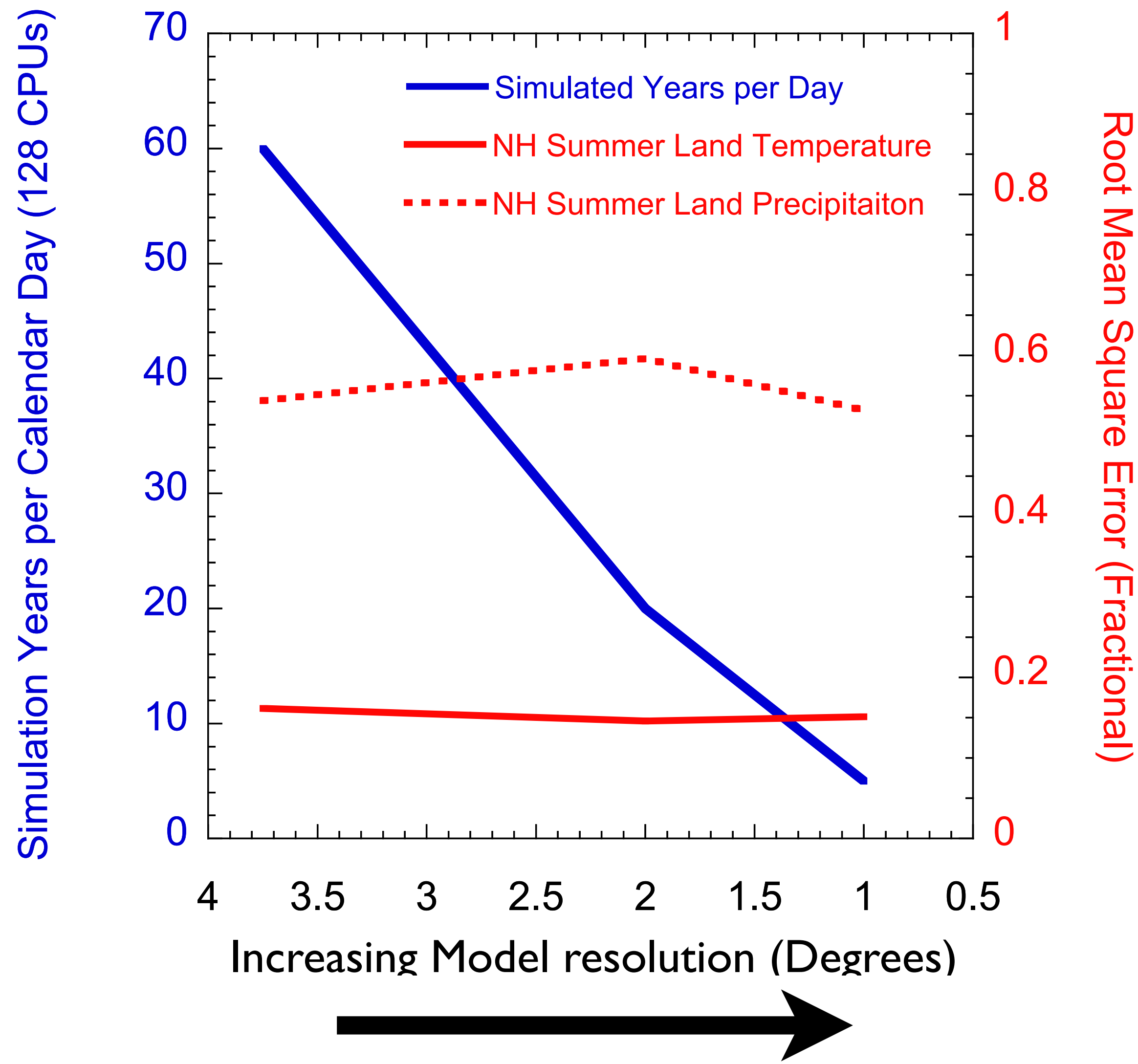


Example: Computational trade-off in CESM

Computational demand increases with resolution

CESM skill appears relatively insensitive to resolution for **<u>some</u>** key climate variables



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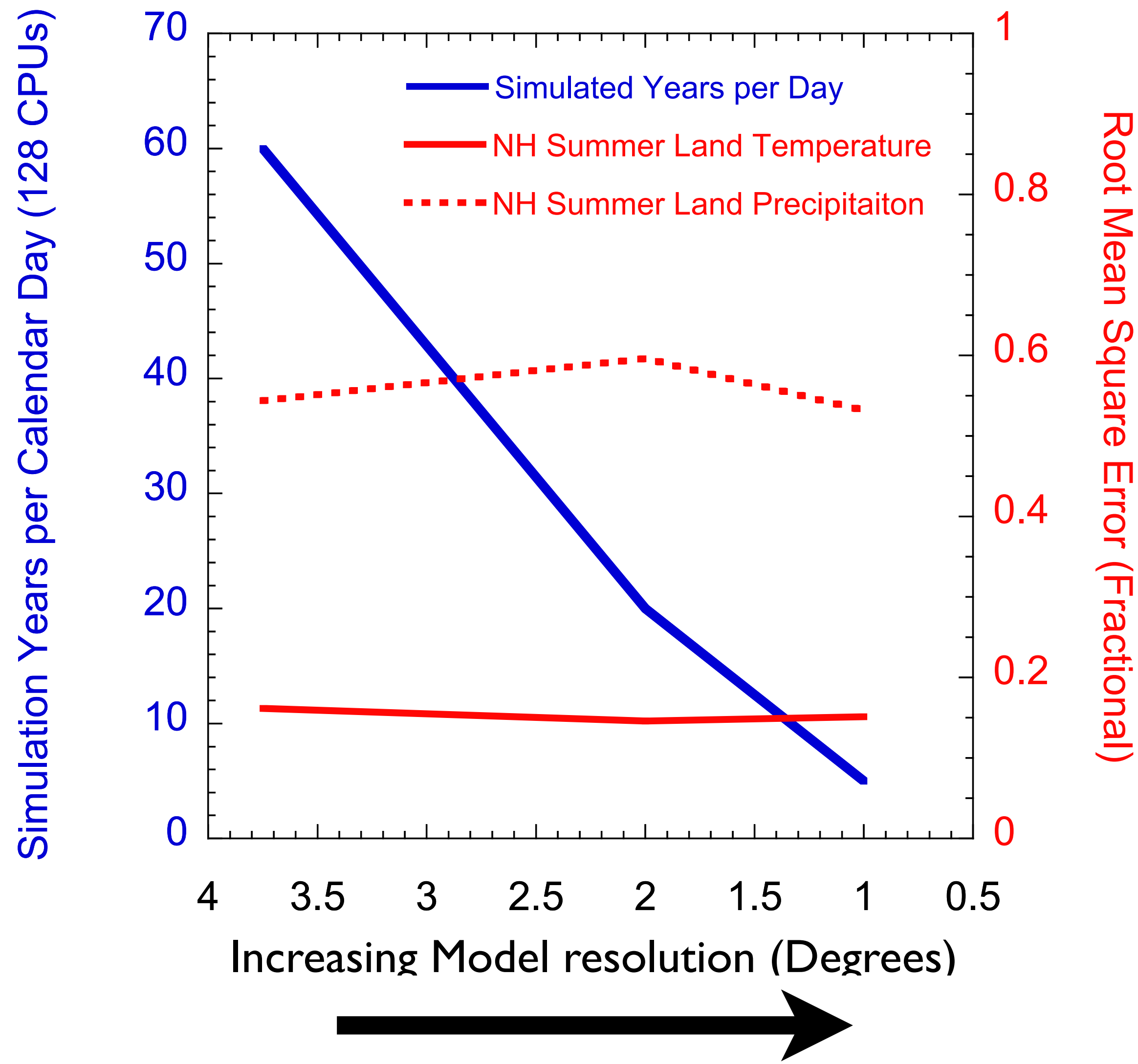


Low-resolution CESM may potentially provide "sweet spot" to Computational Tradeoff

- Mechanistically sound
- Tractable enough to perform large number of simulations required for UQ and IA

Connecting CESM to integrated assessment and impacts/risk analysis

<u>Uncertainty Quantification to inform decisions</u>

- different from usual UQ methods used in model development
    - e.g. parameter estimation
- focus on quantifying uncertainty surrounding decision-relevant metrics
    - applications: regional-scale temperature, precipitation, and sea-level rise variations

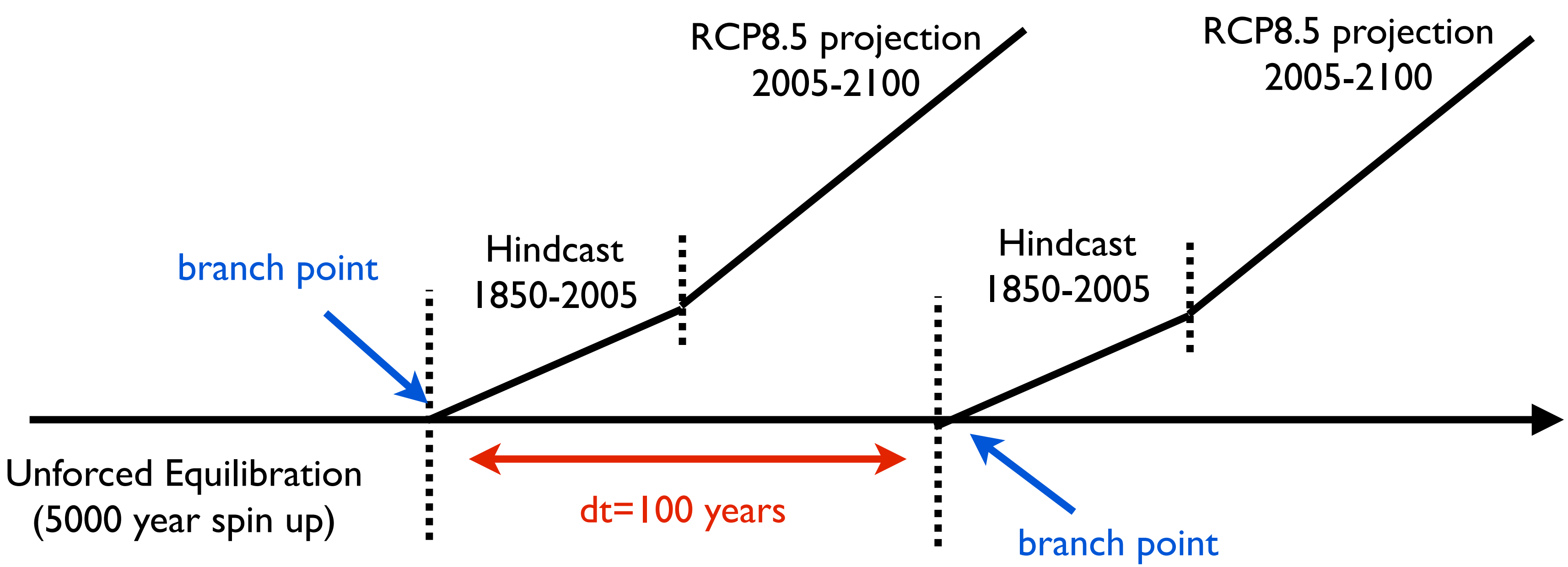
<u>CESM ensemble of hindcasts and projections</u>

- low resolution version (T31, gx3v7) Community Earth System Model (CESM)
- spin-up the fully coupled model for 5000 years
    - approximate dynamic equilibrium of the deep ocean
- branch off transient simulations every 100 years from the equilibrium run
    - forced with historic and projected forcings from the RCP8.5 scenario (1850-2100)

- currently 50 members (~50 TeraBytes of monthly and daily output)
    - monthly: full ocean/atmosphere fields
    - daily: max/min/average surface temperature, precipitation, relative humidity

CESM ensemble samples the internal variability of the fully-coupled ocean atmosphere system

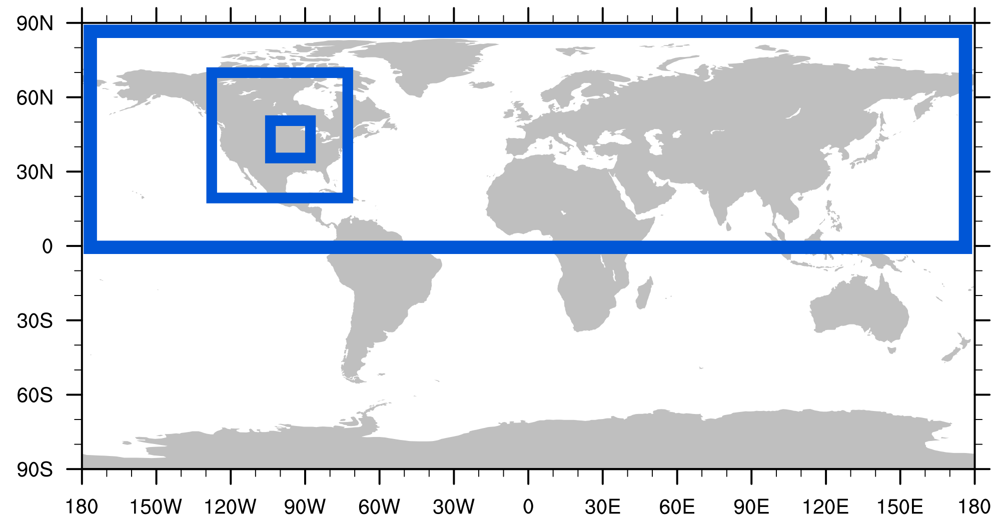
- enables a self-consistent method for analyzing the effect of unforced variability
  - features consistency between atmosphere/ocean states
  - enables analysis of multiple spatial and temporal scales



Our ensemble focuses solely on internal variability (initial conditions uncertainty)

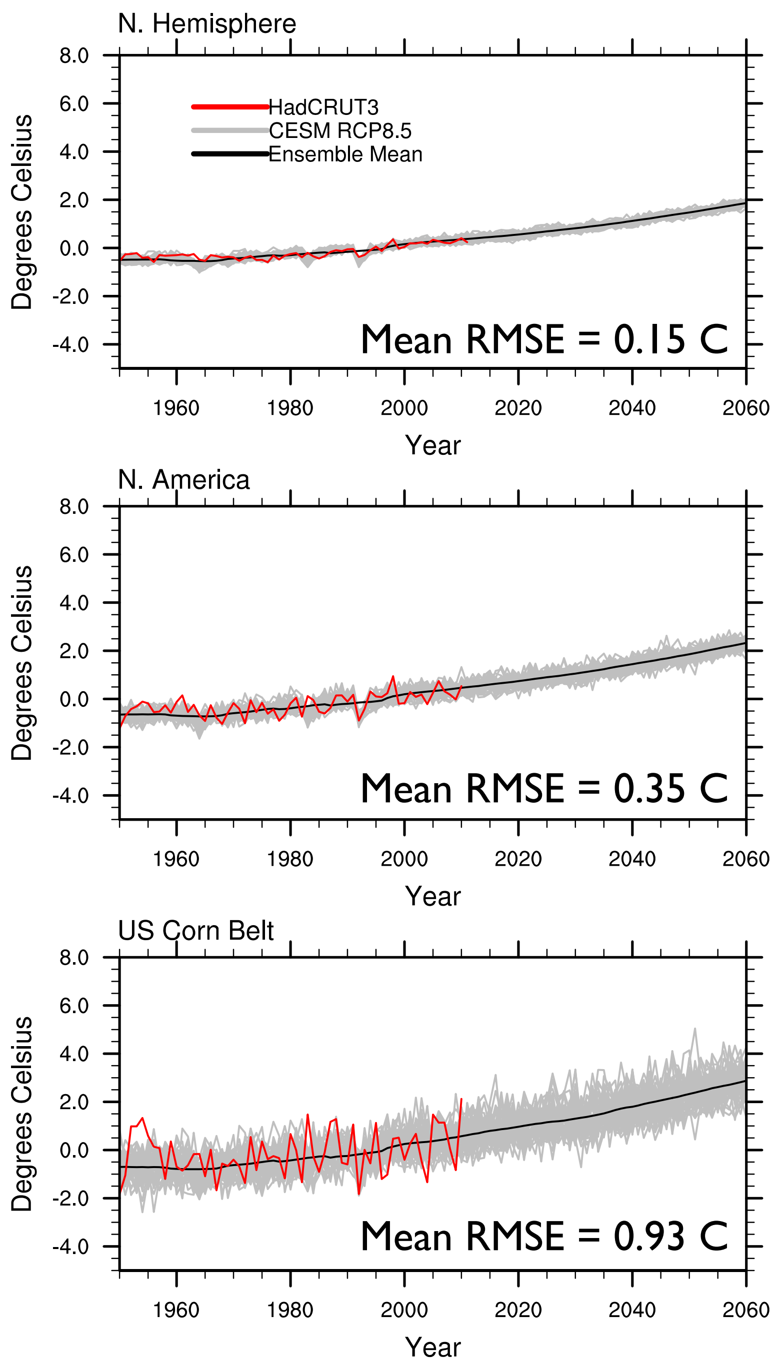
- Silent on other uncertainties:
  - parametric uncertainties, forcing scenarios, different model structures

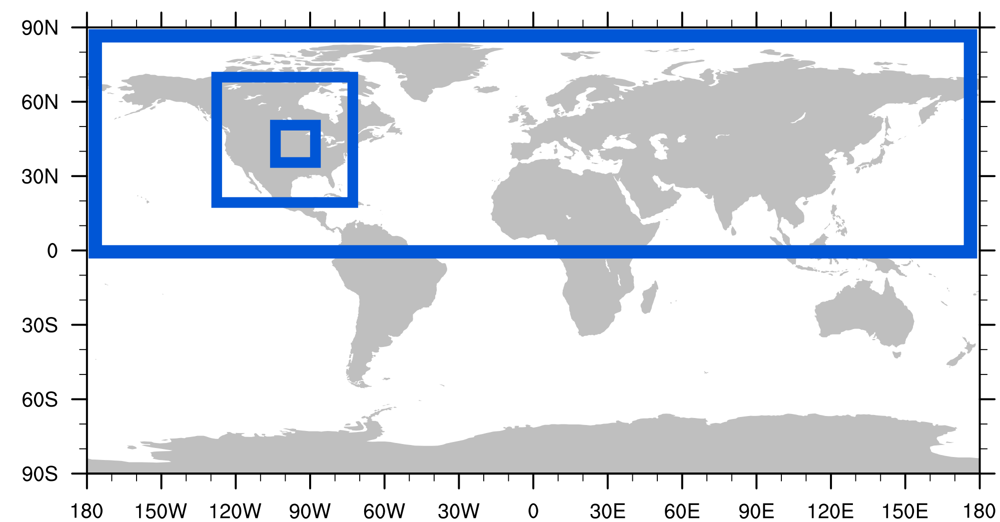
N. Hemisphere Summer (JJA) Temperature



N. Hemisphere Summer (JJA) Temperature

CESM Ensemble (50 members)





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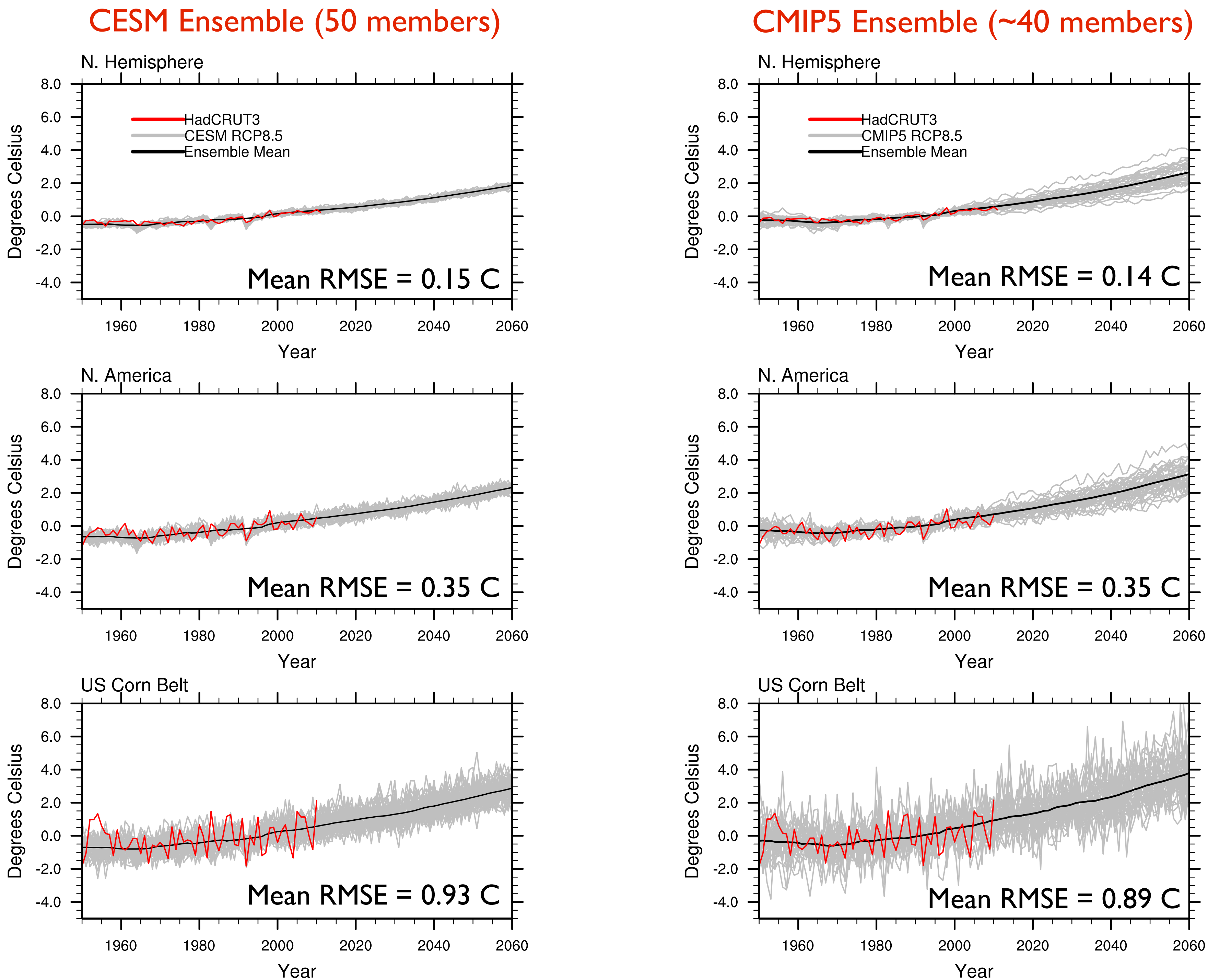
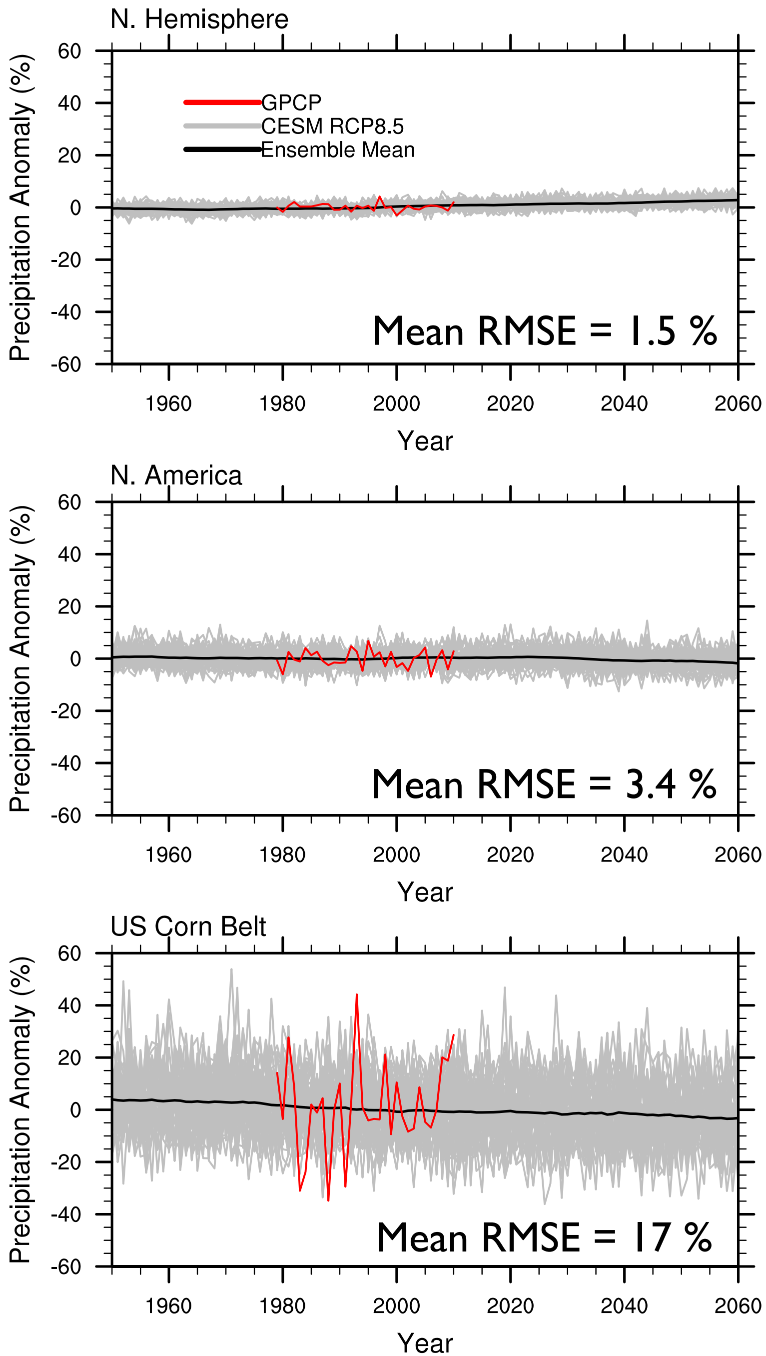
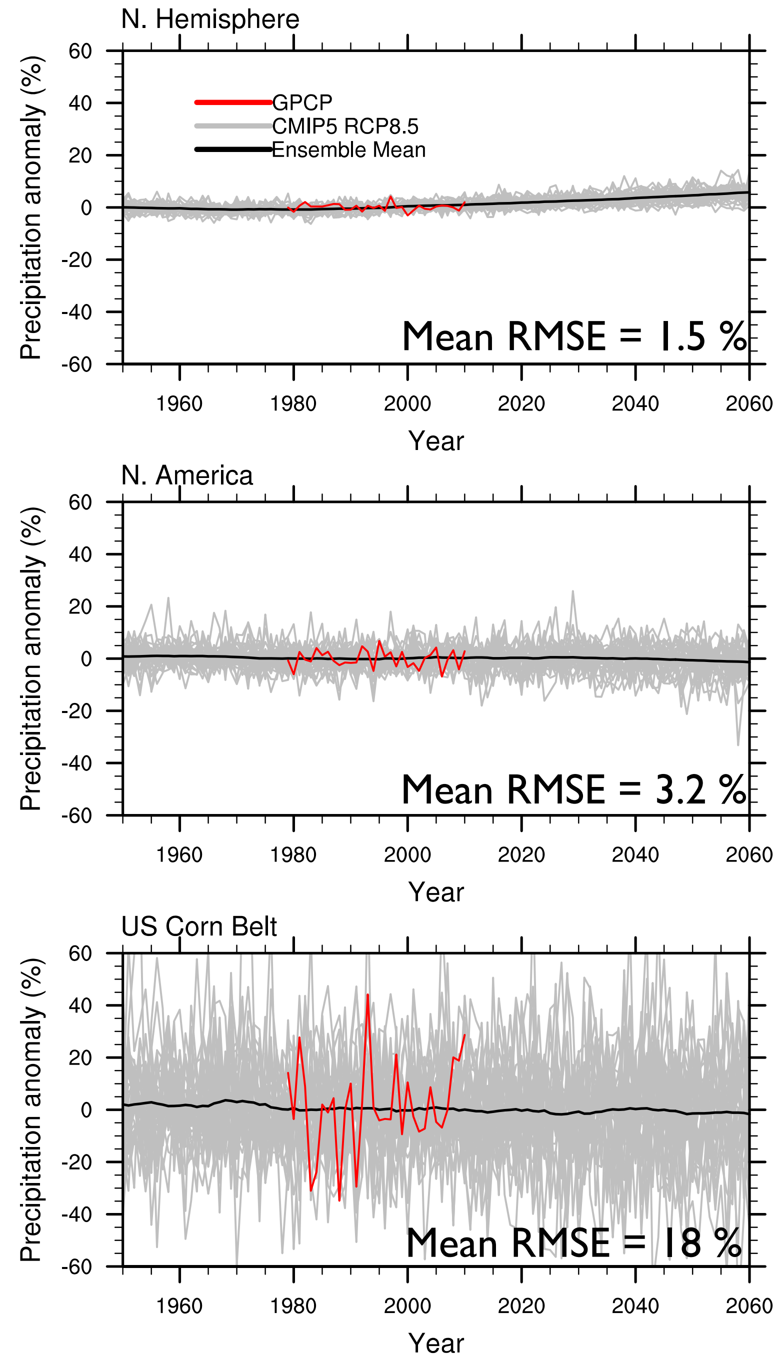


N. Hemisphere Summer (JJA) Precipitation

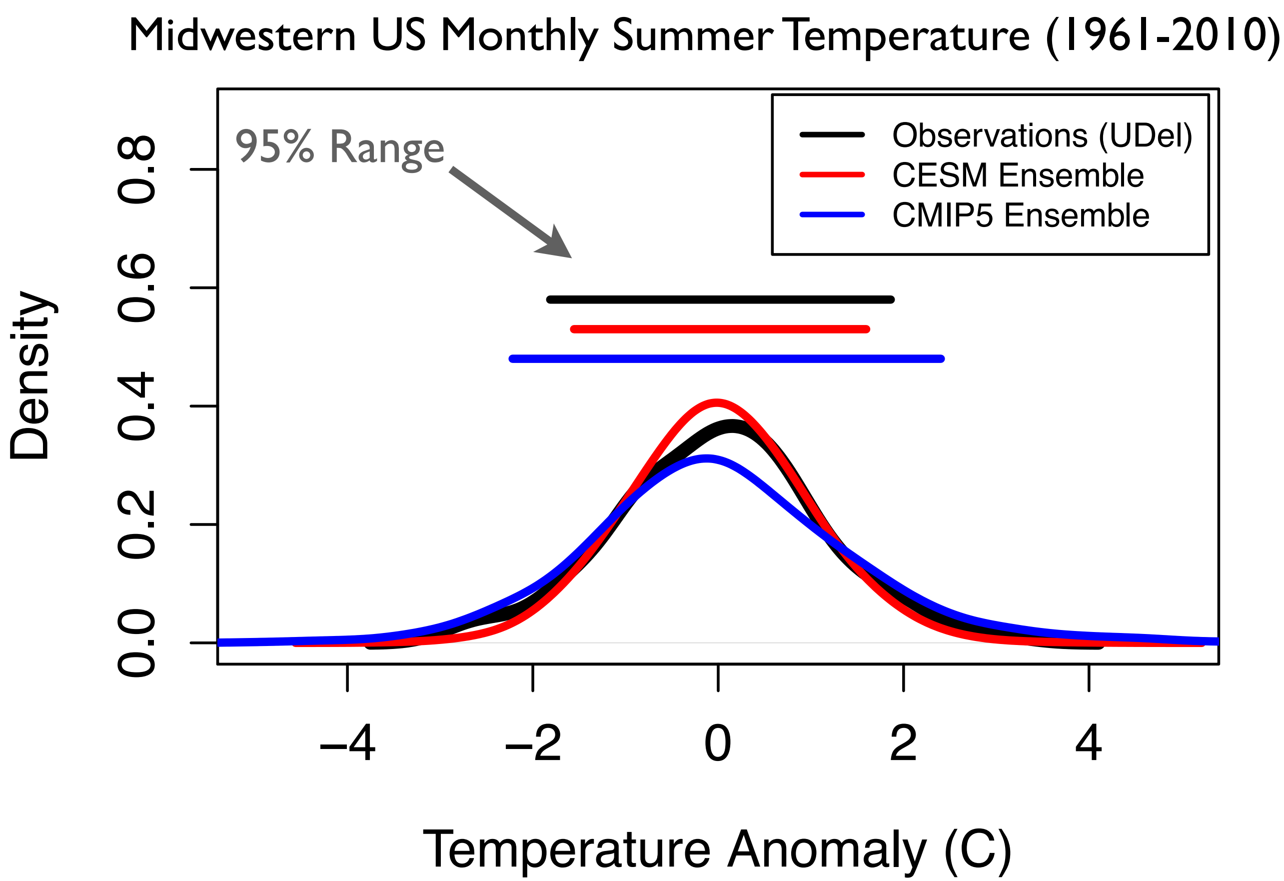
CESM Ensemble (50 members)



CMIP5 Ensemble (~40 members)



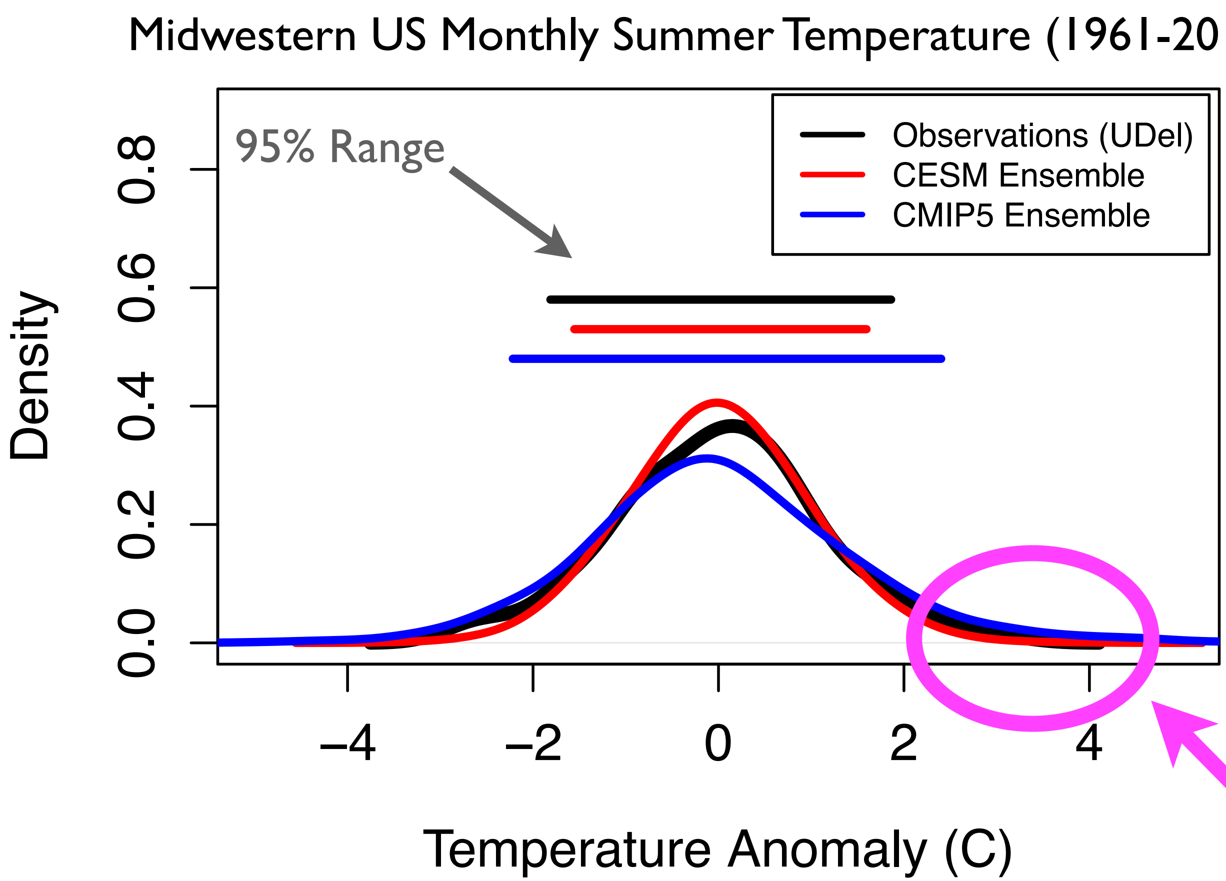
Evaluating CESM ensemble skill



Both ensembles generally capture observed statistics

- CESM overconfident
- CMIP5 underconfident

Evaluating CESM ensemble skill



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- CESM overconfident
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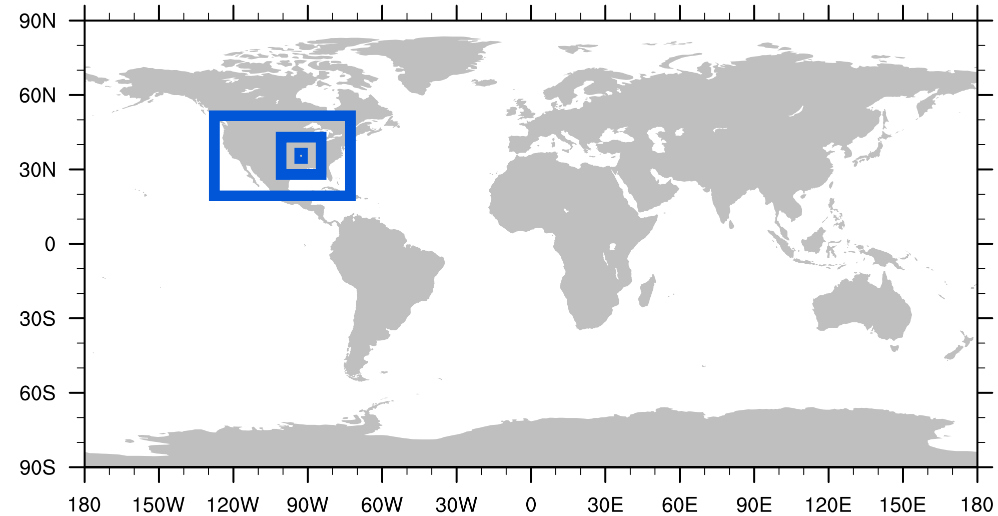
What about the tails?

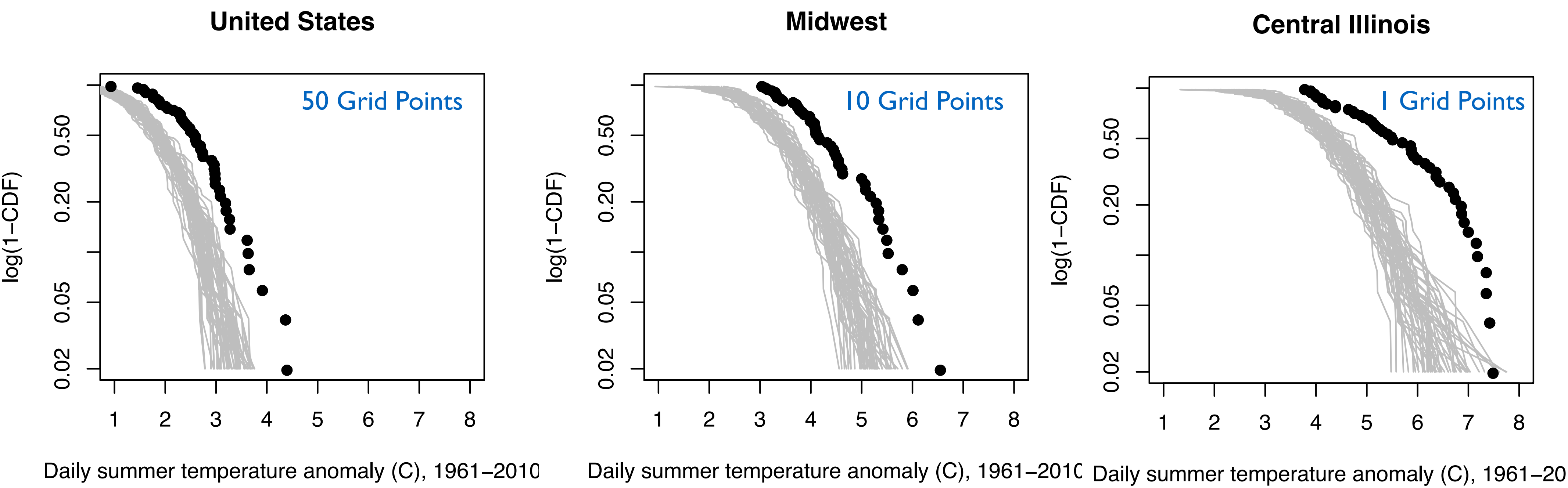
- Can we leverage CESM's flexibility to analyze skill in simulating tail area events?
  - particularly at high-temporal resolution (e.g. daily scales)?
- At what scales does the model show skill?
- What are the advantages/disadvantages of this ensemble approach?

Does CESM capture the extremes?

Distributions of summer block maxima of daily temperature (1961-2010)

Black —> Gridded Observations
Gray —> CESM ensemble

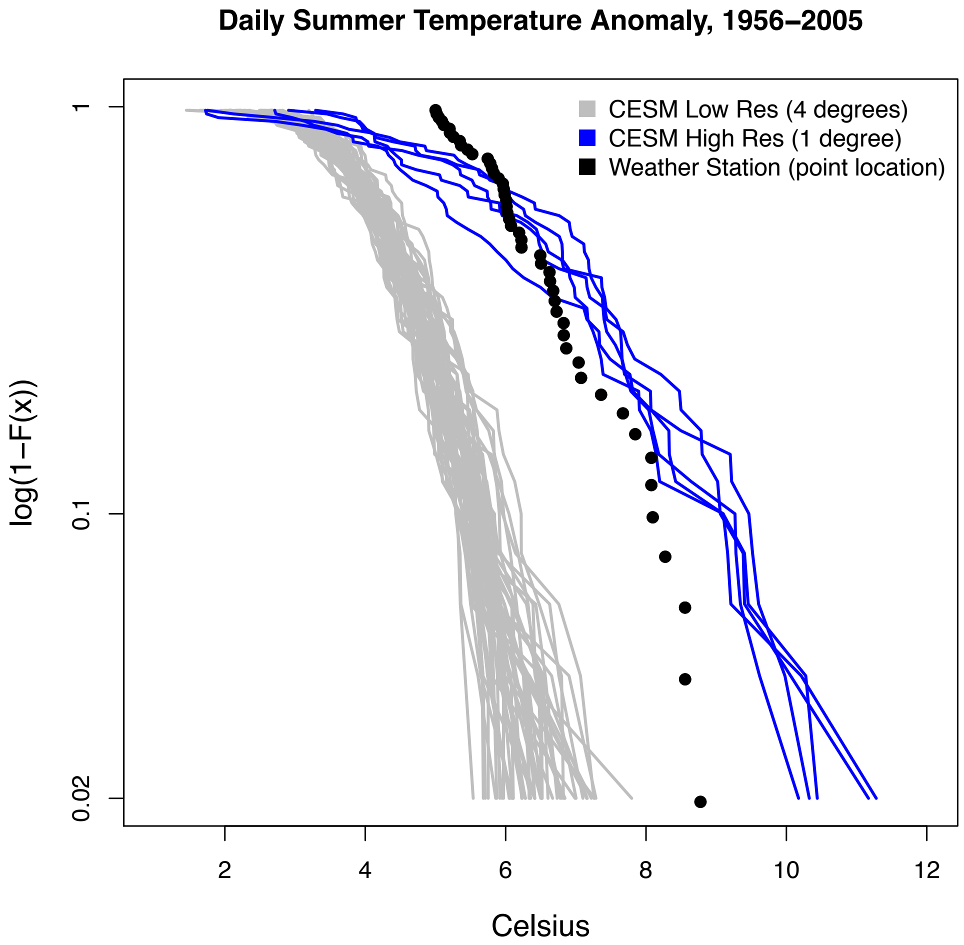


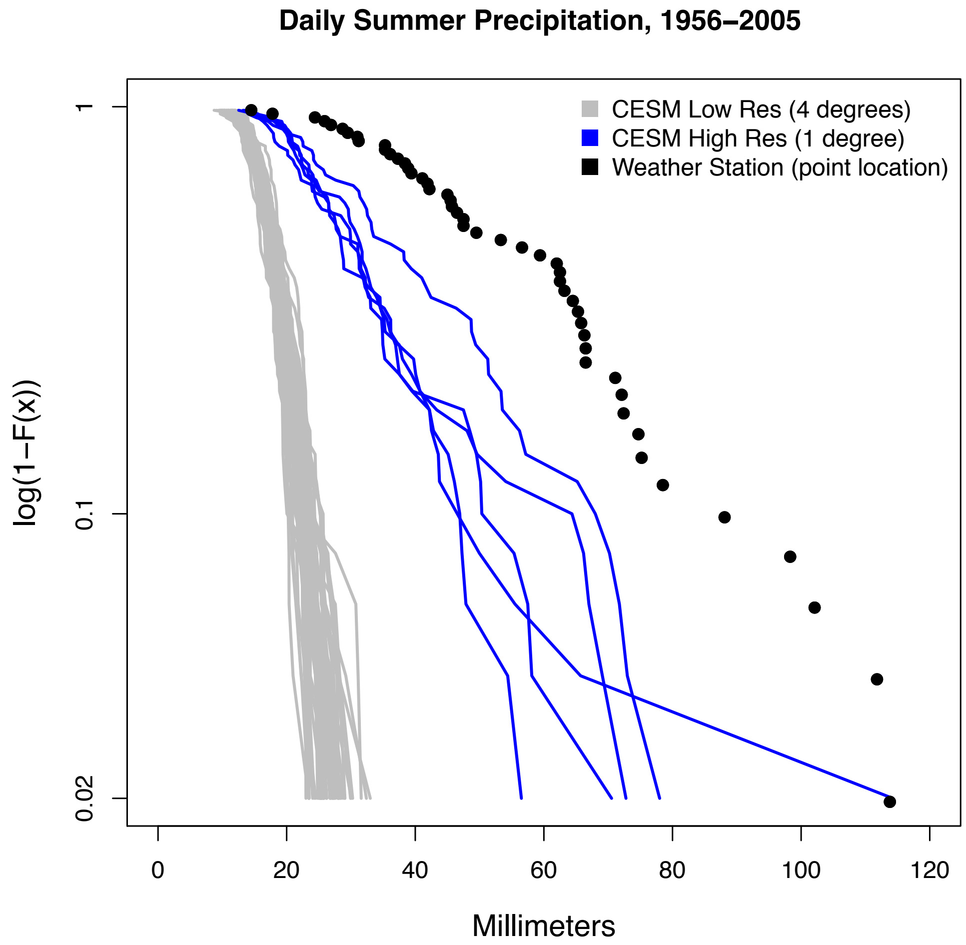


Low-resolution CESM under-estimates the tails, but captures the shape and scale
- Bias correction may be useful for regional-scale analysis of extremes

What is the effect of data/model resolution?

Distributions of summer block maxima of daily temperature (left) and precipitation (right) at a single location (Springfield Illinois)





Low resolution CESM shows skill for temperature, but not for precipitation

Relevance to SDWG

Fostering dialogue

Focusing the science questions on end-user needs
- Ensemble targeted at decision-relevant metrics and uncertainties

Needs for CESM development

Relationships between model resolution and skill
- particularly for extremes

Relevant CESM simulations

Work represents application of large ensemble approach with emphasis on decision-relevant climate metrics and uncertainties

New CESM linkage code

Ensemble output is readily adaptable to impacts analysis
—> Next steps: sea-level rise patterns, agricultural damages

Conclusions

We utilize CESM to characterize initial conditions (or internal variability) uncertainty using a self-consistent modeling methodology

- features fully-coupled spin-up and hindcasts/projections using the RCP8.5 scenario
- accounts for ocean state variability (important for decadal scale predictability)

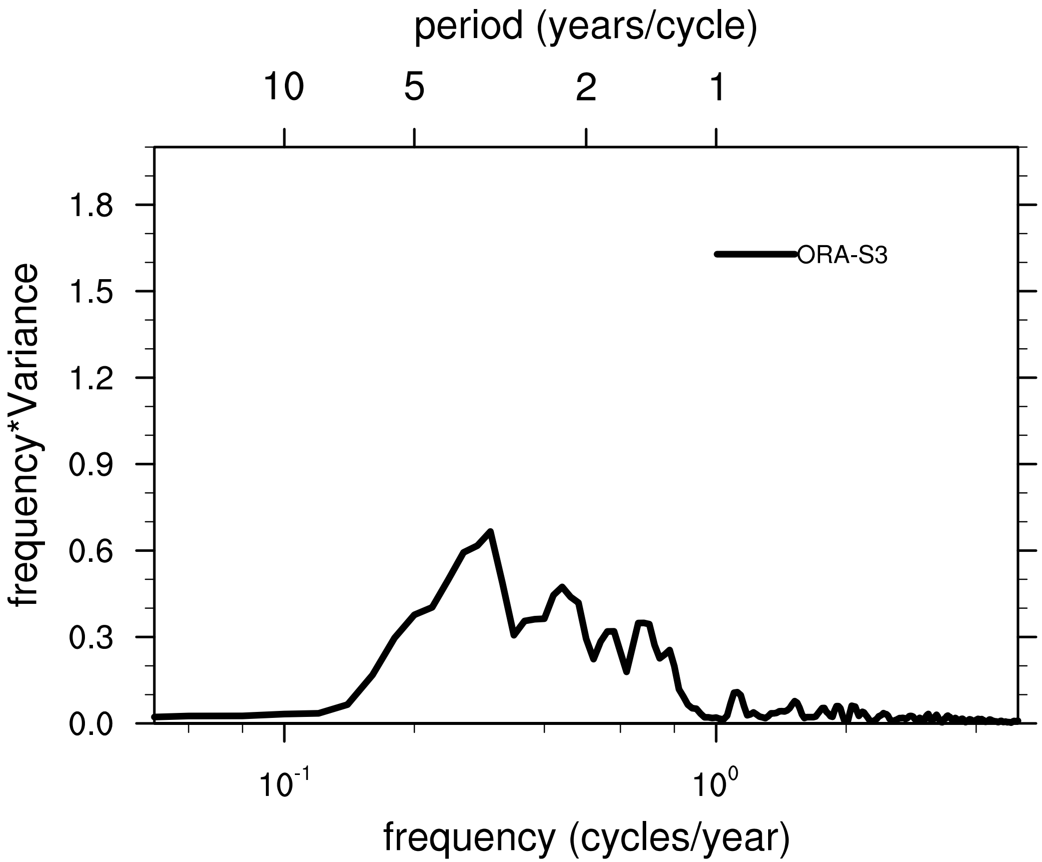
Key Results

- The low resolution CESM shows skill in simulating interannual variability of key climate metrics across multiple spatial scales
- Ensemble range at regional scales is consistent with CMIP5
- The ensemble under-estimates the magnitude of extremes (tail events), but captures the general features of observed distributions of temperature and precipitation

Supplemental Slides

Does CESM capture the dynamics controlling regional climate?

Power spectrum of monthly SST anomalies in the Nino3 Region



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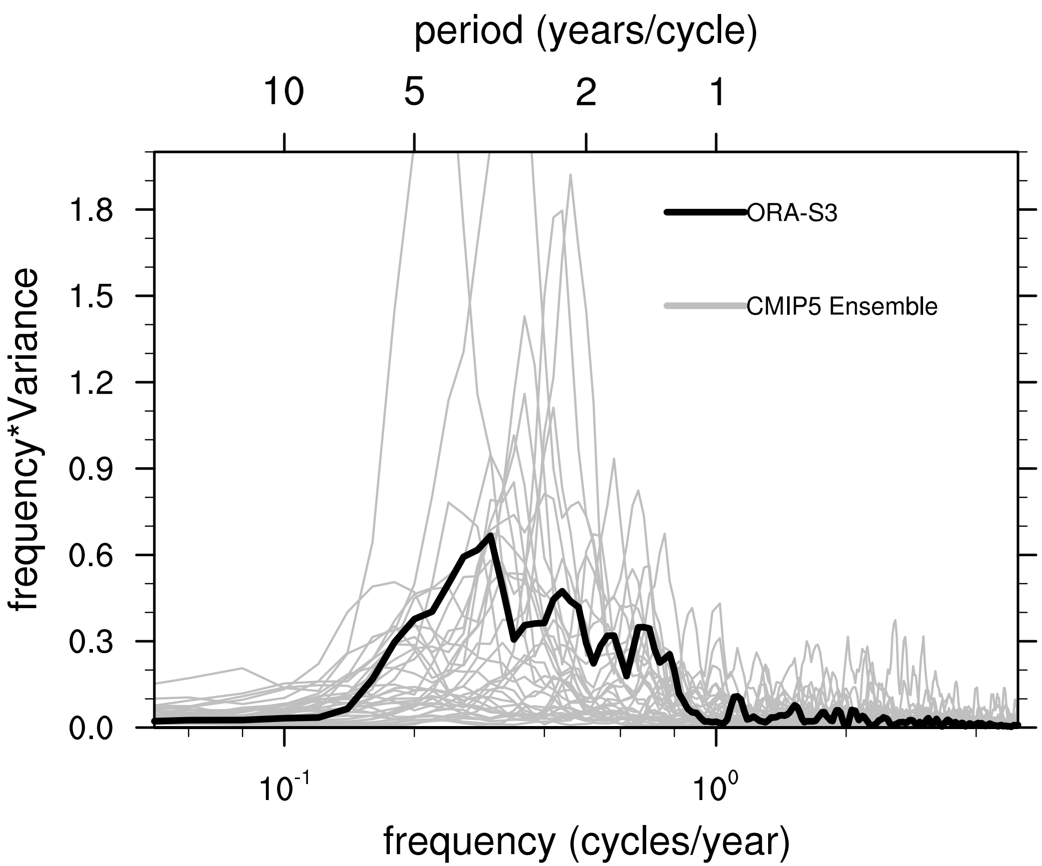

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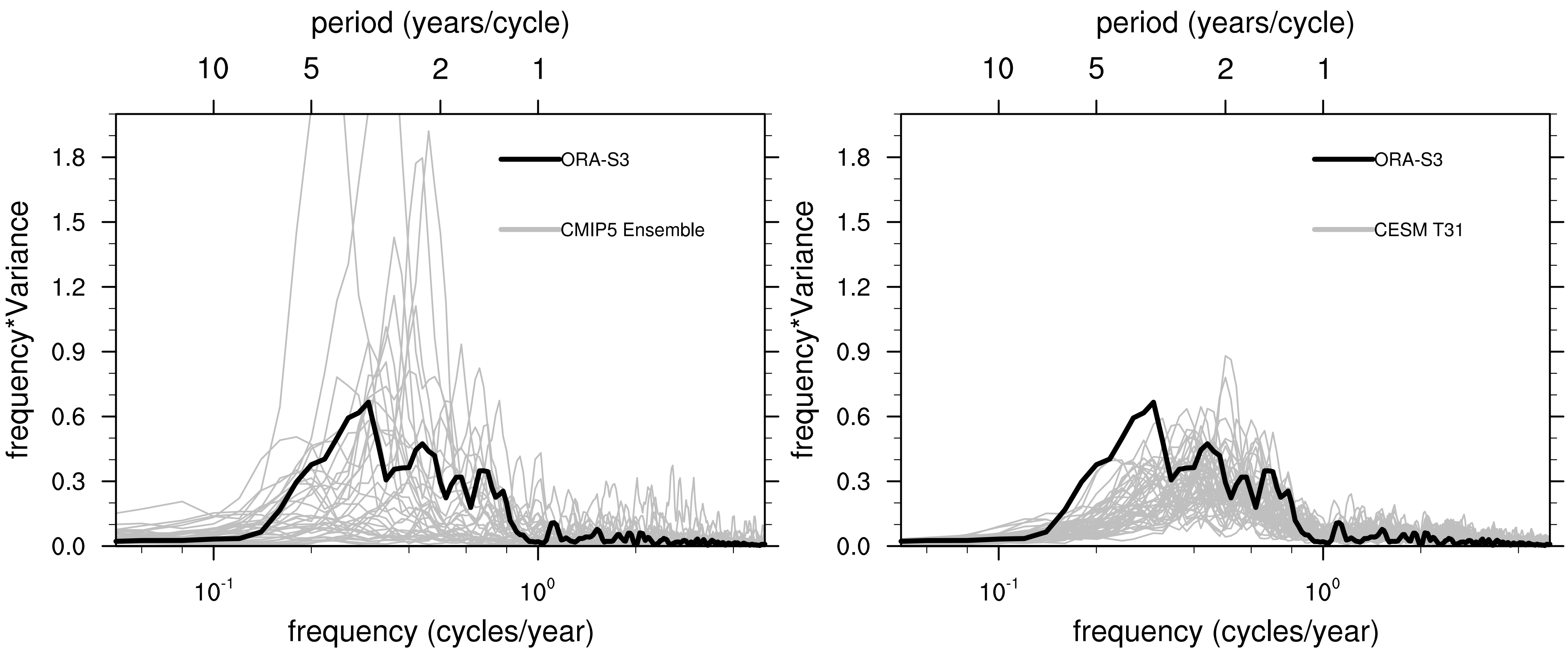


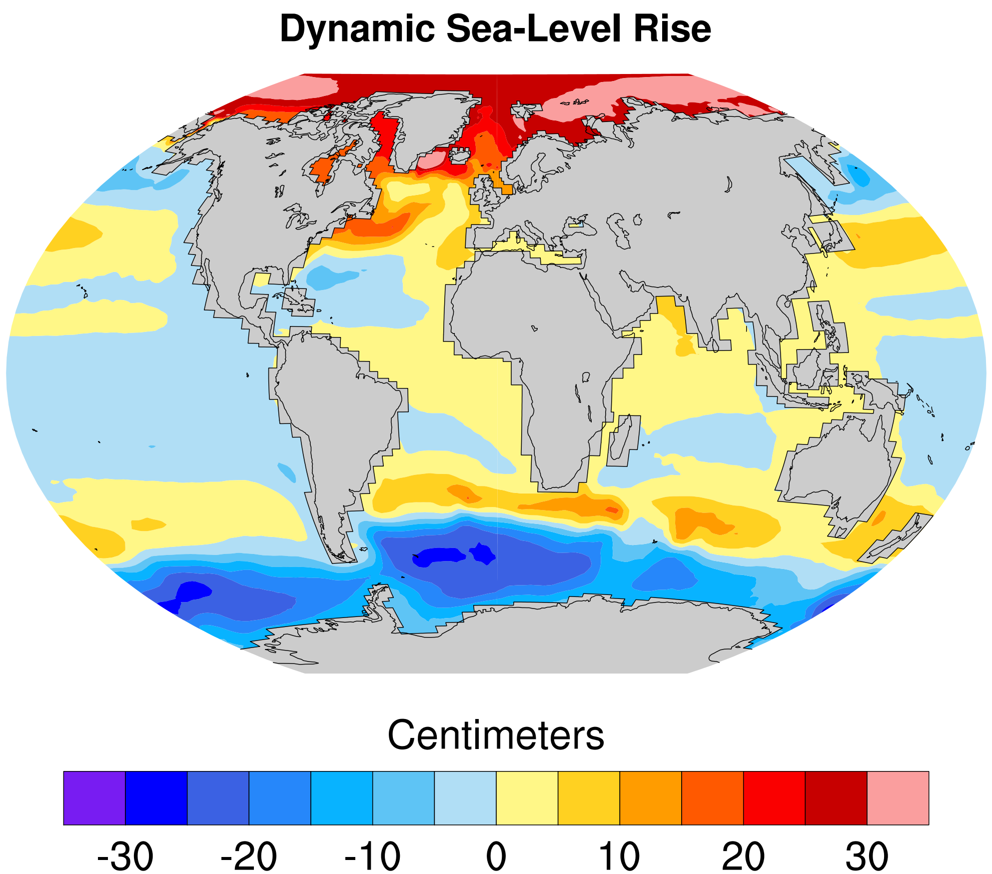
Low resolution CESM simulates realistic ENSO variability

- ENSO teleconnections important for remotely controlling regional-scale precipitation and temperature variability

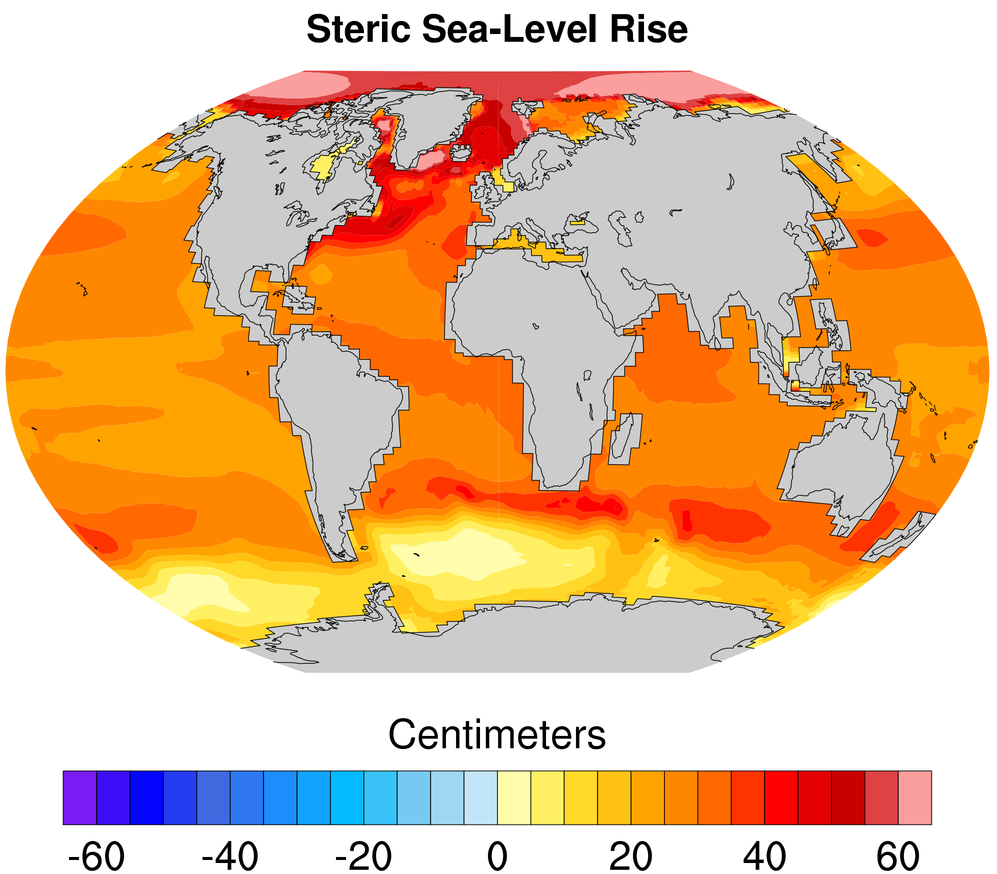
Sea-level Rise in CESM for the RCP8.5 scenario

CESM ensemble provides a useful tool for analyzing spatial patterns of sea-level rise and variability due to dynamic and steric effects

- Includes internal variability of the full-ocean



Ensemble Mean (2081-2099)



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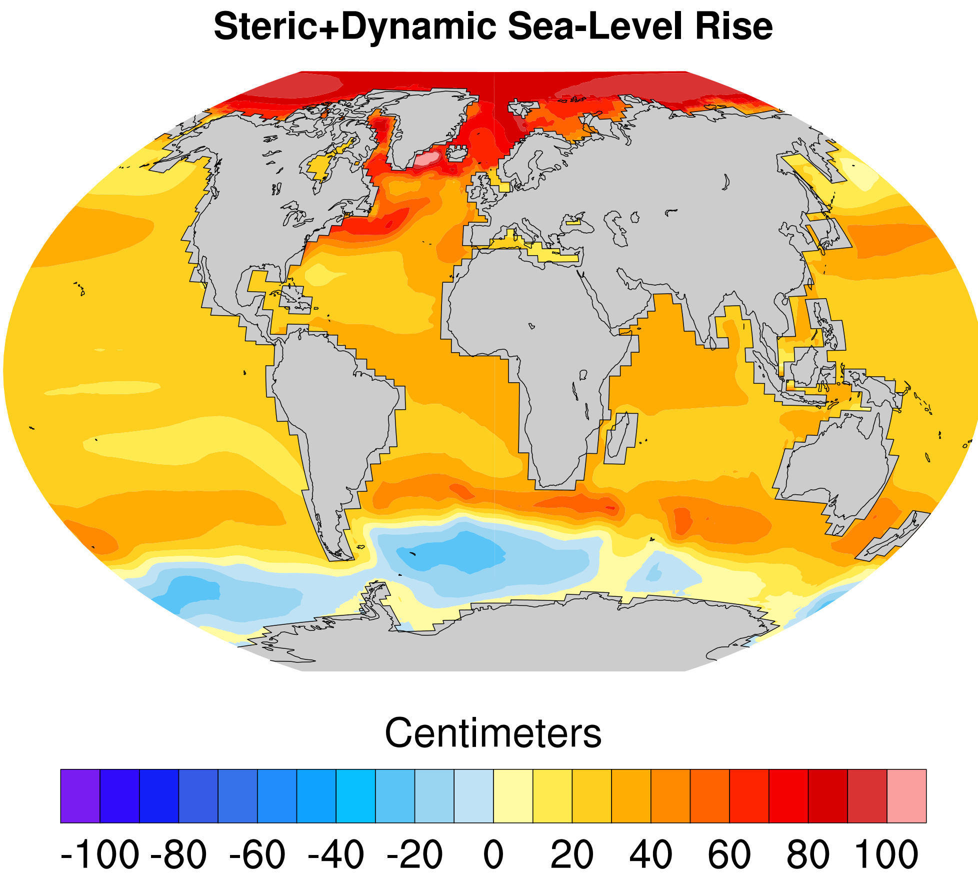
Sriver et al., In Preparation

Sea-level Rise in CESM for the RCP8.5 scenario

CESM shows large spatial variations in Steric+Dynamic SLR.



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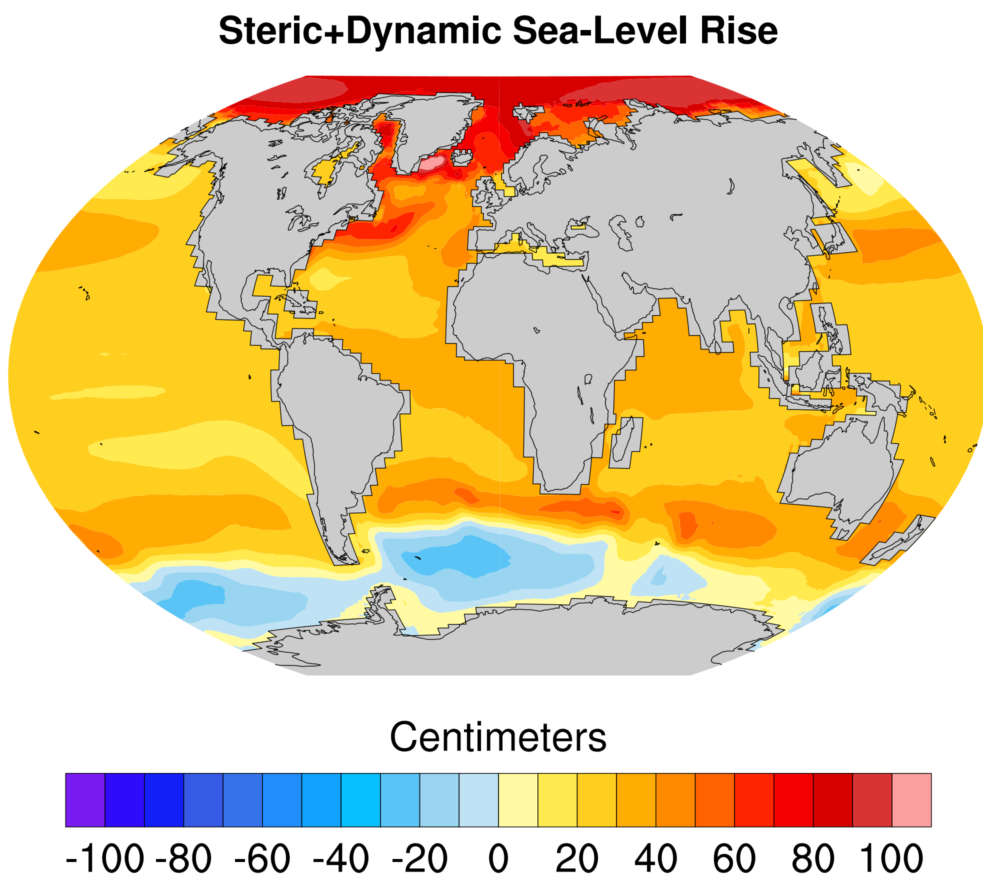

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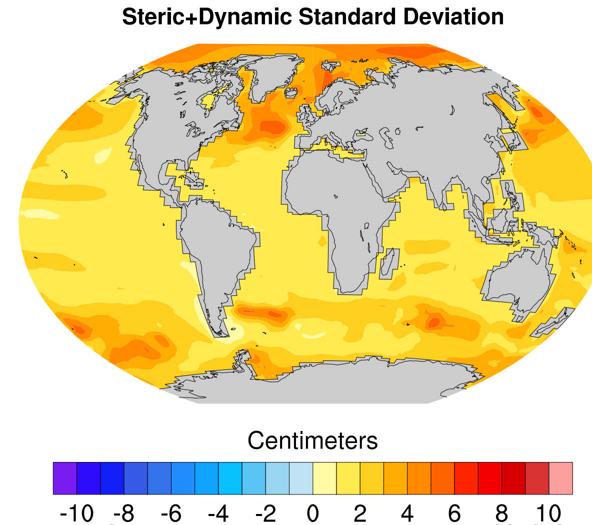
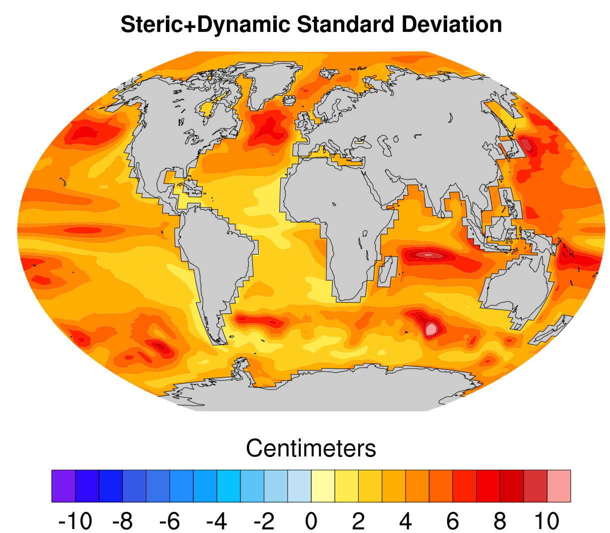


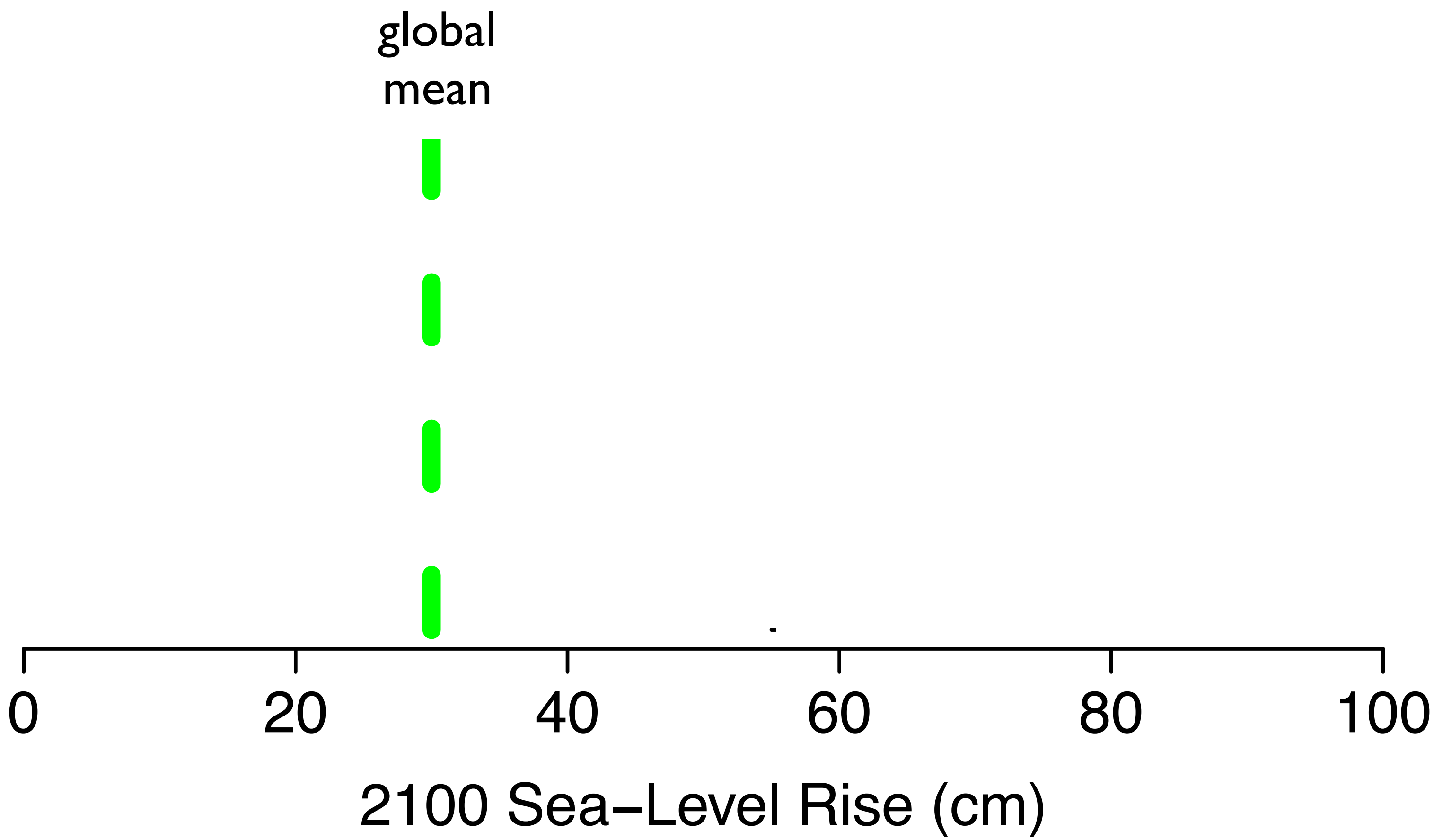
Ensemble Standard Deviation (2081-2099)



Ensemble Standard Deviation (2099)

- Internal model variability leads to relatively large SLR annual and decadal variability

Spatial Patterns in SLR Projections



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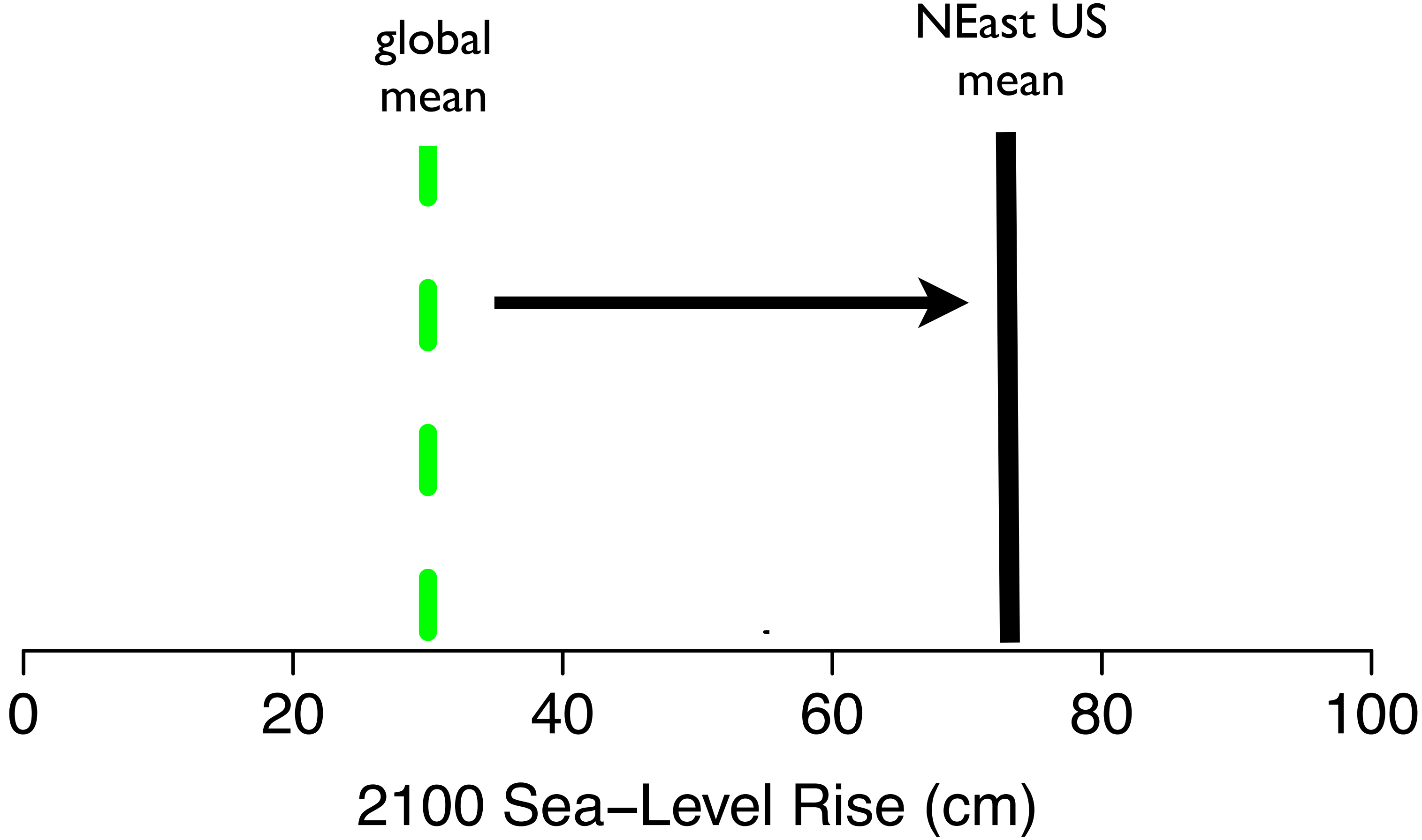

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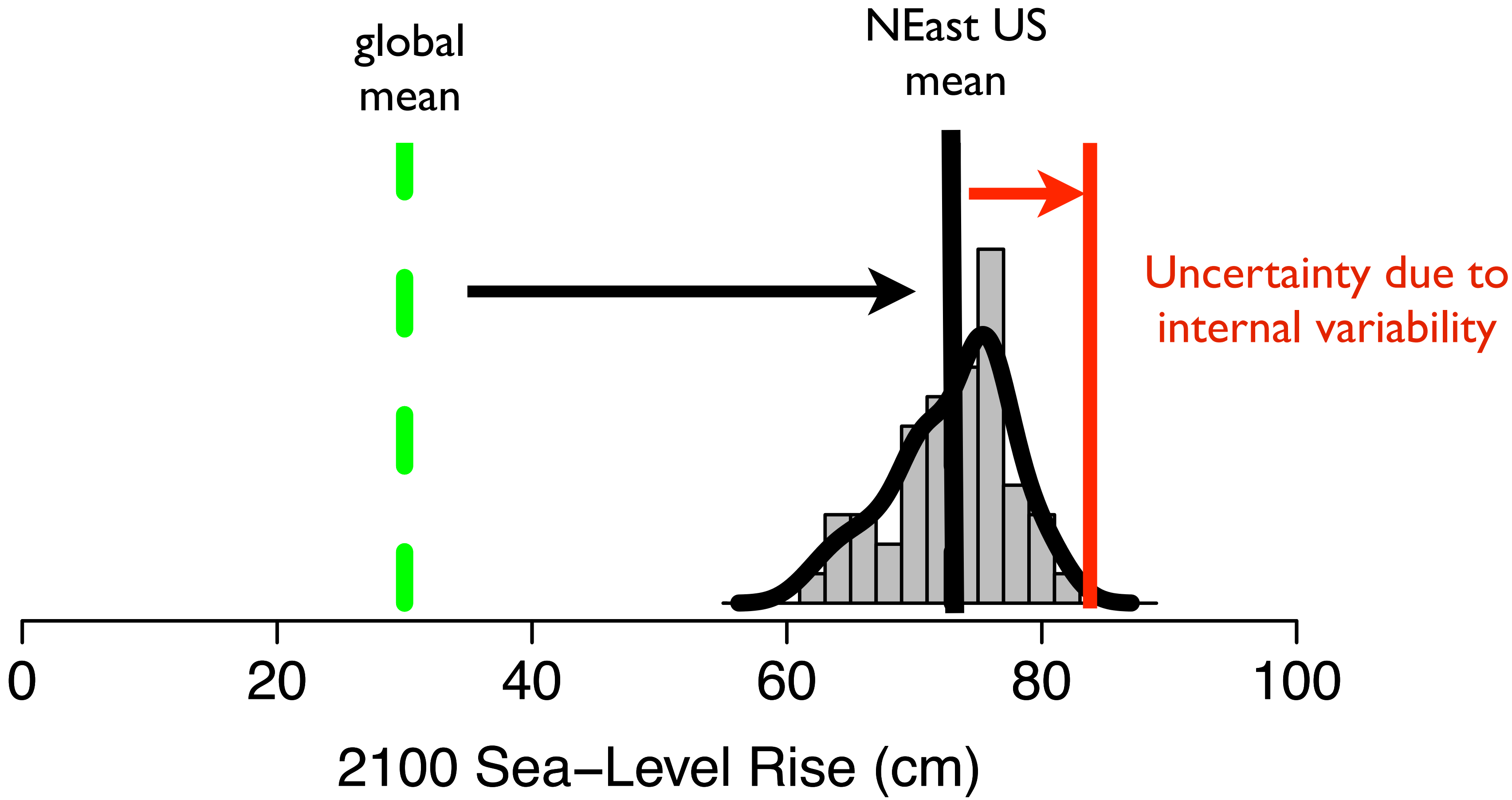

Sriver et al., In Preparation

- Regional projections can differ substantially from the global mean
- Small underestimations of SLR uncertainties can result in major downward biases of local flooding risks (Sriver et al., 2012 - Clim Change)
- Global mean projections of steric SLR are inadequate for regional/local risk and impacts assessments