Assessing skill of a low-resolution CESM ensemble

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UQ informs likelihood estimates of extreme events

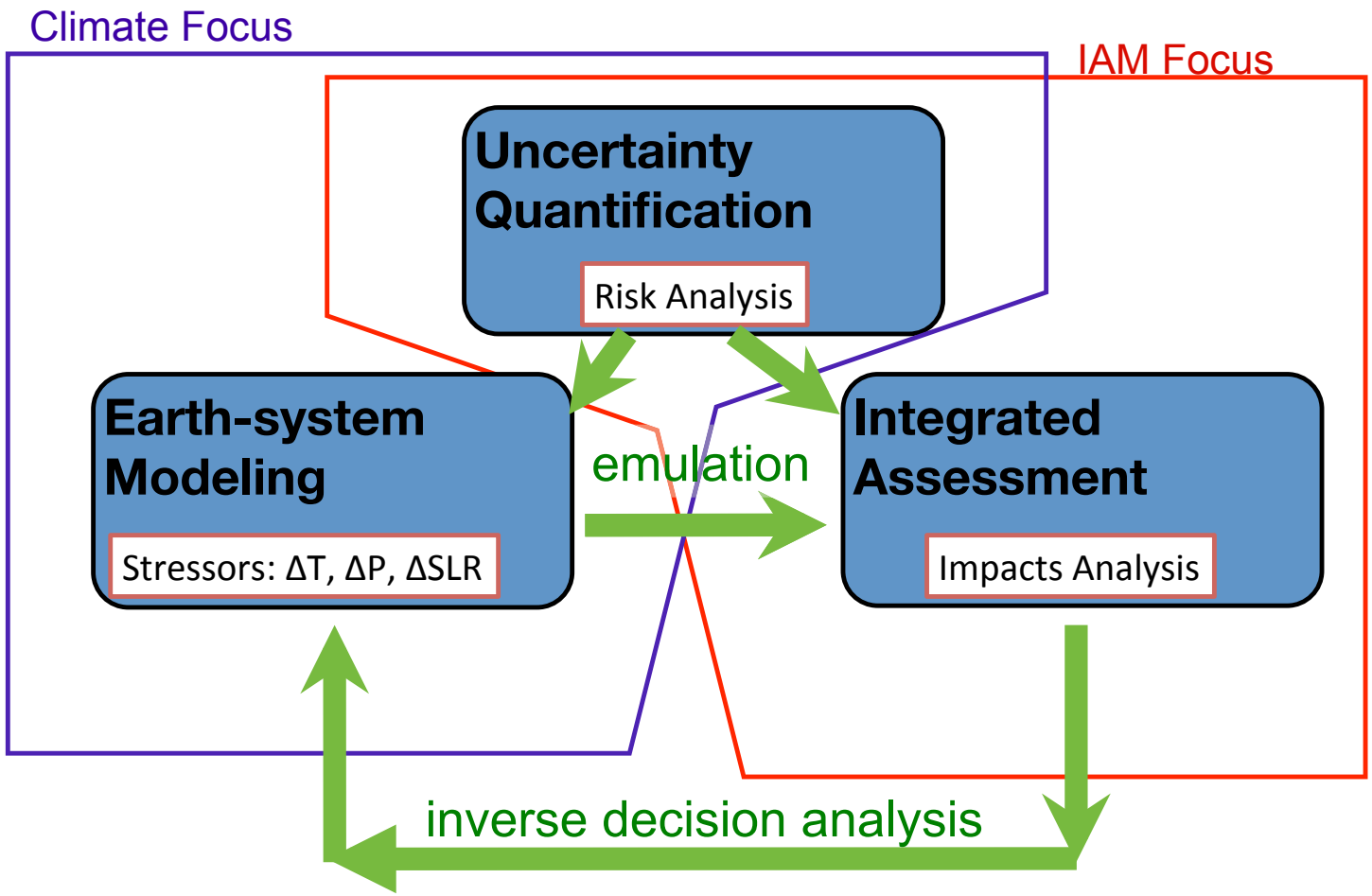
IA requires robust treatment of decision-relevant uncertainties to address impacts and damages associated with low-probability, extreme climate events

source: AP/Seth Perlman

source: NOAA

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

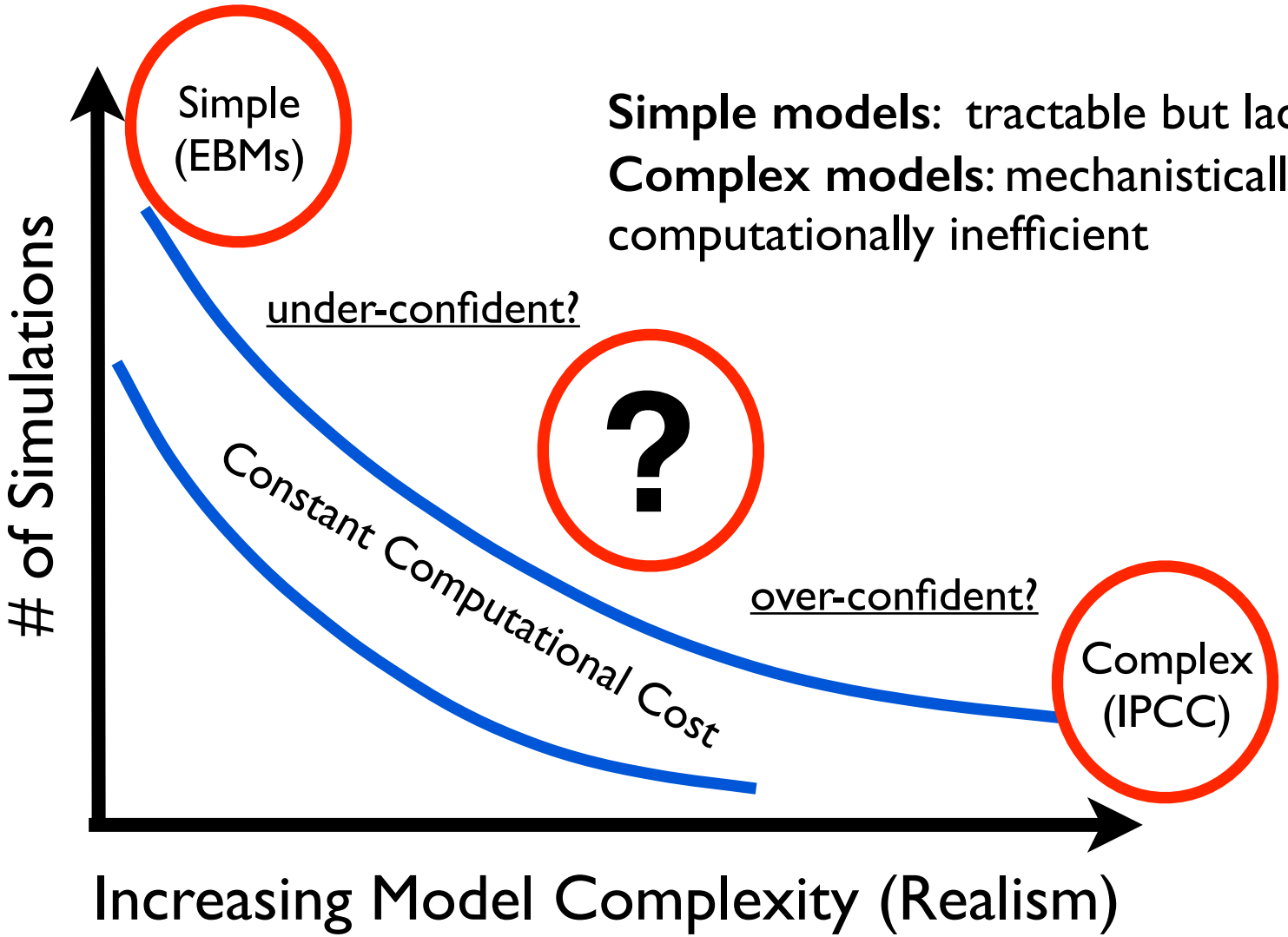
Uncertainty Quantification provides an important link between Earth-system modeling and Integrated Assessment, Risk Analysis and Impacts Analysis



Questions:

1. What uncertainties are important?
2. What drives the uncertainties?
3. How do the uncertainties affect decision-relevant metrics and impacts?

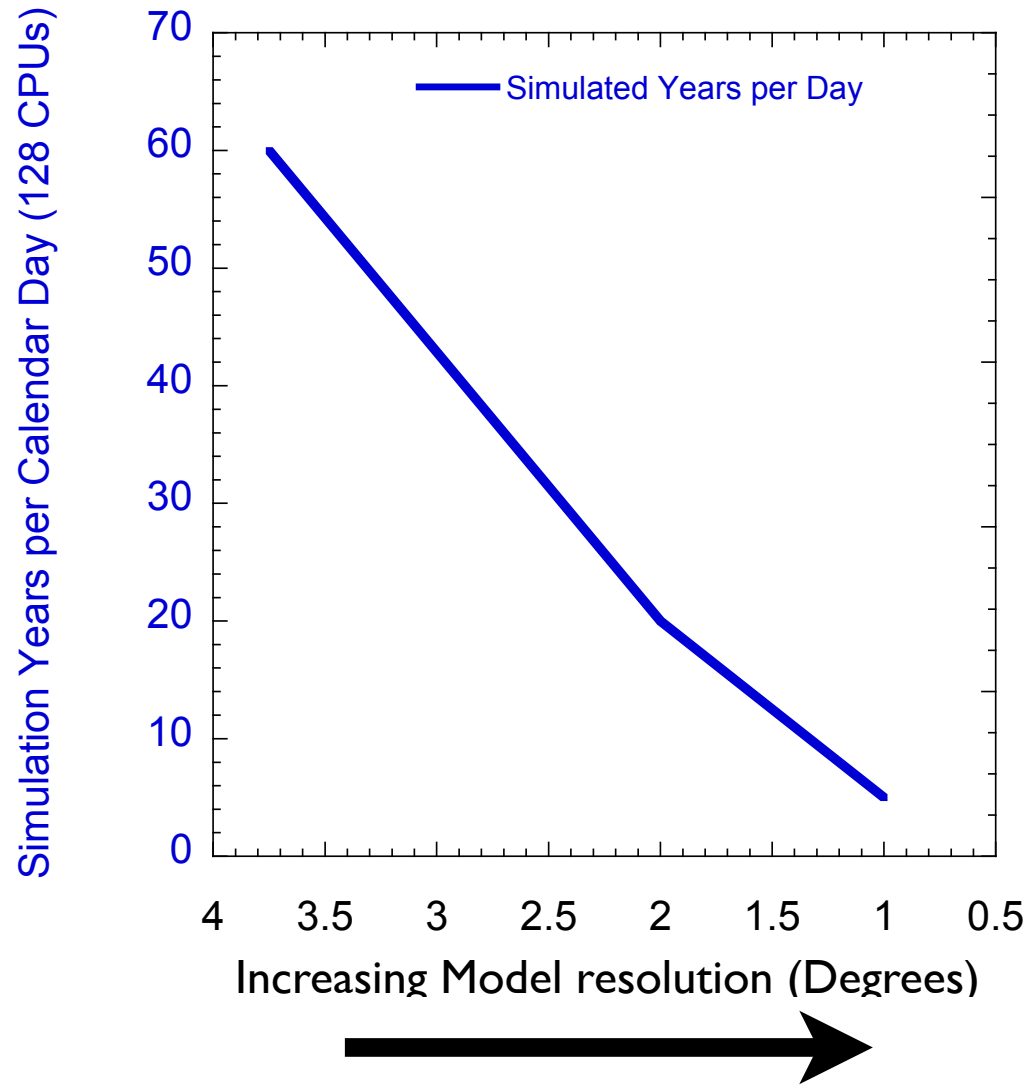
Tradeoff between model realism and computational tractability



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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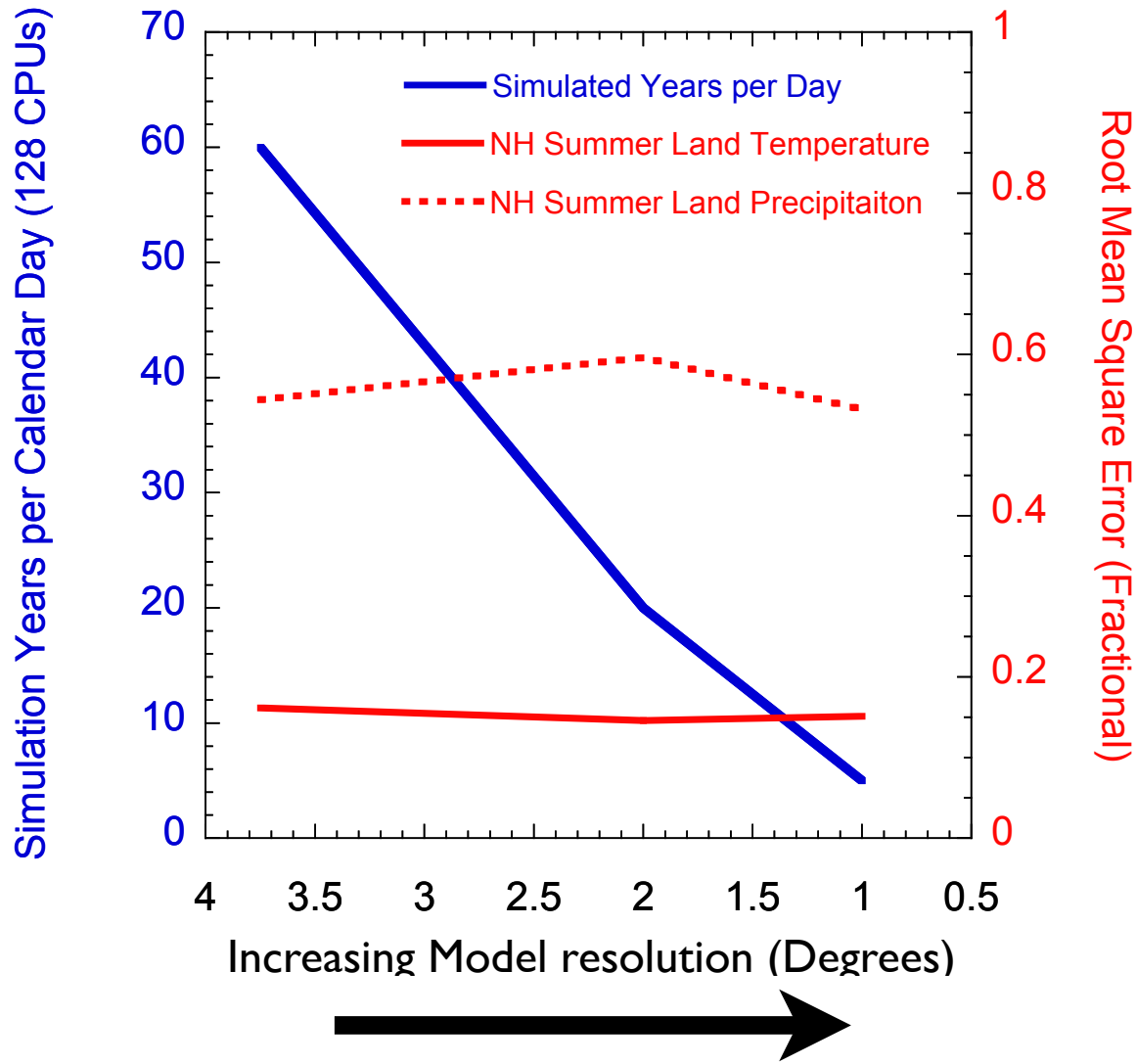
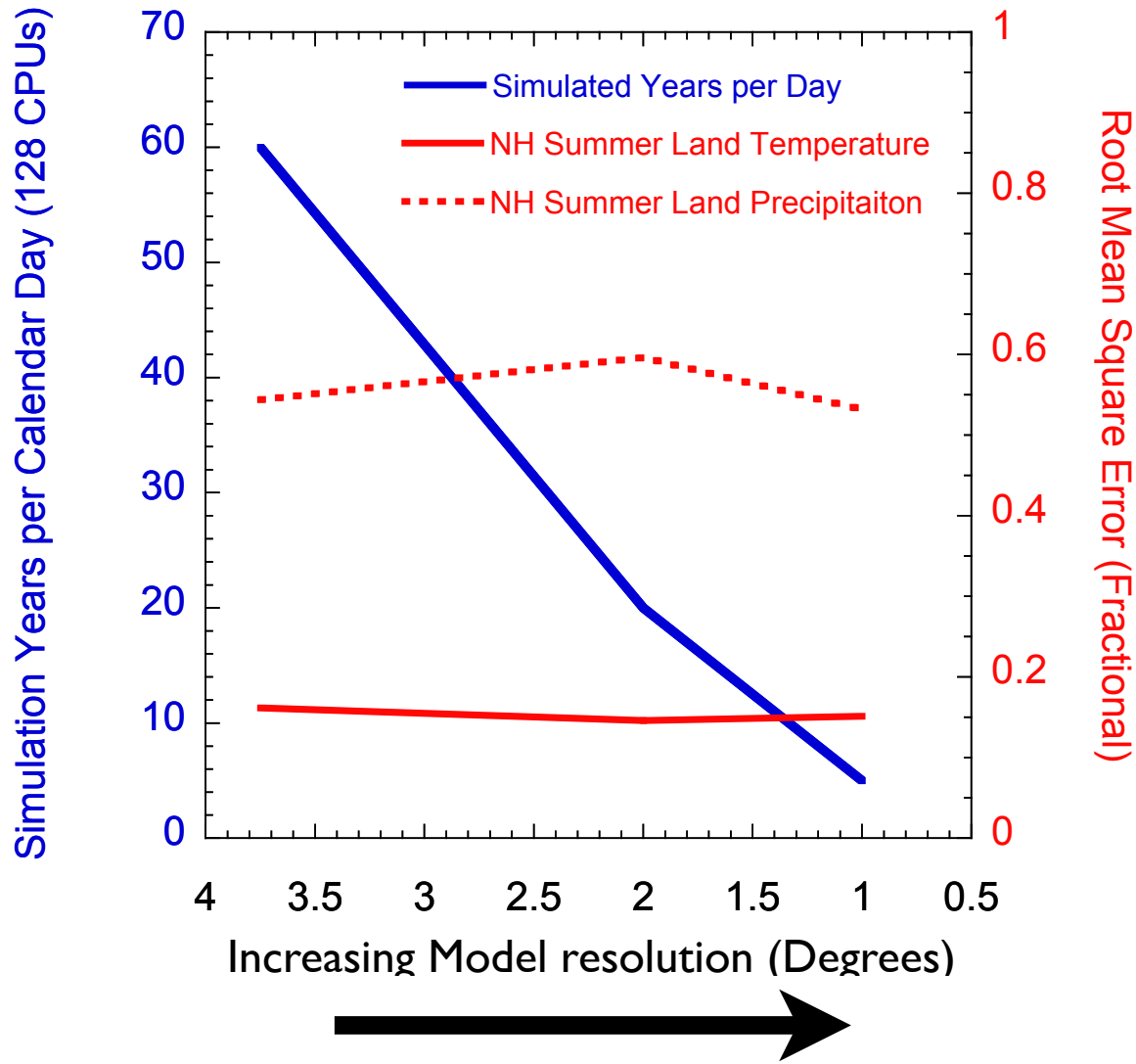


Example: Computational trade-off in CESM

Computational demand increases with resolution

CESM skill appears relatively insensitive to resolution for **some** key climate variables



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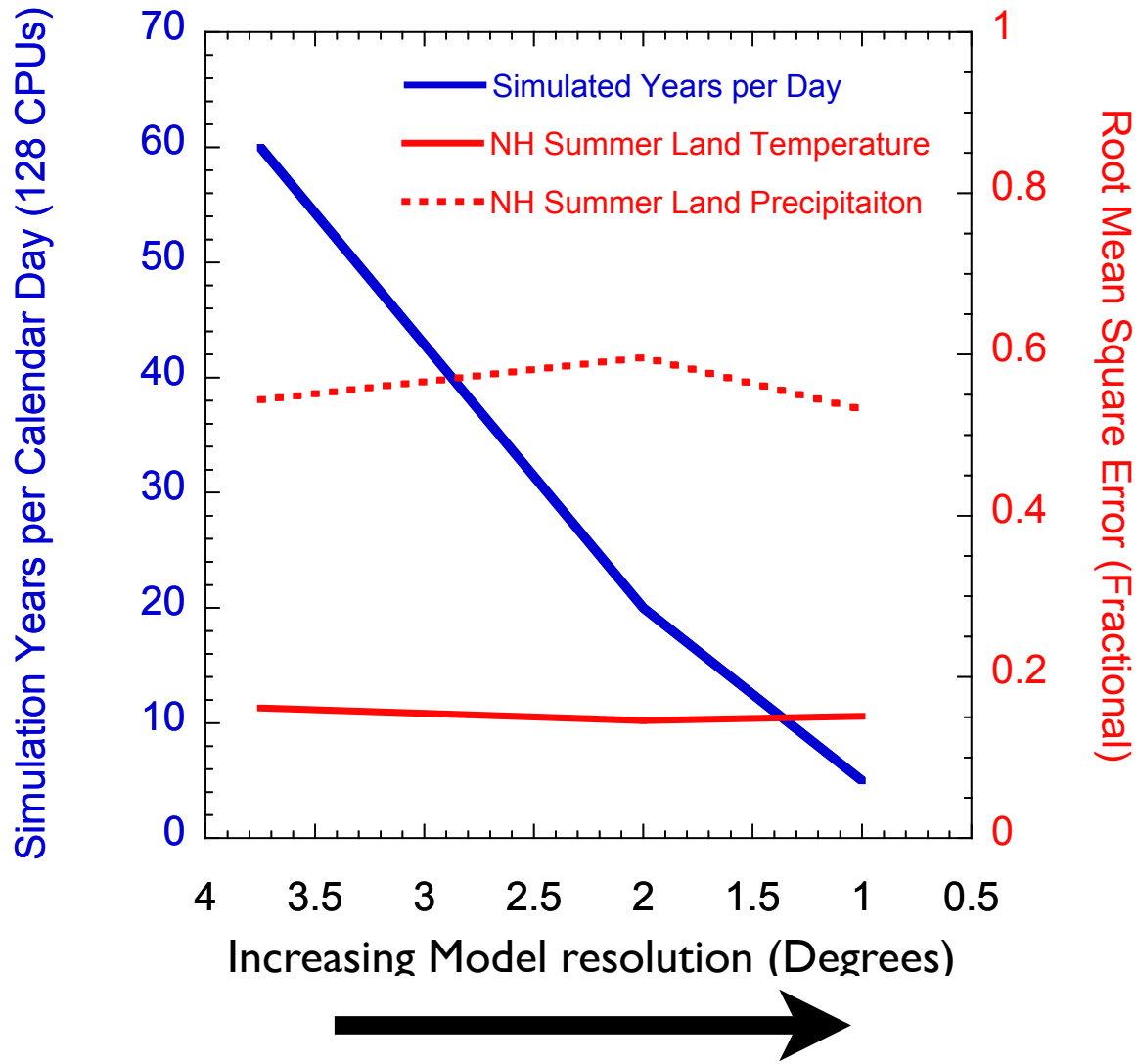


Low-resolution CESM may potentially provide "sweet spot" to Computational Tradeoff

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

Connecting CESM to integrated assessment and impacts/risk analysis

Uncertainty Quantification to inform decisions

- 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

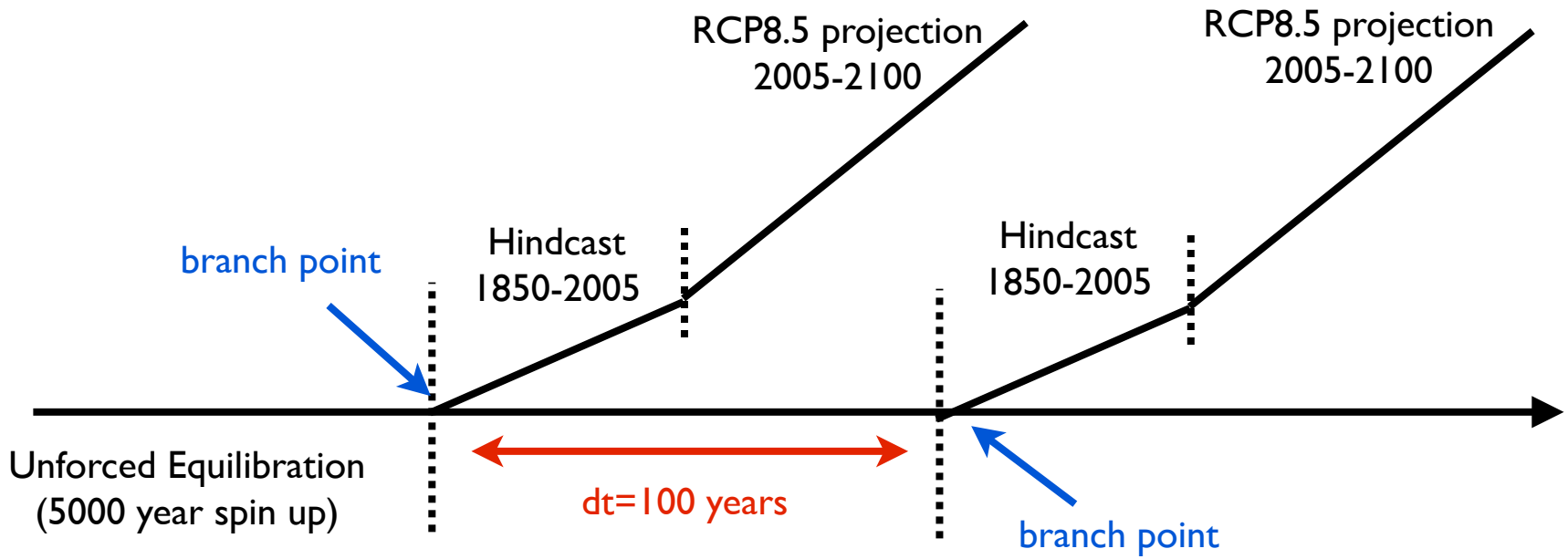
CESM ensemble of hindcasts and projections

- 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 on Evergreen)
    - 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

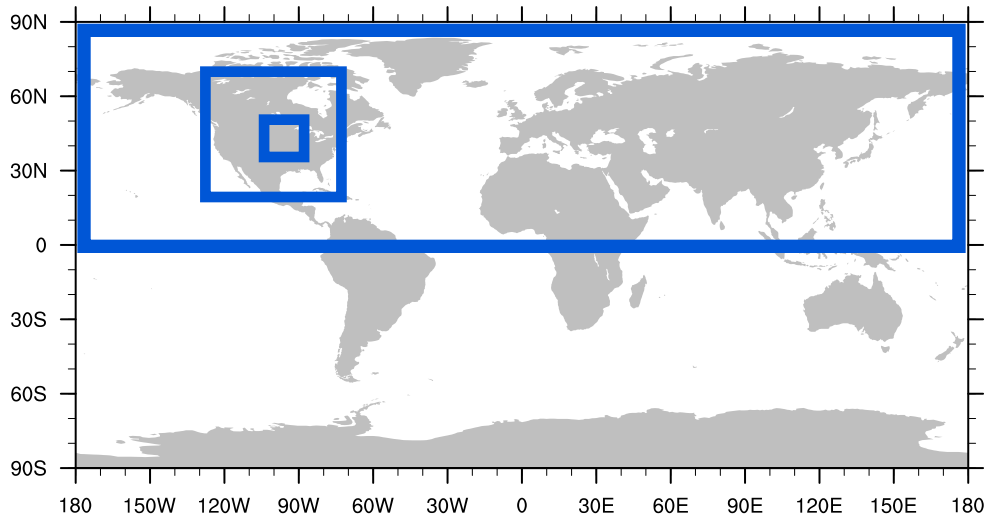
- enables a self-consistent method for analyzing the effect of unforced variability
  - features consistency between atmosphere/ocean states
  - enables analysis of multiple spatial and temporal scales



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

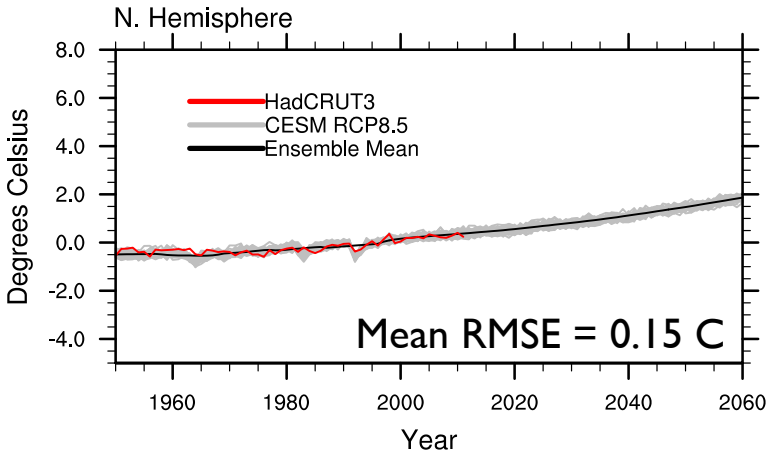
- Silent on other uncertainties:
  - parametric uncertainties, forcing scenarios, different model structures

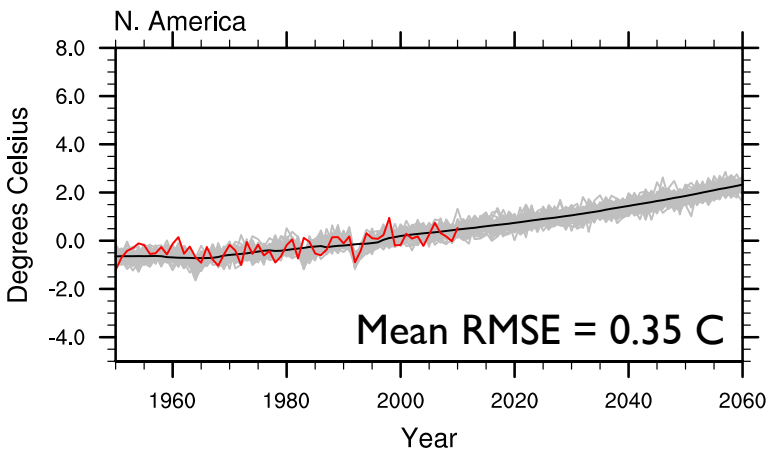
N. Hemisphere Summer (JJA) Temperature

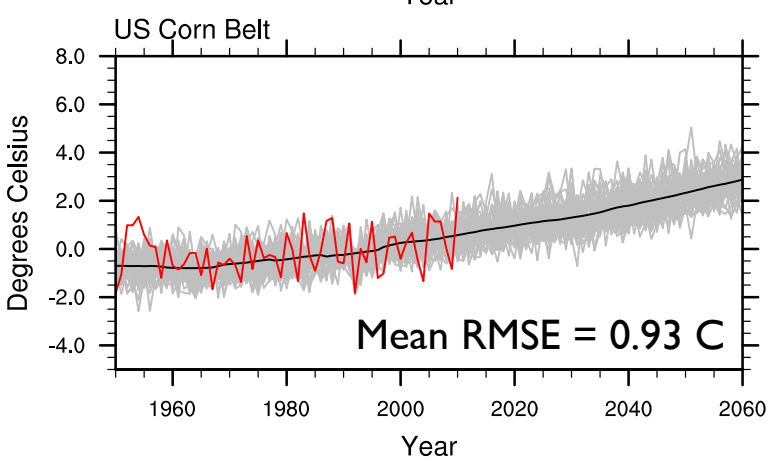


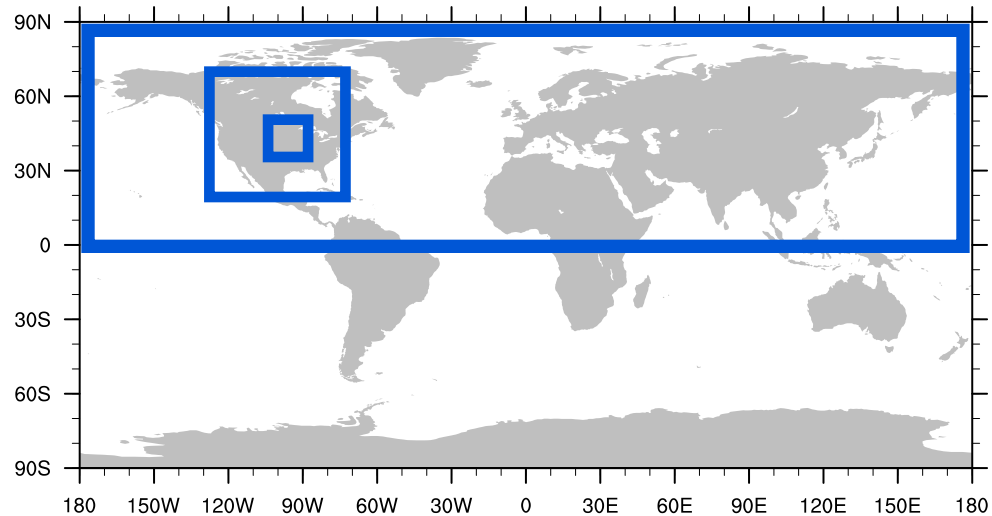
N. Hemisphere Summer (JJA) Temperature

CESM Ensemble (50 members)









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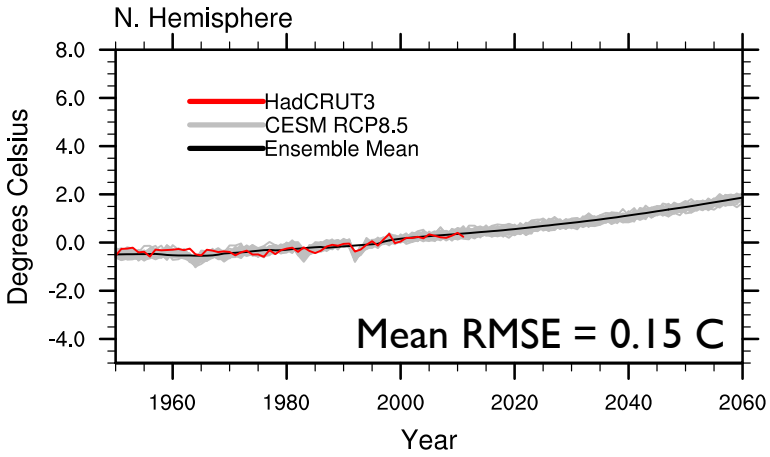
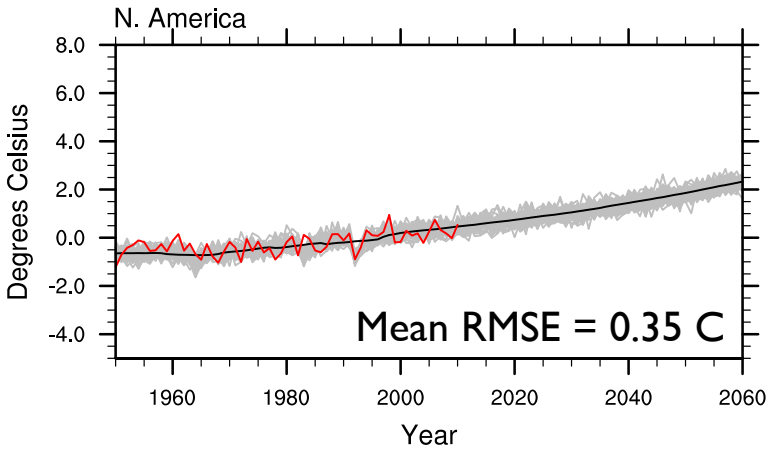
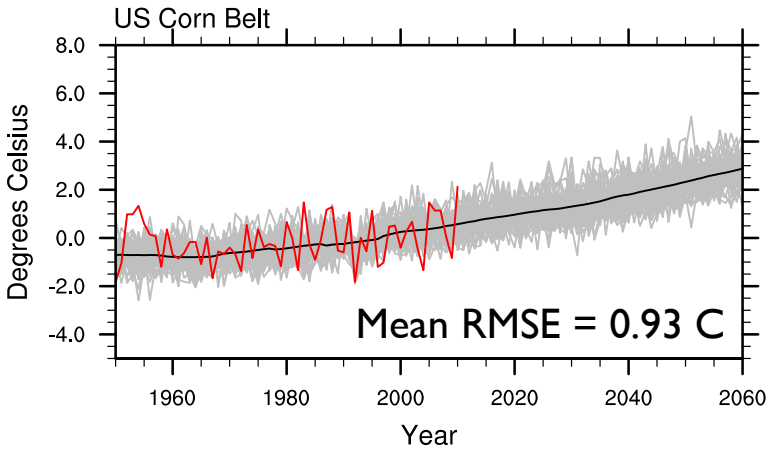
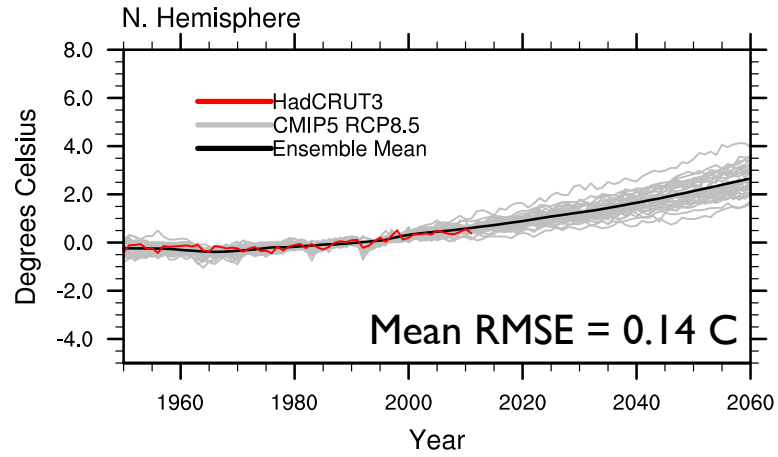
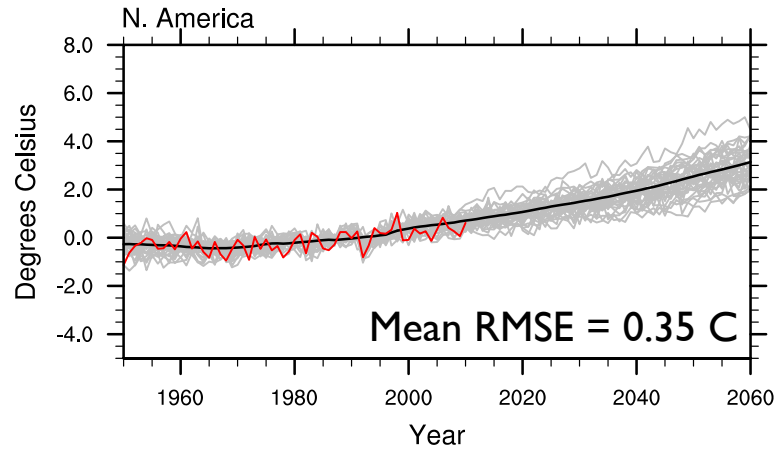


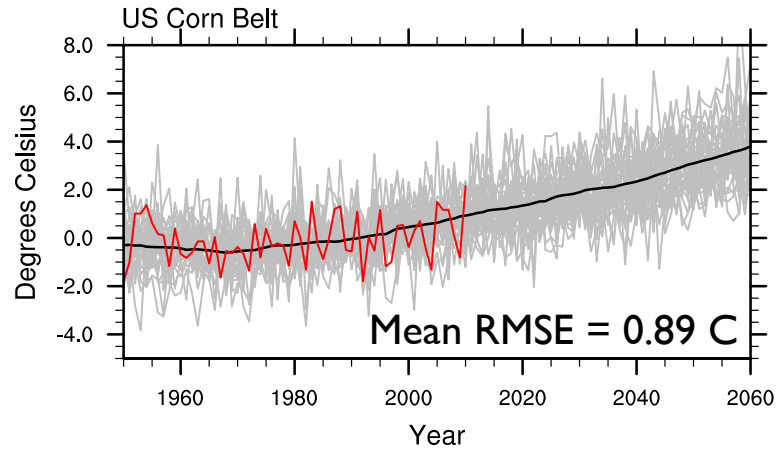




CMIP5 Ensemble (~40 members)

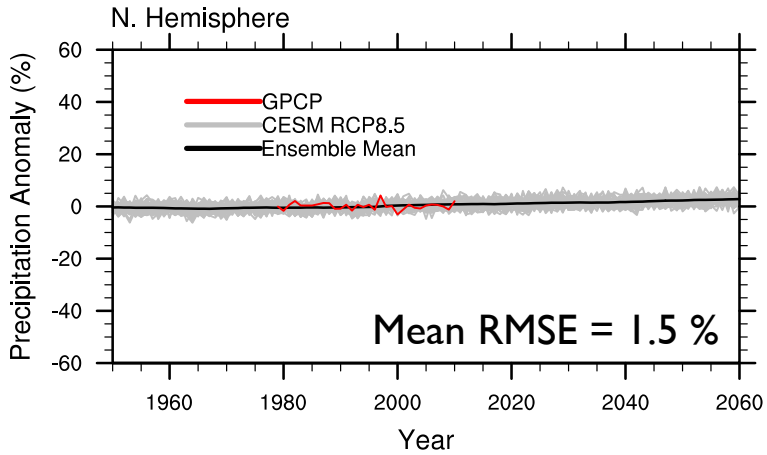


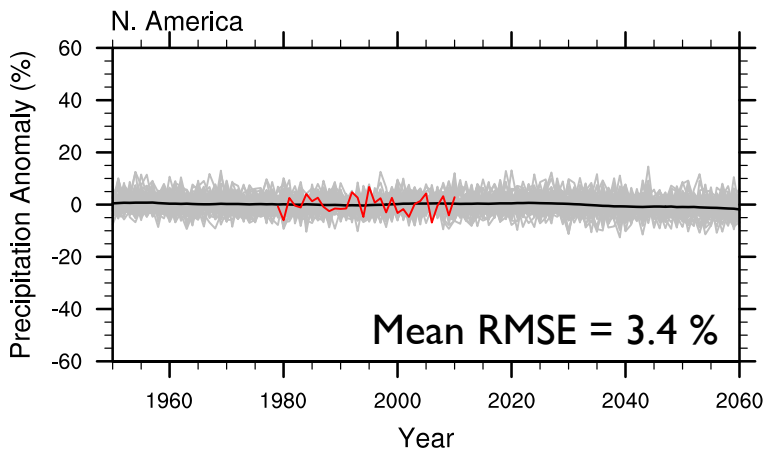


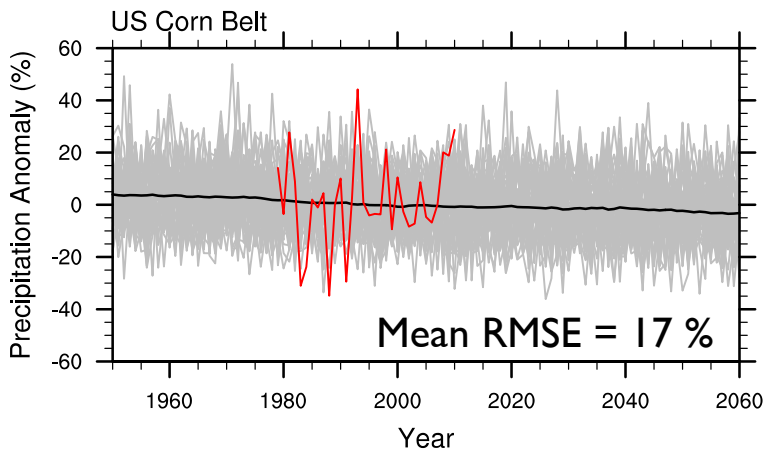


N. Hemisphere Summer (JJA) Precipitation

CESM Ensemble (50 members)







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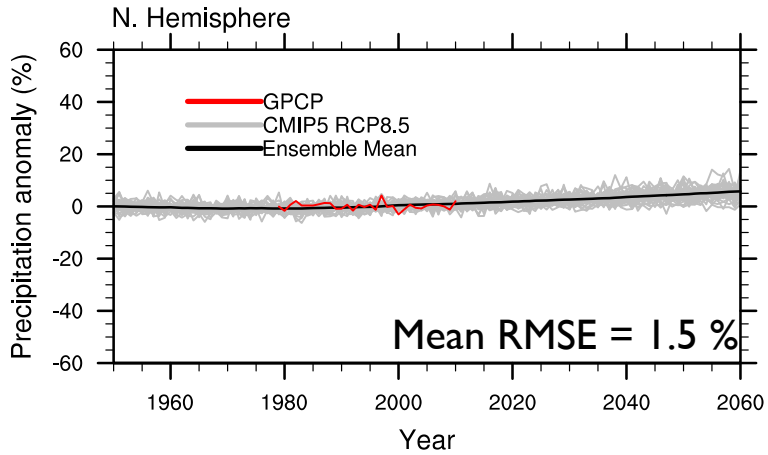
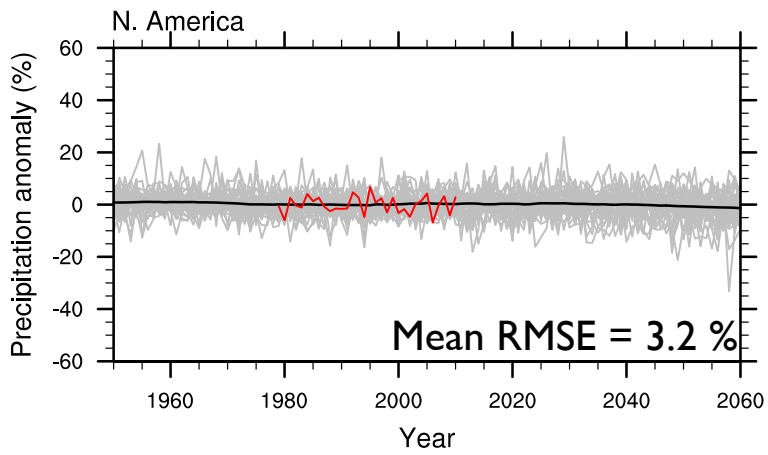
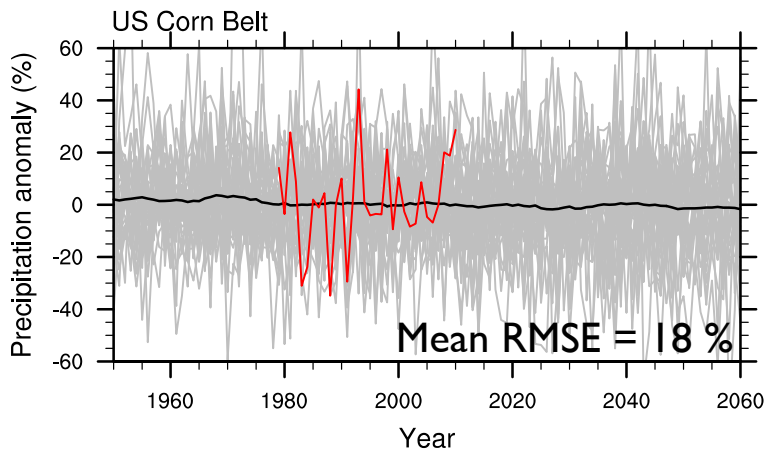
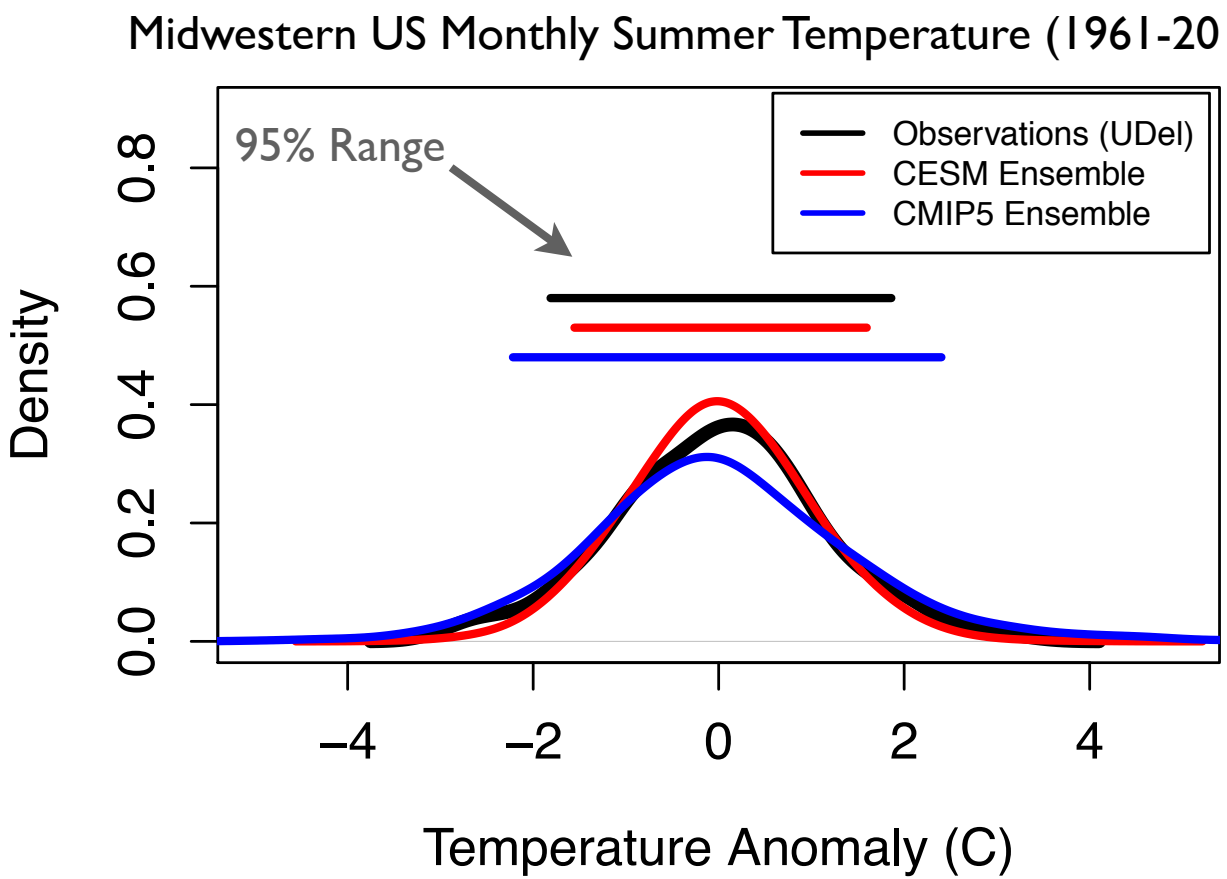






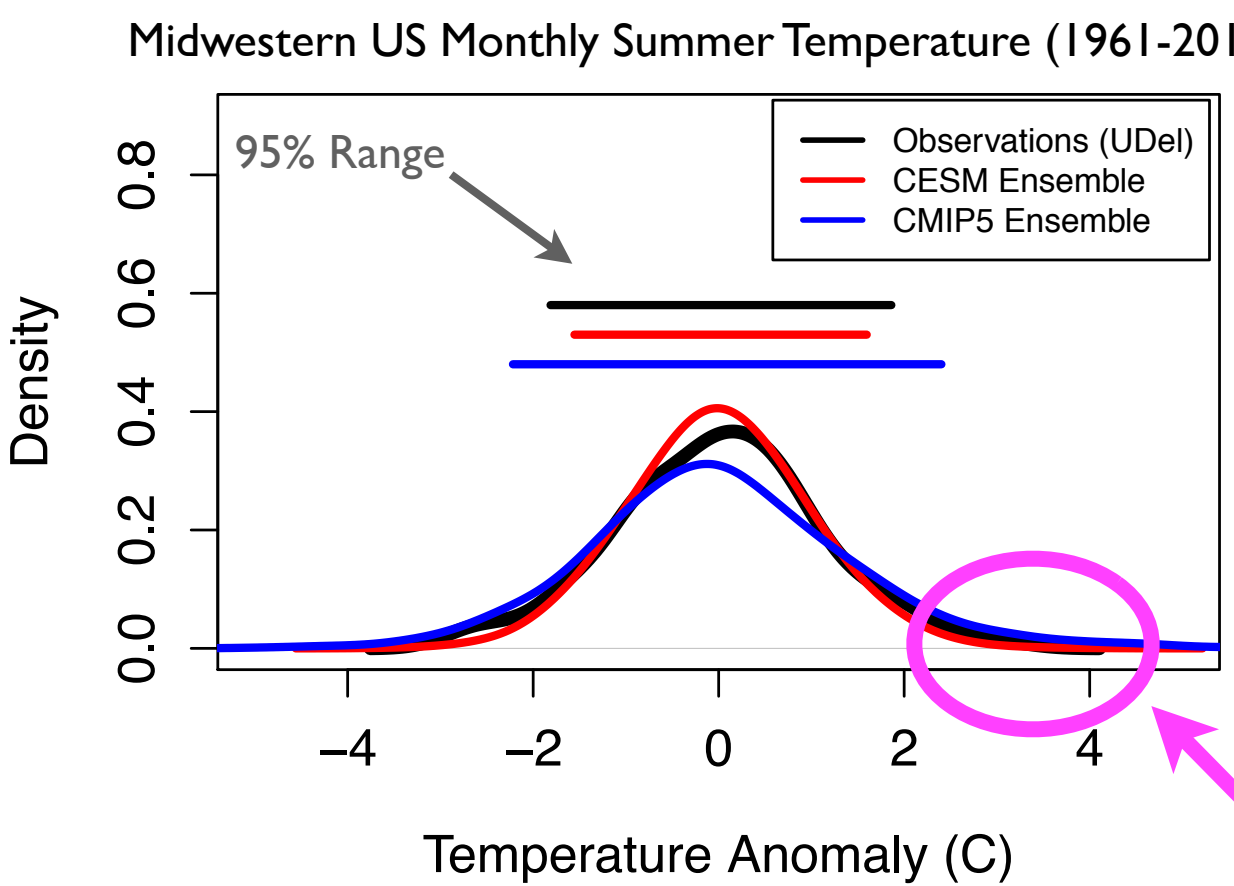
Evaluating CESM ensemble skill



Both ensembles generally capture observed statistics

- CESM overconfident
- CMIP5 underconfident

Evaluating CESM ensemble skill



Both ensembles generally capture observed statistics
- CESM overconfident
- CMIP5 underconfident

What about the tails?

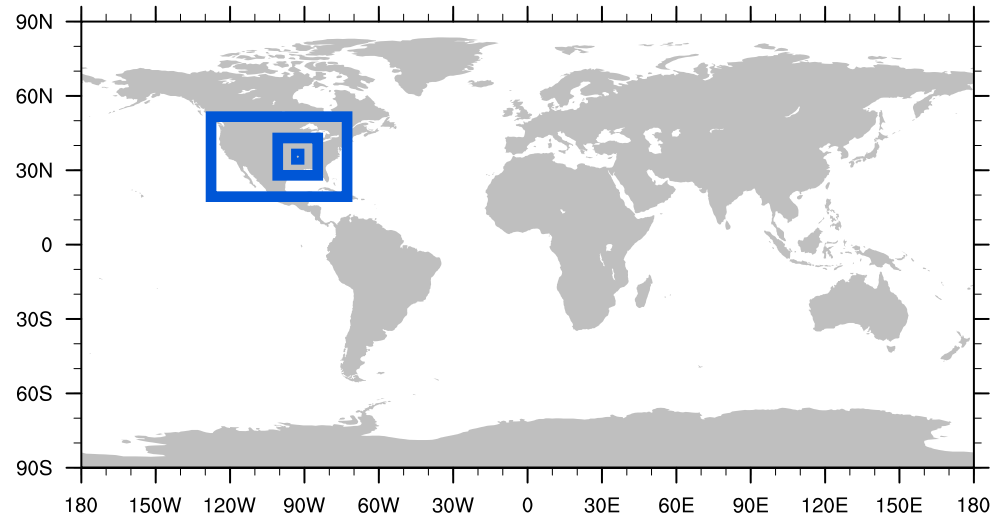
- Can we leverage CESM's flexibility to analyze skill in simulating tail area events?
  - particularly at high-temporal resolution (e.g. daily scales)?
- At what scales does the model show skill?
- What are the advantages/disadvantages of this ensemble approach?

Does CESM capture the extremes?

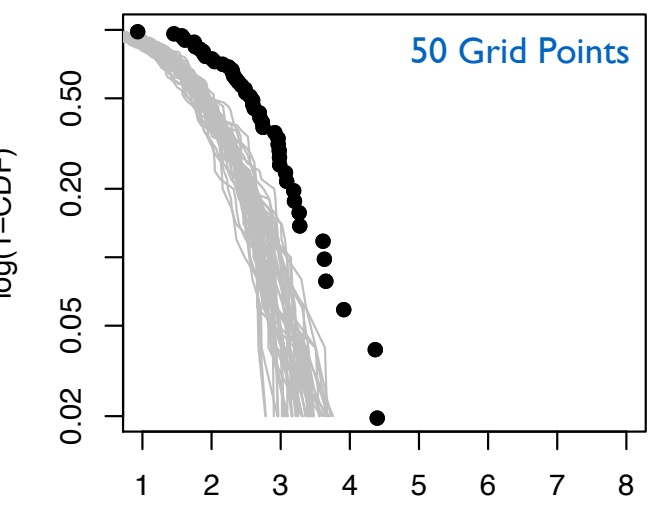
Distributions of summer block maxima of daily temperature (1961-2010)

Black —> Gridded Observations

Gray —> CESM ensemble

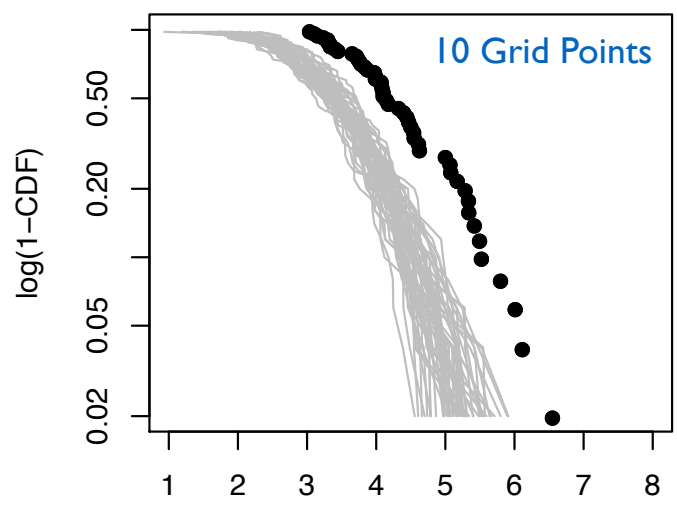


United States



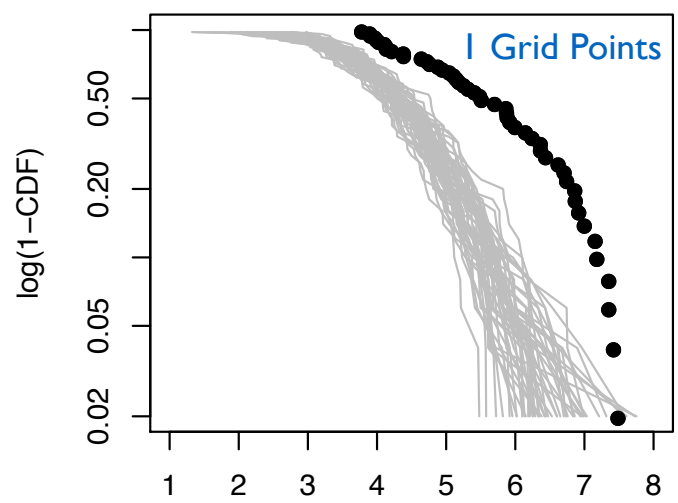
Daily summer temperature anomaly (C), 1961–2010

Midwest



Daily summer temperature anomaly (C), 1961–2010

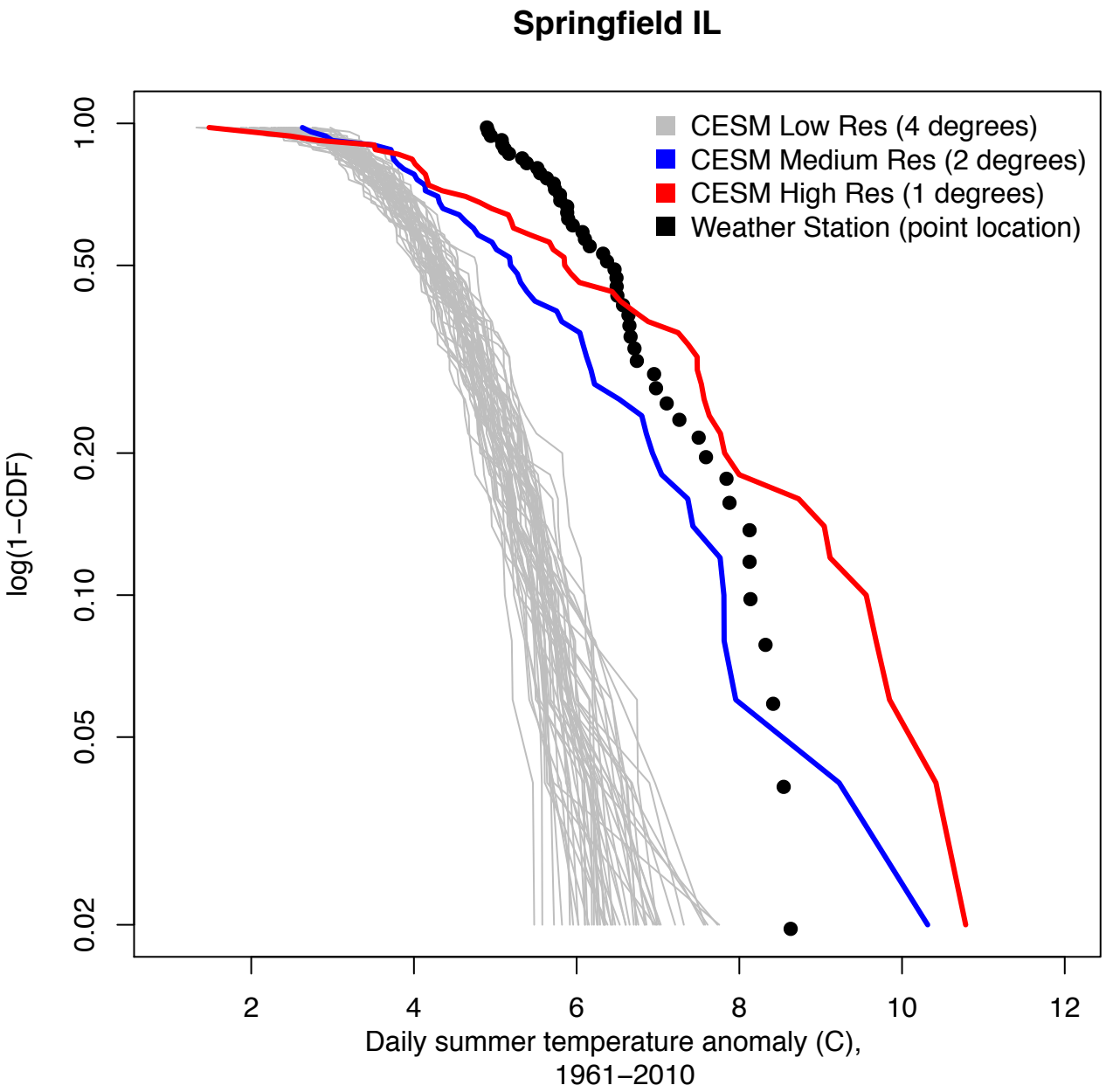
Central Illinois



Daily summer temperature anomaly (C), 1961–20

Low-resolution CESM under-estimates the tails, but generally captures the shape

What is the effect of data/model resolution?



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

Increasing model resolution does not necessarily improve skill

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