Analyzing climate impacts using a low resolution CESM ensemble

Ryan L. Sriver¹, Chris Forest²,³, Klaus Keller³,⁴

1. Dept. of Atmospheric Science, University of Illinois at Urbana-Champaign
2. Dept. of Meteorology, Penn State University
3. Earth and Environmental Systems Institute, Penn State University
4. Dept. of Geosciences, Penn State University

Work supported by:
- DOE-sponsored Program on Integrated Assessment Model Development, Diagnostics and Inter-Model Comparisons (PIAMDDI)
- NSF-sponsored research network for Sustainable Climate Risk Management (SCRiM)

19th Annual CESM Workshop (SDWG working group)
Breckenridge, CO
June 19, 2014
Climate impacts/damages closely linked to extreme (low probability) events

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

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

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

# of Simulations

Increasing Model Complexity (Realism)

Simple (EBMs)
Complex (IPCC)

Constant Computational Cost

under-confident?
over-confident?
Example: Computational trade-off in CESM

![Graph showing the relationship between simulation years per calendar day and increasing model resolution. The graph indicates that as model resolution increases, the number of simulated years per day decreases.](image-url)
Example: Computational trade-off in CESM
Example: Computational trade-off in CESM

Computational demand increases with resolution.

CESM skill appears relatively insensitive to resolution for some key climate variables.
Example: Computational trade-off in CESM

Computational demand increases with resolution.

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

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)
  - 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)

Mean RMSE = 0.15°C

Mean RMSE = 0.35°C

Mean RMSE = 0.93°C
N. Hemisphere Summer (JJA) Temperature

**CESM Ensemble (50 members)**

- **Mean RMSE = 0.14 °C**

**CMIP5 Ensemble (~40 members)**

- **Mean RMSE = 0.14 °C**
N. Hemisphere Summer (JJA) Precipitation

**CESM Ensemble (50 members)**

- **N. Hemisphere**
  - Mean RMSE = 1.5%
  - ![Graph showing precipitation anomaly](graph1)

- **N. America**
  - Mean RMSE = 3.4%
  - ![Graph showing precipitation anomaly](graph2)

- **US Corn Belt**
  - Mean RMSE = 17%
  - ![Graph showing precipitation anomaly](graph3)

**CMIP5 Ensemble (~40 members)**

- **N. Hemisphere**
  - Mean RMSE = 1.5%
  - ![Graph showing precipitation anomaly](graph4)

- **N. America**
  - Mean RMSE = 3.2%
  - ![Graph showing precipitation anomaly](graph5)

- **US Corn Belt**
  - Mean RMSE = 18%
  - ![Graph showing precipitation anomaly](graph6)
Evaluating CESM ensemble skill

Midwestern US Monthly Summer Temperature (1961-2010)

- CESM overconfident
- CMIP5 underconfident

Both ensembles generally capture observed statistics
Evaluating CESM ensemble skill

Midwestern US Monthly Summer Temperature (1961-2010)

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

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
Does CESM capture the dynamics controlling regional climate?

Power spectrum of monthly SST anomalies in the Nino3 Region
Does CESM capture the dynamics controlling regional climate?

Power spectrum of monthly SST anomalies in the Nino3 Region

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

---

Dynamic Sea-Level Rise

Steric Sea-Level Rise

Ensemble Mean (2081-2099)

Sriver et al., In Preparation
Sea-level Rise in CESM for the RCP8.5 scenario

CESM shows large spatial variations in Steric+Dynamic SLR.

Steric+Dynamic Sea-Level Rise

Centimeters

Ensemble Mean (2081-2099)
Sea-level Rise in CESM for the RCP8.5 scenario

CESM shows large spatial variations in Steric+Dynamic SLR.

- Internal model variability leads to relatively large SLR annual and decadal variability
Spatial Patterns in SLR Projections

2100 Sea-Level Rise (cm)

Sriver et al., In Preparation
Spatial Patterns in SLR Projections

2100 Sea–Level Rise (cm)

global mean

NEast US mean

Sriver et al., In Preparation
Spatial Patterns in SLR Projections

- 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

Sriver et al., In Preparation