Earth & Environmental Systems Modeling

5. Model Bias, Model Uncertainties, and Fitness-for-Purpose

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Challenge 1: Integrating Top-Down and Process-Oriented Constraints

- Current capabilities in EESM
  - **Base capability in diagnostics for ESMs:** Many packages exist that look at large (Top-Down) constraints and some that are process-oriented (e.g. E3SM-diags, MPAS-Analysis, ILAMB, etc…)
  - **Models and observations at various scales and complexities**: Satellite and observation networks to benchmark and constrain model states across different scales.
  - **Ultrahigh-Resolution Modeling**: Implementation of LES models and cloud chambers to capture microscale processes and their
- Gaps
  - **Data Integration**: Limited ability to seamlessly integrate high-resolution observational data into model grids, leading to inconsistencies and gaps in model accuracy. (integration often requires higher resolution simulations)
  - **Diagnostics and observations**: Interagency and inter modeling center discussions are needed are needed to understand what diagnostics are needed
  - **Joint Constraints Application**: Challenges in effectively combining top-down constraints with process-level diagnostics to create a comprehensive understanding of model biases and uncertainties.
- Goals
  - **Meeting key top down constraints (ECS, TCS, RESTOM, Aerosol sensitivity, OHC drift) while respecting bottom-up (process oriented metrics)**

Challenge 1: Comprehensive Uncertainty Quantification

- Current capabilities in EESM
  - Existing frameworks provide methods to quantify individual types of uncertainties (e.g., parametric or scenario) in Earth system models.
  - Application of joint sampling techniques to some key uncertainty sources, though not yet comprehensive or fully integrated.
- Gaps
  - Limited understanding of how different forcing, scenario, parameter and structural uncertainties interact and combine, affecting overall model outputs.
  - Lack of comprehensive, standardized frameworks that can simultaneously quantify and propagate multiple types of uncertainties (parametric, structural, scenario, forcing) in a unified manner.
  - Sampling of complex models is computationally expensive, limiting uncertainty quantification
- Goals
  - Expand existing model sampling and diagnostics tools to quantify and propagate various types of uncertainties in Earth system models, considering their interactions and combined effects.
  - Synthesize historical data and expert knowledge to evaluate different types of uncertainties, how they interact, and how to reduce them.
  - Integrate machine learning and AI methods to accelerate uncertainty quantification.

Challenge 3: Effective utilization of high resolution and ensembles for bias reduction

Current capabilities in EESM

- Increasing volumes of model output across configuration complexity, scenarios and resolutions
- Observations across spatial and temporal scales
- Process based models (e.g. LES/CRM) to examine processes in detail

Gaps

- Efficient and effective ways to analyze very large volumes of data
- Methods to distill the vast amount of climate data for use in impacts and assessment related models
- An understanding in the ESM community of most critical biases for stakeholders to help dedicate resources

Goals

- Efficient and equitable analysis capabilities of large volumes of data and frameworks to couple process understanding to ESM simulation biases