Approaches to Forward Looking Datasets: The Energy Exascale Earth System Model (E3SM)

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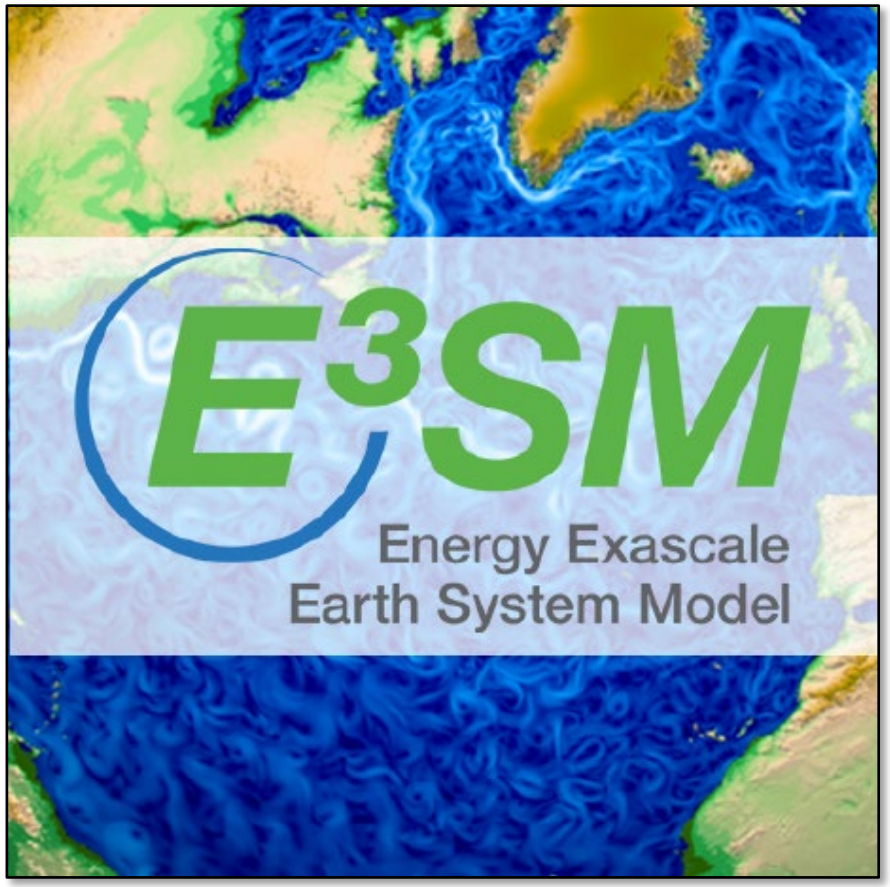
Outline

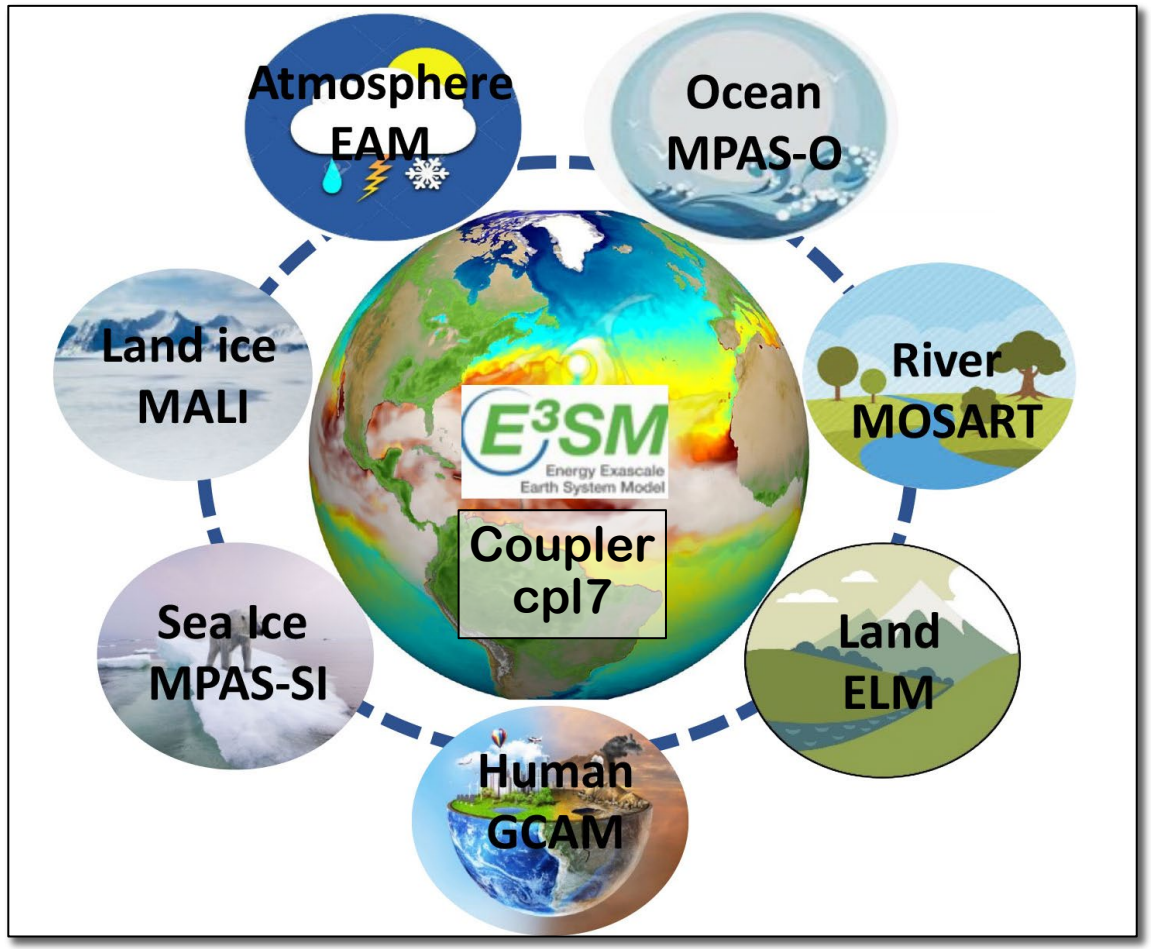
- E3SM overview
  - Model basics
  - Available configurations
- E3SM energy infrastructure applications
  - Model evaluation for wind and solar resource assessment
  - Climate-informed capacity expansion planning



The Energy Exascale Earth System Model (E3SM)

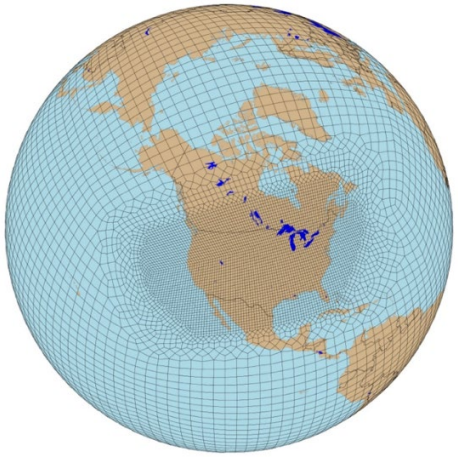
- E3SM is the US DOE's global climate model
  - Fully-coupled earth system model
  - Leaders and contributors across the DOE National Laboratories
- Included in global climate assessments:
  - Coupled Model Intercomparison Project Phase 6 (CMIP6)
  - Intergovernmental Panel on Climate Change (IPCC) reports

E3SM has unique high-resolution capabilities that LLNL is leveraging for energy infrastructure applications.



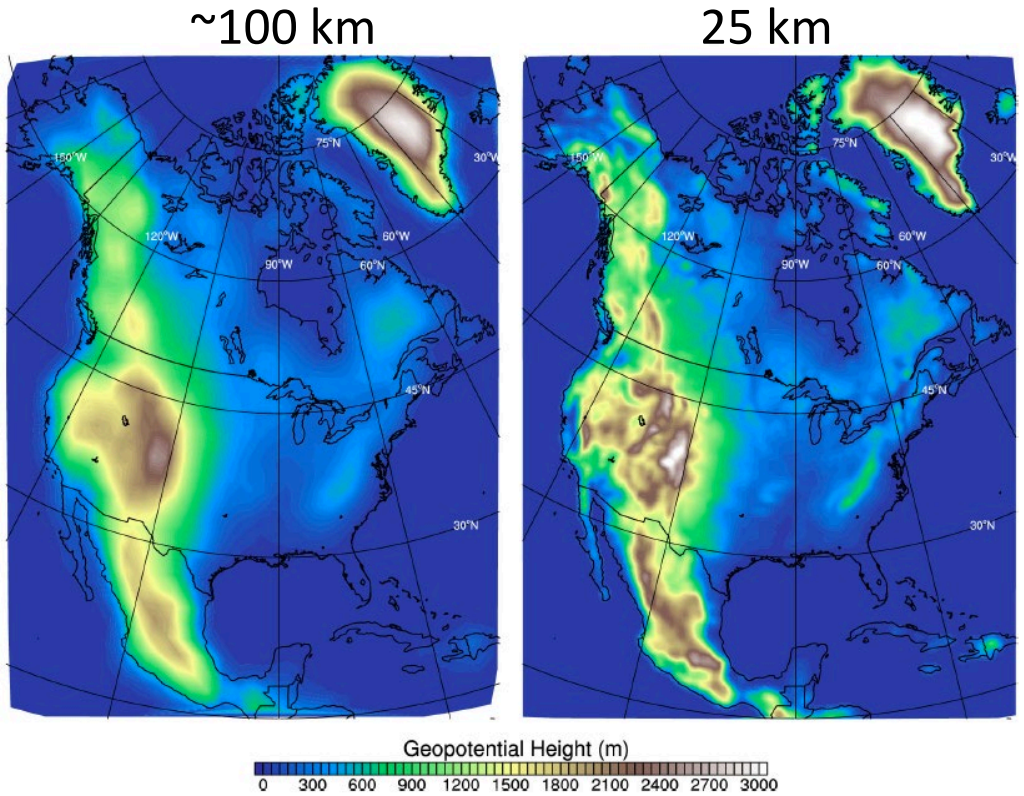
E3SM Configurations

- Constant global resolution
  - Standard 1° (~100 km) global
  - 3 km global (SCREAM)
- Regionally-Refined Mesh (RRM)
  - 25 km North America RRM (~100 km globally)
  - 3 km California RRM (~100 km globally)



North America RRM (25 km)

Model Terrain Resolution



Tang et al. (2023)

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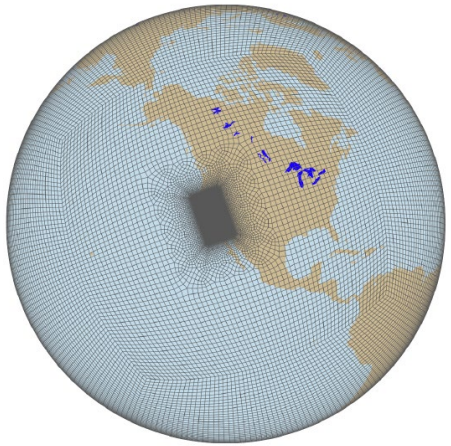
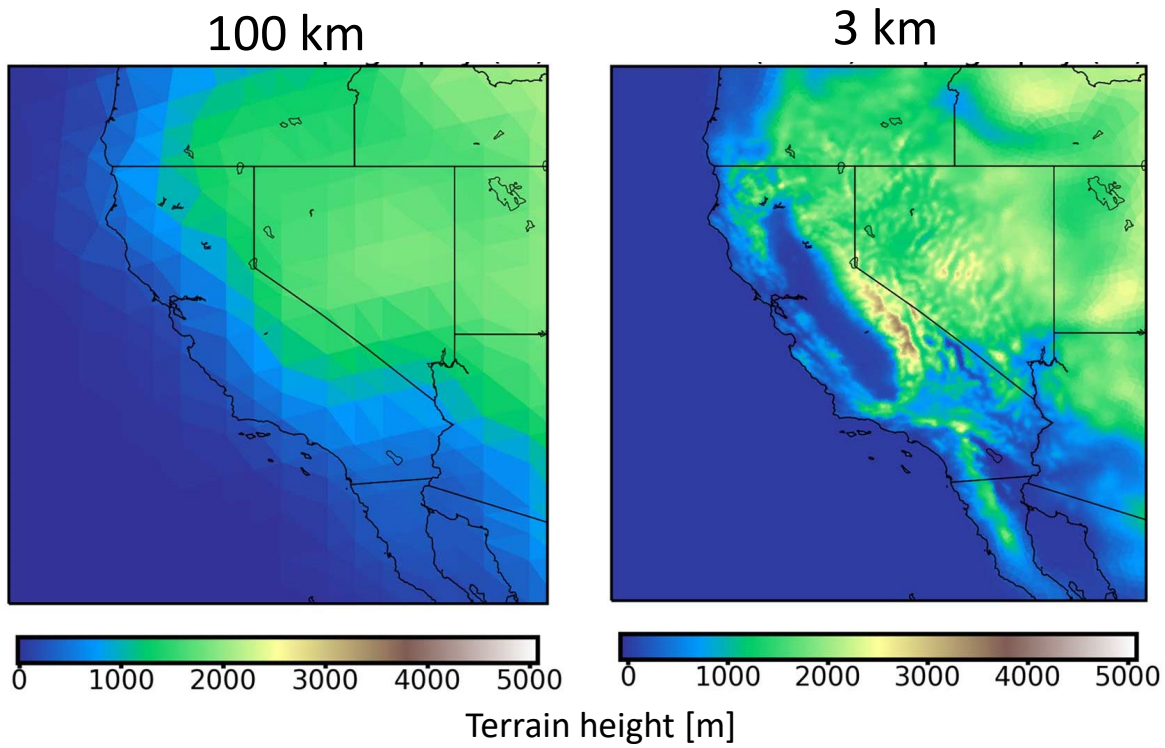


California RRM (3 km)

Model Terrain Resolution



Zhang et al. (2024)

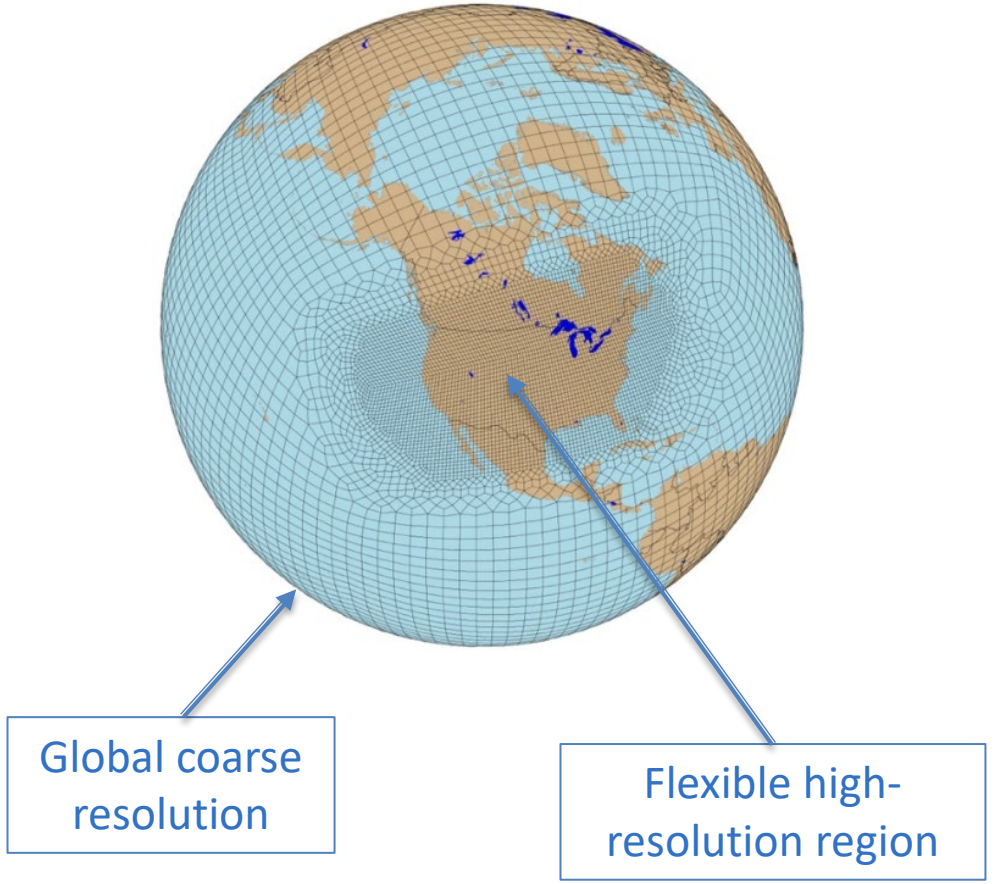
E3SM Configurations

	Standard	SCREAM	North America RRM	California RRM
Resolution	~100 km global	3 km global	25 km (~100 km global)	3 km (~100 km global)
Simulated periods	1850-2014; 2015-2100	4 seasonal runs (40 days each)	1850-2014; *2010-2014*	2015-2020; 2029-2034; 2044-2049; 2094-2099
Output frequency	Monthly/Daily/3-hour	3-hour	Monthly/Daily/3-hour; *Hourly*	Hourly
Climate scenario	Historical; SSP370 (upper-moderate)	Historical	Historical	SSP585 (most extreme)
References	Golaz et al. (2022); Fasullo et al. (2024)	Donahue et al. (2024)	Tang et al. (2023)	Zhang et al. (2024)
Data availability	See references and https://e3sm.org/data-from-e3sm-v2-0-is-available/	See reference	See reference and https://e3sm.org/data-from-e3sm-v2-0-is-available/	See reference

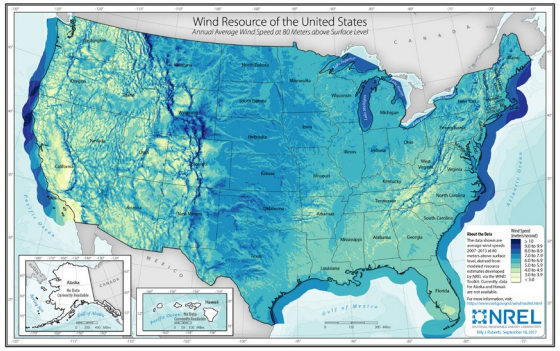
Benefits of E3SM Regionally-Refined Mesh Capability

Regional refinement facilitates customized climate simulations for energy infrastructure applications.

- Flexible configuration
  - Balance grid resolution with computational expense
  - Refined mesh can be placed in any location of interest
- "Storyline" approach
  - Simulate notable events (e.g., heat waves) in future climate states
- No need for a separate regional downscaling model (e.g., WRF)



E3SM RRM Evaluation for Renewable Resource Assessment



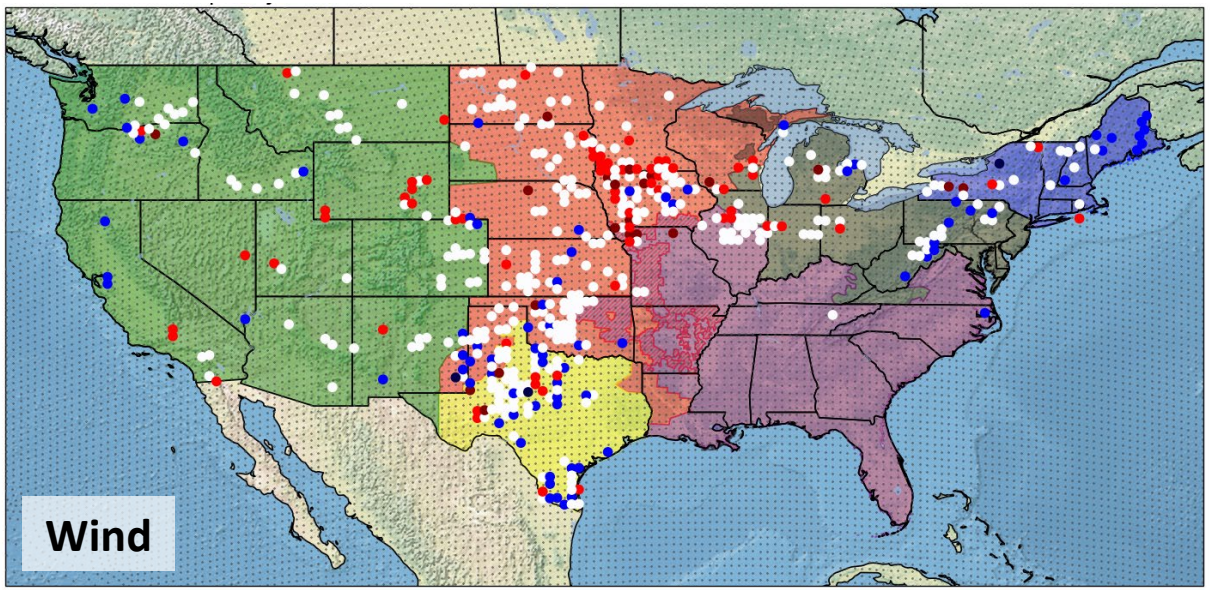
- Publicly available production data from existing utility-scale wind and solar installations
  - Forms 860 and 923 (monthly data 2013-2022)
  - Processing scripts and a quality controlled dataset will be released to the community for model evaluation efforts

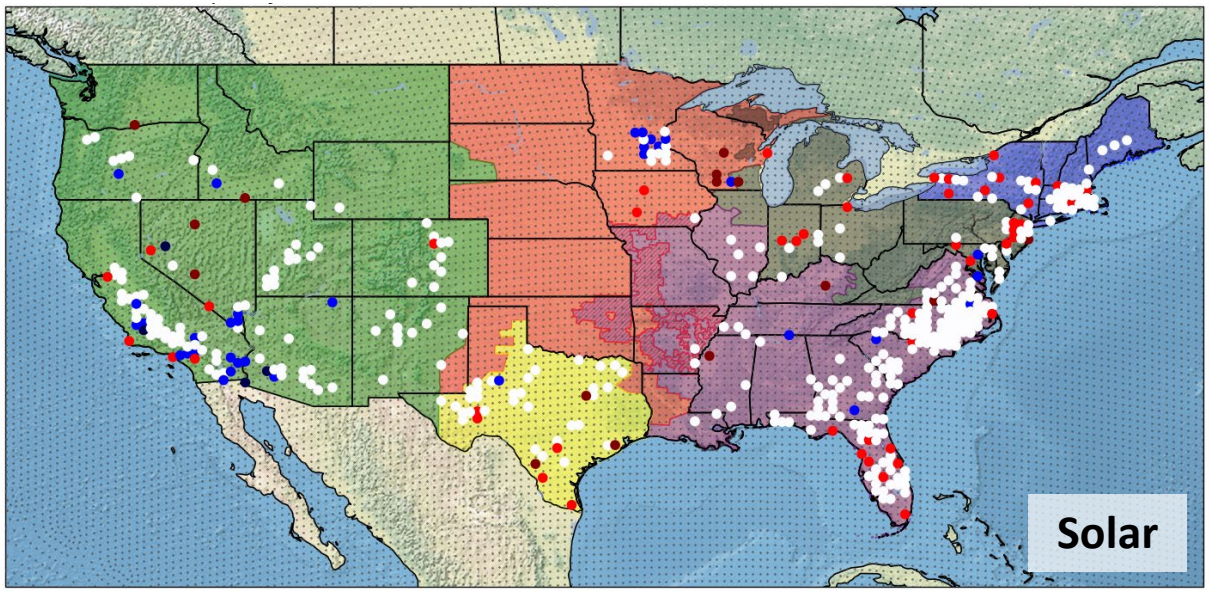
- Benchmark model datasets:
  - NREL Wind Integration National Dataset (WIND) Toolkit
  - NREL National Solar Radiation Database (NSRDB)

Present-day model evaluation provides guidance for future renewable resource assessments.

E3SM RRM Evaluation for Renewable Resource Assessment

Multi-year average comparisons of E3SM North America RRM vs. EIA data



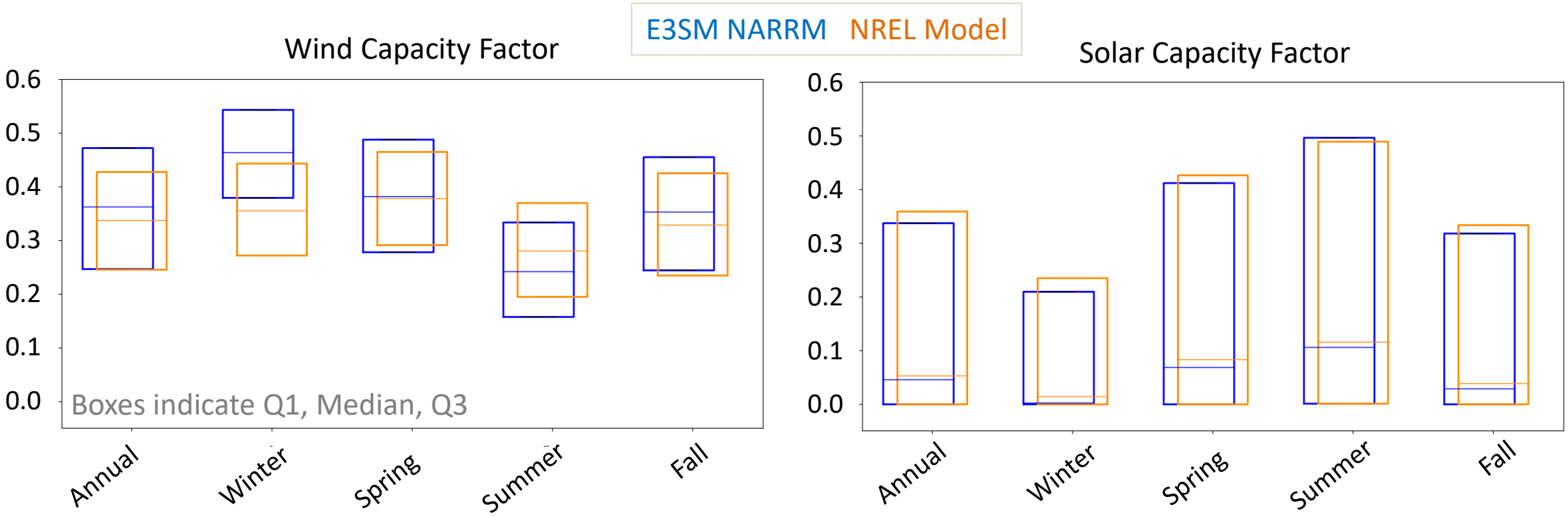


White: +/20%
Red: >20% overestimate
Blue: <-20% underestimate

E3SM performs well overall, with site-to-site variability.

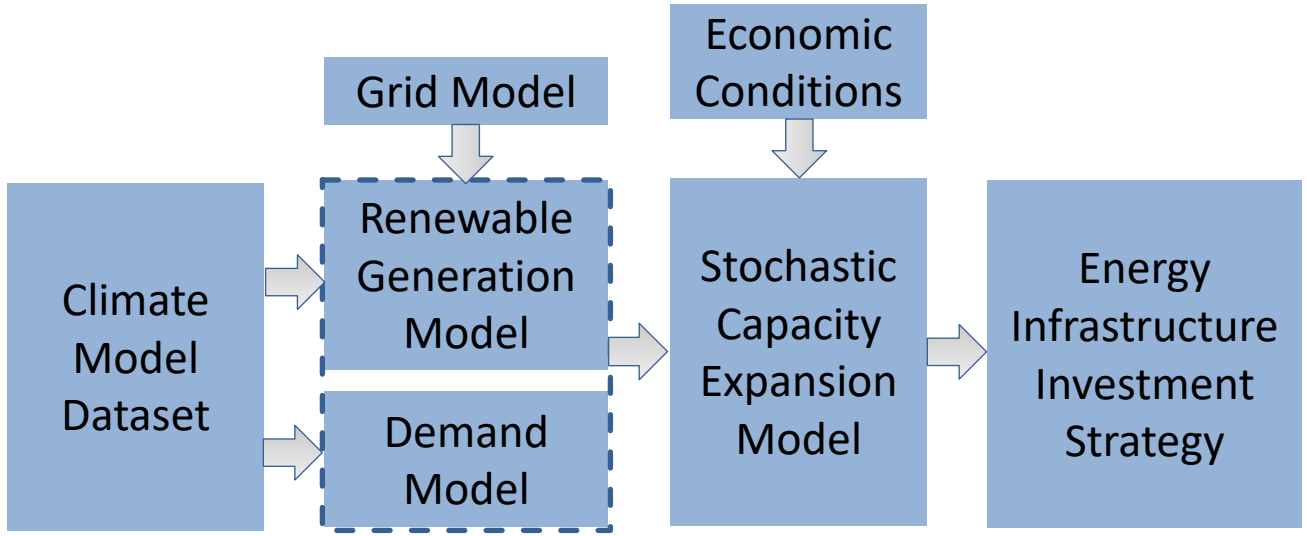
E3SM RRM Evaluation for Renewable Resource Assessment

Multi-year comparisons of E3SM North America RRM vs. NREL benchmark model datasets

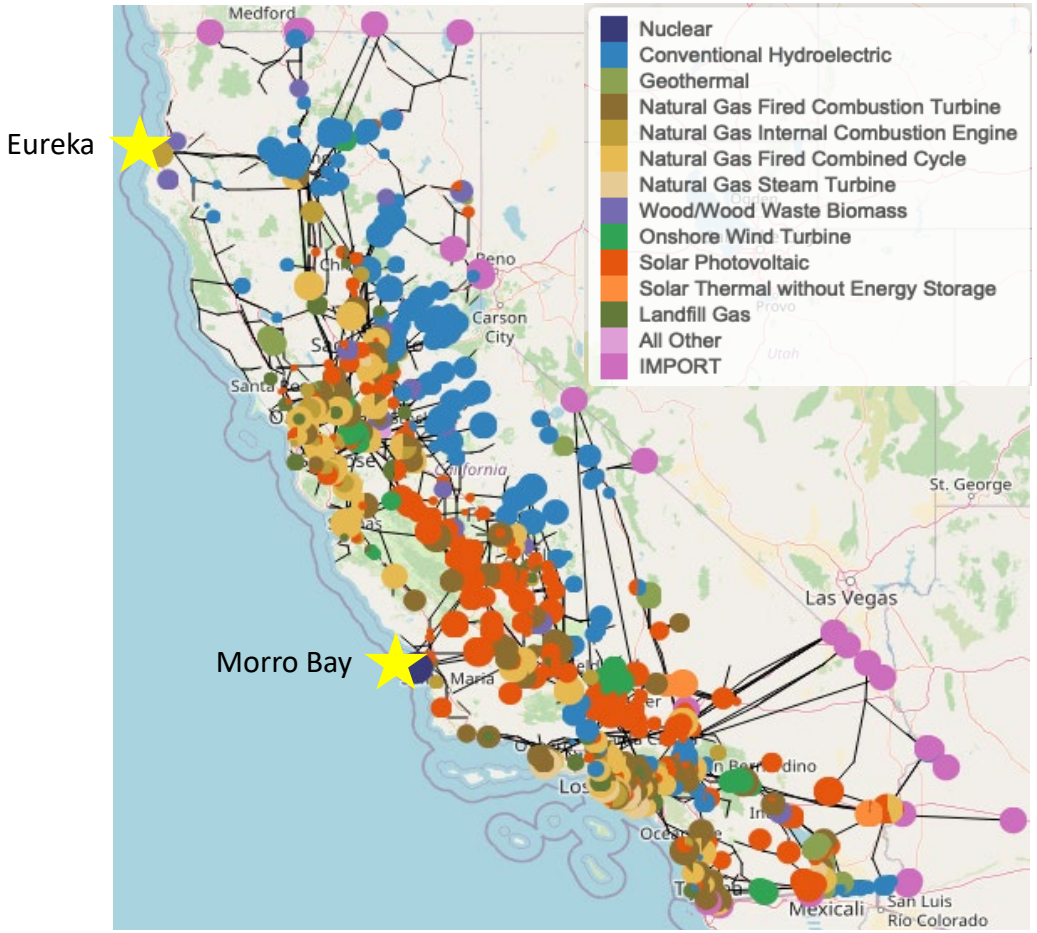


The models show similar seasonal trends, with more variability for wind than solar.

Climate-Informed Capacity Expansion Planning

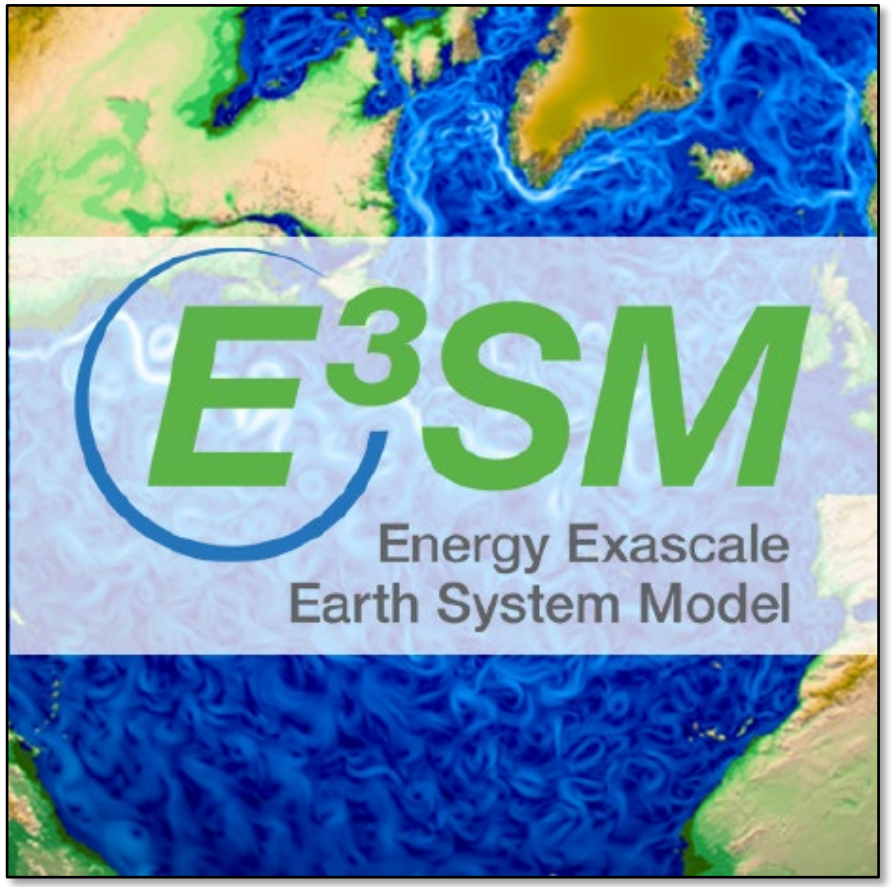


- High-resolution future projections from **E3SM California RRM** (3km) for the year 2045
- Stochastic optimization over multiple "representative days" that capture seasonal variability
- The California Test System synthetic grid network (with new nodes at planned offshore lease areas)
- Economic scenarios from the *NREL Annual Technology Baseline*



S. Taylor, *et al.*, "California Test System (CATS): A Geographically Accurate Test System based on the California Grid," *IEEE Transactions on Energy Markets, Policy and Regulation*, vol. 2, no. 1, pp. 107-118, March 2024.

Summary



- E3SM has unique high-resolution capabilities that LLNL is leveraging for energy infrastructure applications
- Regional refinement facilitates customized climate simulations for given scenarios and locations of interest
- Ongoing evaluation and application includes:
  - Comparisons to EIA data and benchmark models
  - Climate-informed capacity expansion planning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Capacity expansion model details

- E3SM Climate Model [1] (California Regionally Refined Model [2]) used to inform
  - Hourly bus-level demand [3]
  - Hourly renewable resource availability [4], [5]
- Stochastic program [6], [7] run under two different cost conditions
  - High/low technology costs of offshore wind generation
  - Sourced from NREL's Annual Technology Baseline [8]

[1] J.-C. Golaz, *et al.*, "The DOE E3SM Model version 2: Overview of the physical model and initial model evaluation," *Journal of Advances in Modeling Earth Systems*, vol. 14, issue 12, pp. e2022MS003156, Dec. 2022.
[2] J. Zhang, *et al.*, "Leveraging Regional Mesh Refinement to Simulate Future Climate Projections for California Using the Simplified Convection Permitting E3SM Atmosphere Model Version 0," *Geoscientific Model Development*, vol. 17, issue 9, pp. 3687–3731, May 2024.
[3] M. Monteagudo, S. Po-Chedley, J.-P. Watson, "Population and Temperature Impacts on Electricity Demand in California," *AGU23*, Dec. 2023.
[4] PySAM Version 4.2.0 National Renewable Energy Laboratory. Golden, CO. github.com/nrel/pysam.
[5] M. Signorotti, *et al.*, "Computational Pipeline Predicts Solar and Wind Energy Availability under Various Climate Change Projections," *Innovations in Climate Resilience 2024*, 2024.
[6] R. S. Go, F. D. Munoz, J.-P. Watson, "Assessing the economic value of co-optimized grid-scale energy storage investments in supporting high renewable portfolio standards," *Applied Energy*, vol. 183, pp. 902-913, Dec. 2016.
[7] T. Valencia Zuluaga, A. Musselman, S. Oren, J.-P. Watson, "Parallel Computing for Power System Climate Resiliency: Solving a Large-Scale Stochastic Capacity Expansion Problem with mpi-sppy," *Electric Power Systems Research* (accepted), 2024.
[8] NREL (National Renewable Energy Laboratory). 2023. "2023 Annual Technology Baseline." Golden, CO: National Renewable Energy Laboratory. https://atb.nrel.gov/.