NATIONAL LABORATORY OF THE ROCKIES

Multi-Model Linkage to Assess Power System Reliability Against Unseen Weather Futures

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2026 ESIG Summer Workshop

15 June 2026

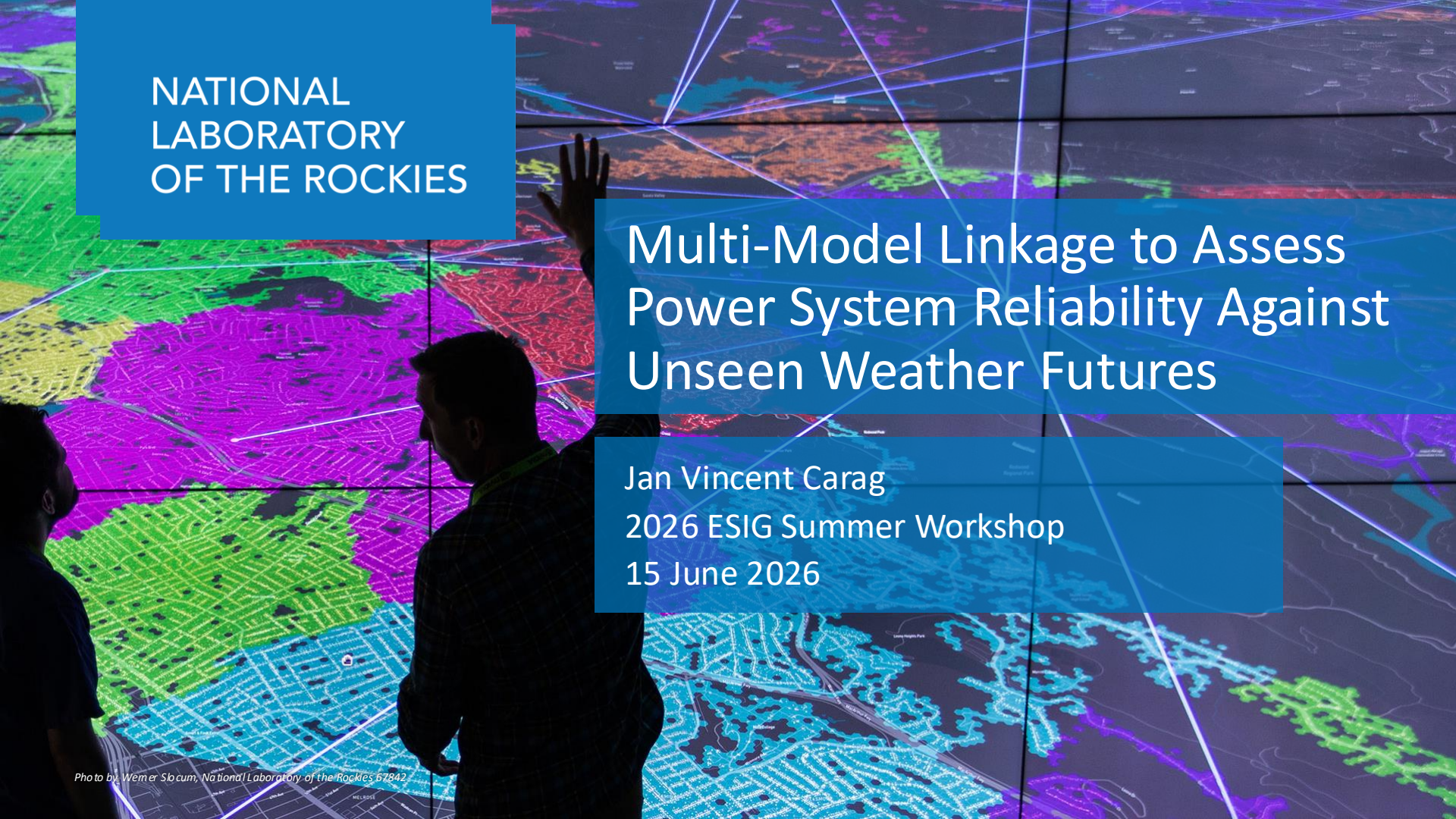


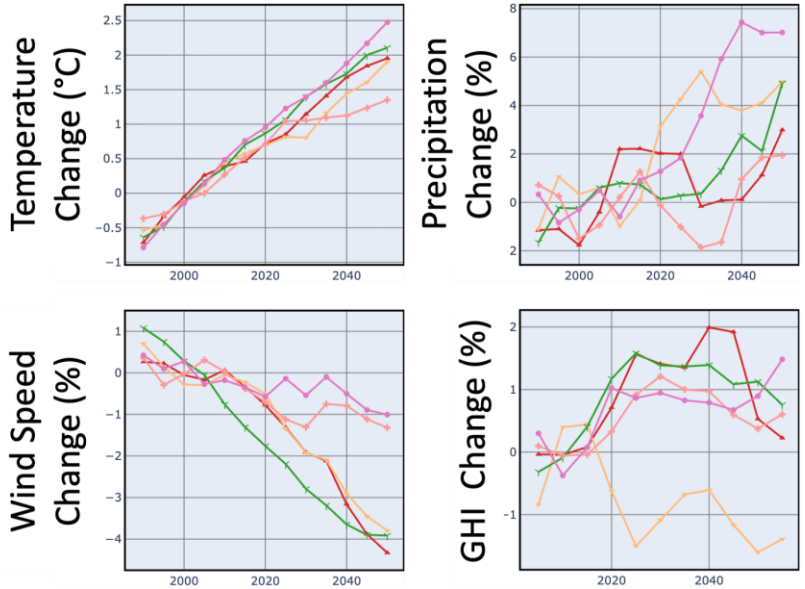
Photo by: Werner Slocum, National Laboratory of the Rockies 67842

Presentation Outline

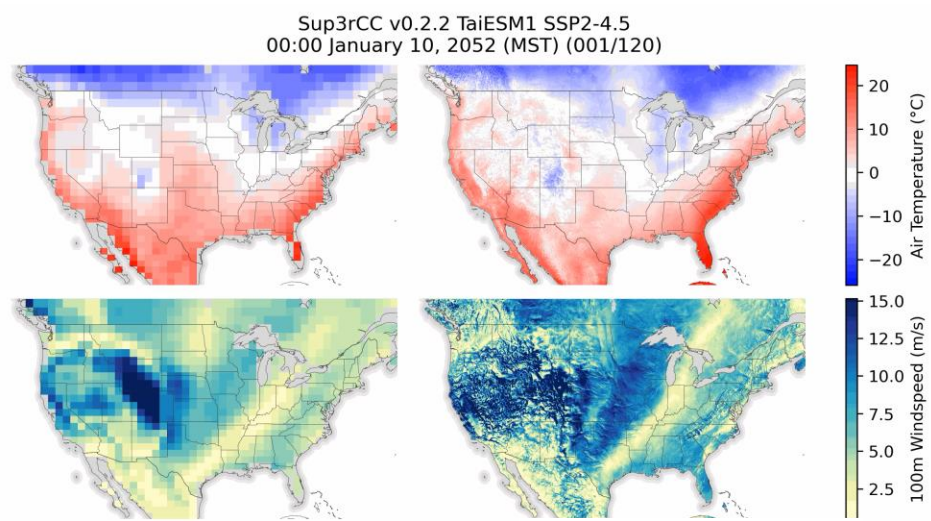
1. **Capacity Expansion with ESM-informed Inputs**
2. **Reliability Testing against Unseen Weather**

Earth System Model Uncertainty and Power System Planning

- **Uncertainty in predicting future weather conditions**: evident by the vast number of **Earth System Models (ESMs)** with varying climate projections



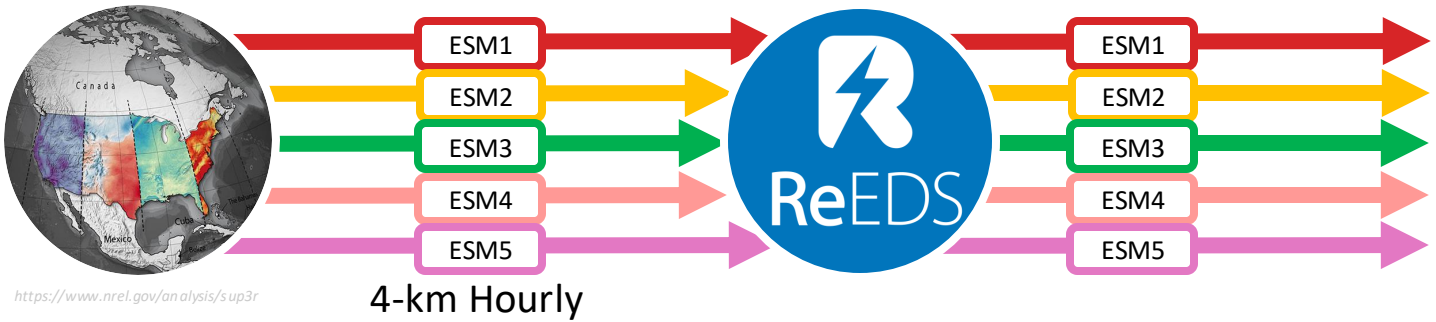
- AI advancements (**Sup3r software)** can downscale ESM projections to produce **high-resolution weather data** for use in **power system planning**



Section 1: Planning Power Systems with Earth System Model Data

ESM-informed
Power System Inputs

ESM-optimized
2050 US Power System



4-km Hourly

Sup3rCC

Machine Learning tool for downscaling ESM projections

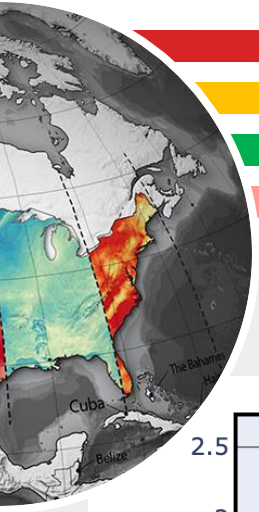
ReEDS

Capacity Expansion Model

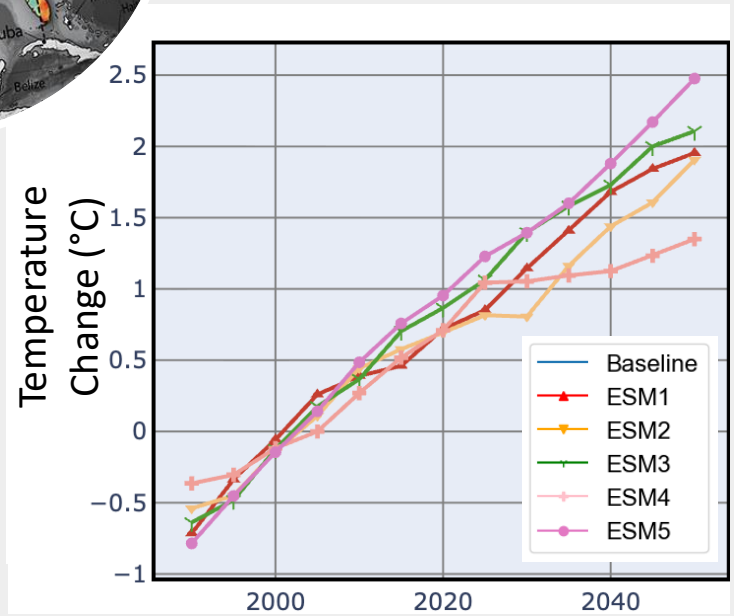
QUESTION:

How do the projections from ESM1 ESM2 ESM3 ESM4 ESM5 affect the resulting power system required to meet future electricity demand?

Translating Data from ESM to CEM

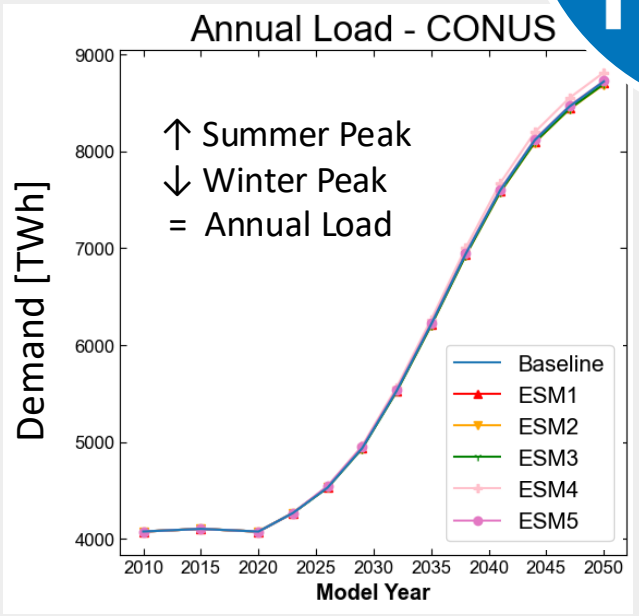


ESM Projections



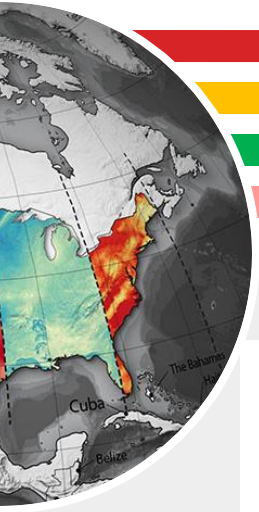
EVOLVED ENERGY RESEARCH

CEM Input Data

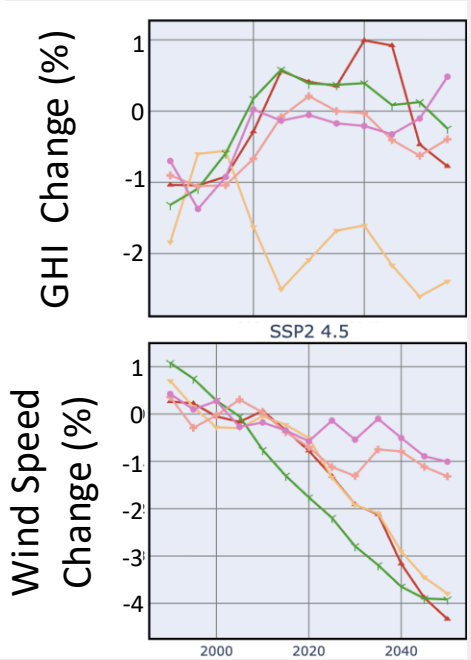


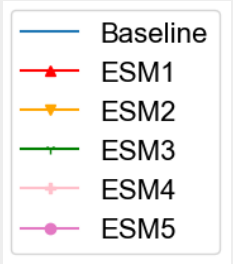
Disclaimer: preliminary data – do not cite or distribute

Translating Data from ESM to CEM



ESM Projections





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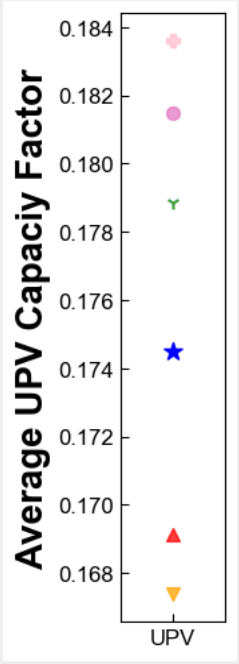
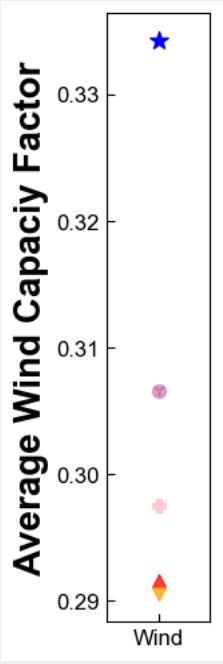
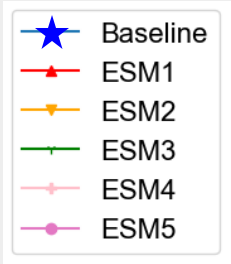
CEM Input Data







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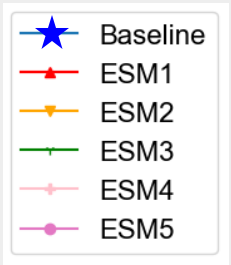
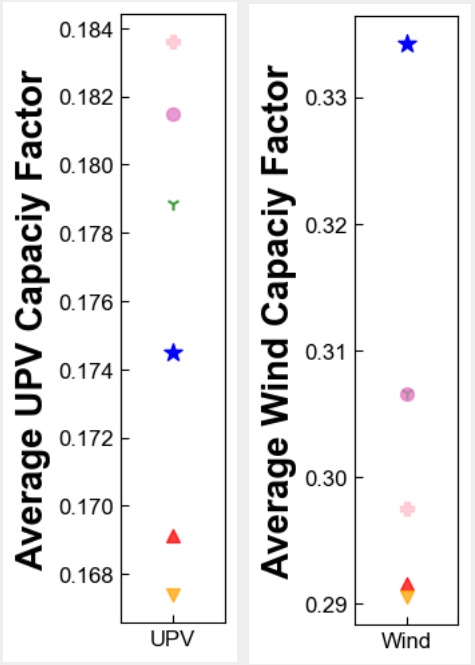
ESM-ReEDS: Results Correlations

ESM-Optimized Future Power System





2050 US: difference from Baseline

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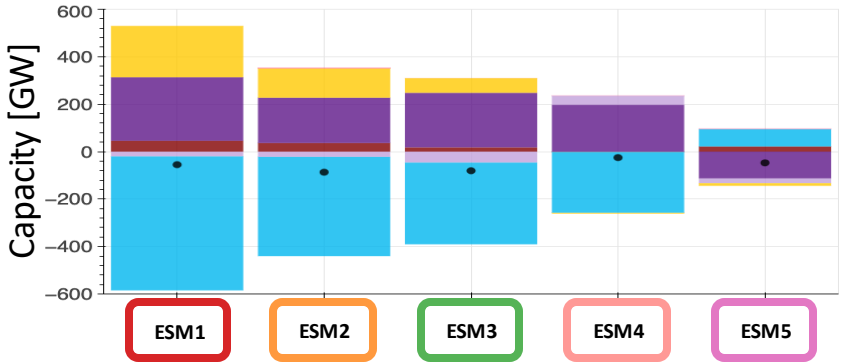
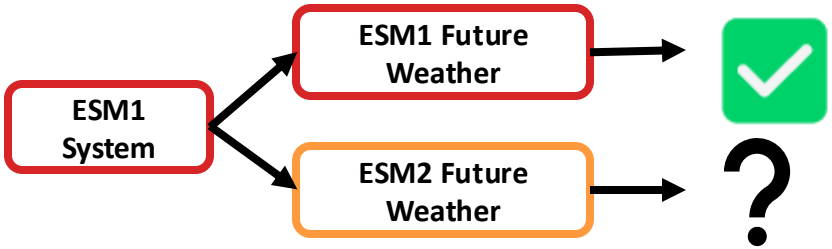
Section 2: Power System Reliability vs Unseen Weather

Capacity expansion modeling with ESM-informed inputs produces varied power systems optimized for the **specific weather future predicted by a given ESM…**





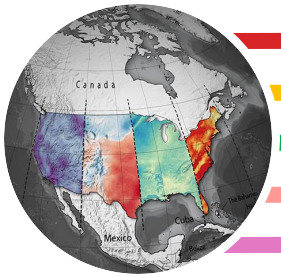
…but **what if the realized future weather conditions are far different** than the predicted conditions the power system was planned against?

How can we test the reliability of a power system against future weather uncertainty?

Let’s take these optimized power systems…

ESM-informed
Power System Inputs

ESM-optimized
2050 US Power System



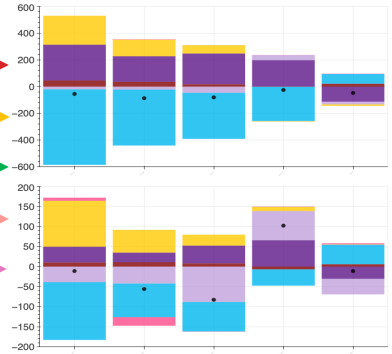
https://www.nrel.gov/analysis/sup3r

ESM1
ESM2
ESM3
ESM4
ESM5

4-km Hourly

ReEDS

ESM1
ESM2
ESM3
ESM4
ESM5



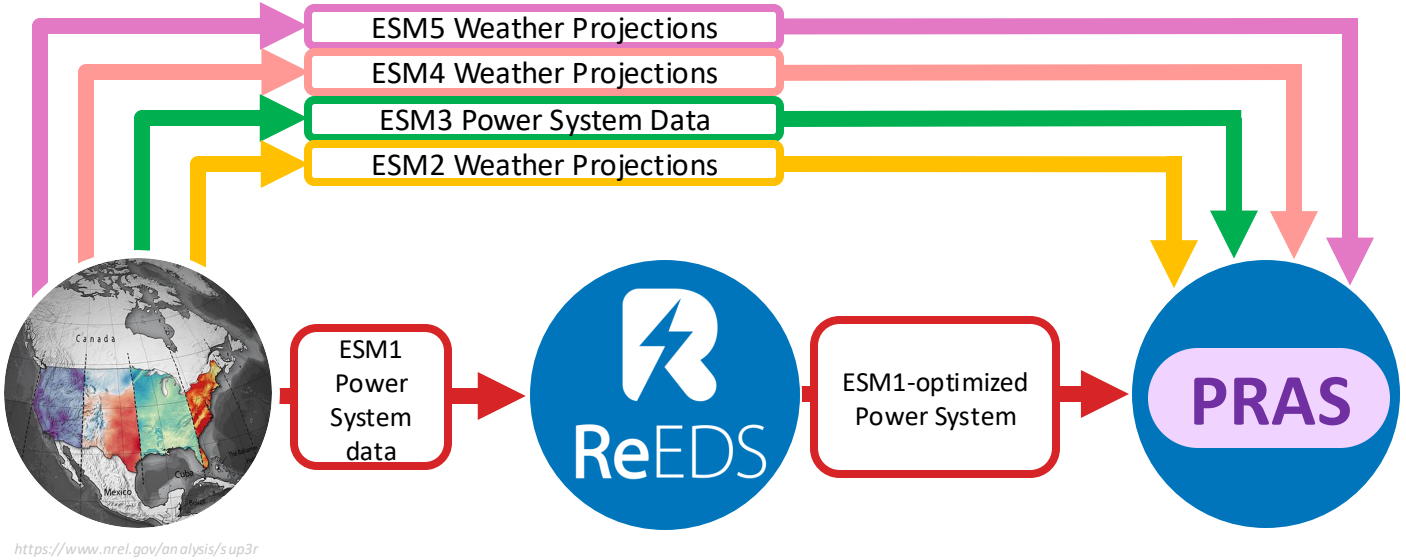
Sup3rCC

Machine Learning tool for downscaling ESM projections

ReEDS

Capacity Expansion Model

…and stress-test their reliability against non-optimal (unseen) future weather conditions



Sup3rCC

Machine Learning tool for downscaling ESM projections

ReEDS

Capacity Expansion Model

PRAS

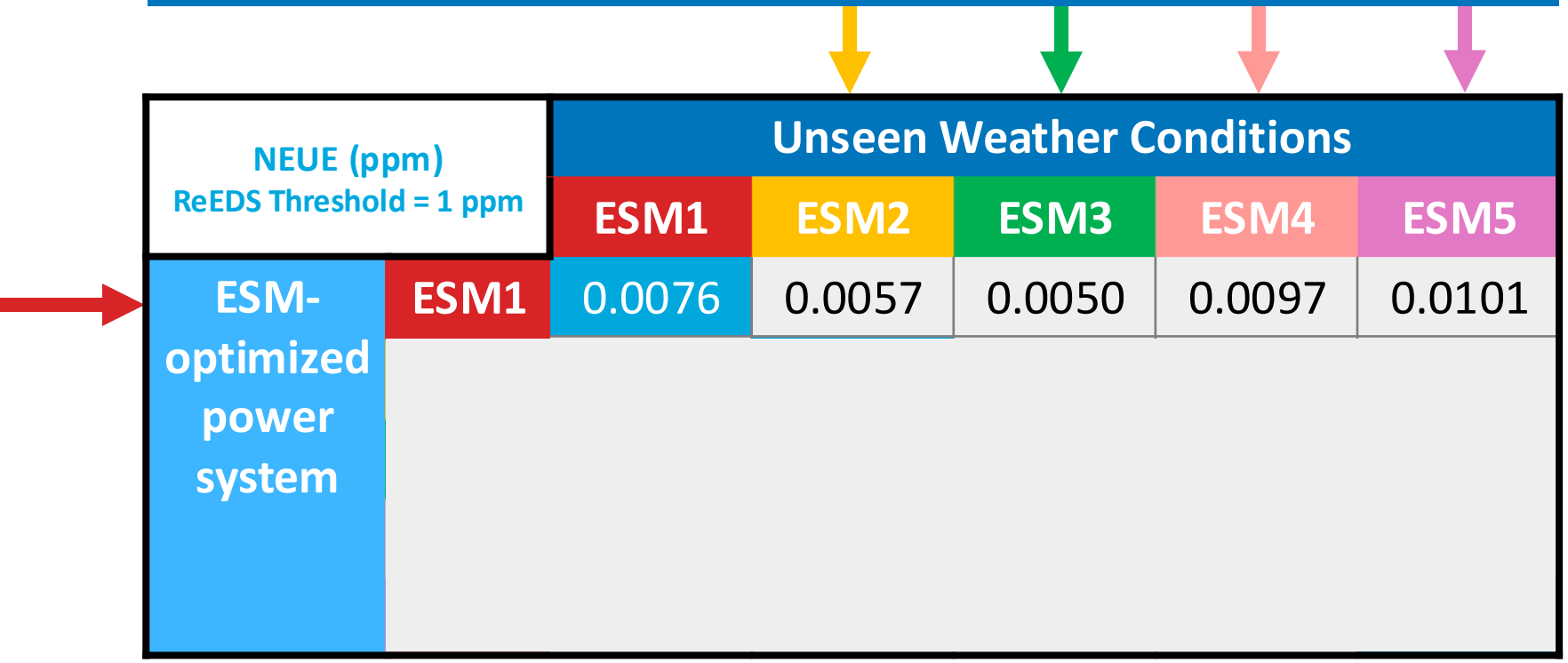
Resource Adequacy

QUESTION:

How reliable is a system designed for **ESM1** when subject to weather conditions of:

ESM2? ESM3? ESM4? ESM5?

Stress-testing Capacity Expansion Investments against Unseen Weather Conditions using a Resource Adequacy Model



NEUE (ppm) ReEDS Threshold = 1 ppm		Unseen Weather Conditions				
		ESM1	ESM2	ESM3	ESM4	ESM5
ESM-optimized power system	ESM1	0.0076	0.0057	0.0050	0.0097	0.0101

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Stress-testing Capacity Expansion Investments against Unseen Weather Conditions using a Resource Adequacy Model

NEUE (ppm) ReEDS Threshold = 1 ppm		Unseen Weather Conditions				
		ESM1	ESM2	ESM3	ESM4	ESM5
Power System	ESM1	0.0076	0.0057	0.0050	0.0097	0.0101
	ESM2	0.0334	0.0360	0.0712	0.0325	0.0413
	ESM3	0.1389	0.1257	0.7069	0.1261	0.1001
	ESM4	0.0678	0.0656	0.0692	0.0740	0.0886
	ESM5	0.0710	0.0798	0.1113	0.0683	0.0947

Row-wise analysis: identifies how robust a system is against unseen weather

Column-wise analysis: identifies weather conditions that are more/less likely to cause system unreliability

Normalized Threshold analysis: allows direct reliability/robustness comparison between power systems

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Key Takeaways

- **Translation of high-resolution data** and **ESM-CEM-RA model linkage** can facilitate cross-model analysis of power system reliability against uncertain weather futures

- Incorporating ESM projections in capacity expansion planning has **varied effects on the power system outcomes**, and stress-testing these systems against unseen weather can **identify robust systems**.

- **Resource adequacy models require further tuning** to provide results capable of **characterizing systems** that are reliable across multiple weather futures