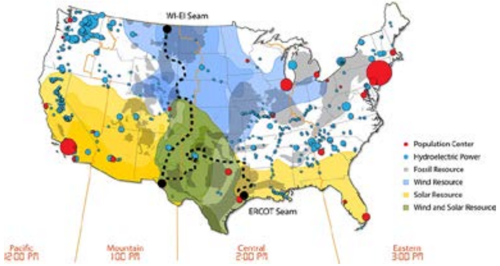
Spatiotemporal Super-Resolution with Generative Machine Learning for Creating Renewable Energy Resource Data Under Climate Change Scenarios

Grant Buster, Brandon Benton,
Paul Pinchuk, Andrew Glaws, Ryan King

Innovations in Climate Resilience
March 29th, 2023

Large Renewable Energy Integration Studies

The NREL Seams Study

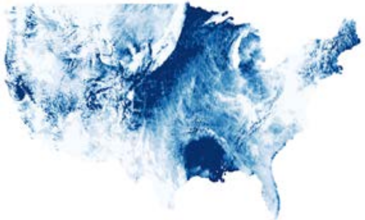


The North American Renewable Integration Study (NARIS)

LA100

The Los Angeles 100% Renewable Energy Study

PR100



"The Evolving Role of Extreme Weather Events in the U.S. Power System with High Levels of Variable Renewable Energy"

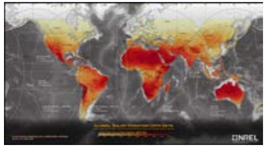
U.S. DEPARTMENT OF ENERGY

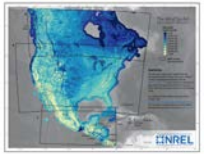
Building a Better Grid

National Transmission Planning Study

How does this all fit together?

Renewable Energy Resource Data (NSRDB, WTK)





rev

Power System Modeling

Capacity Expansion Model (CEM)

Production Cost Model (PCM)

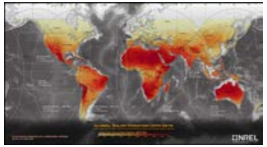
Resource Adequacy (RA)

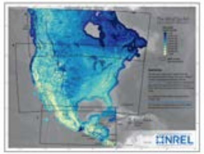
Load Data

Results and Insights!

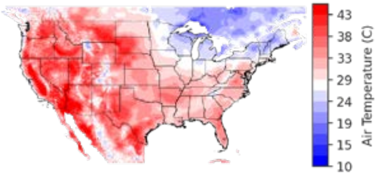
How does this all fit together?

Renewable Energy Resource Data (NSRDB, WTK)





Climate Change Data



rev

Load Data

Power System Modeling

Capacity Expansion Model (CEM)

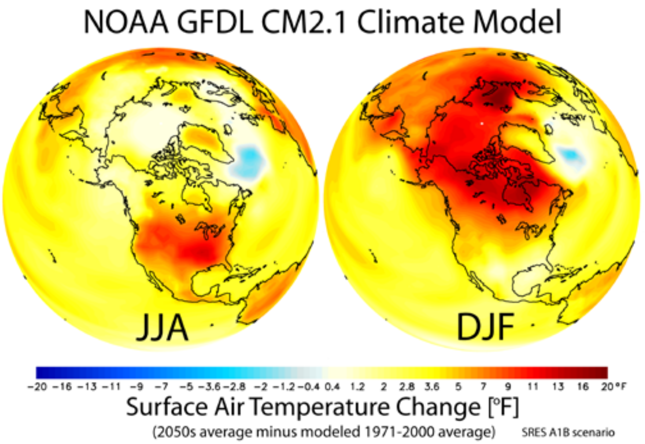
Production Cost Model (PCM)

Resource Adequacy (RA)

Results and Insights!

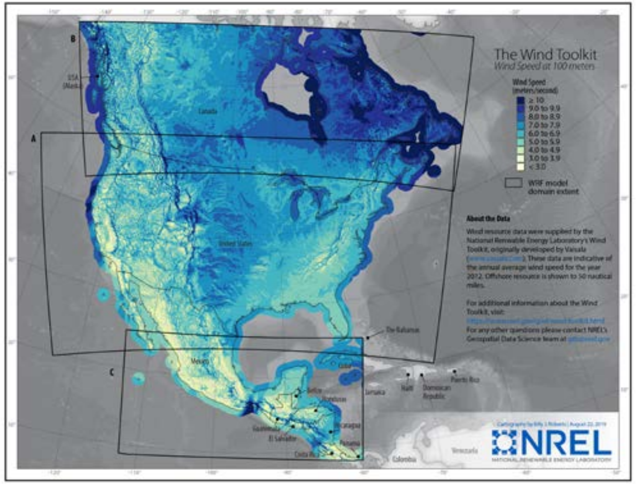
Climate Data Downscaling: Mind the Gap

Global Climate Models (GCMs)



https://www.gfdl.noaa.gov/visualizations-climate-prediction/

Mesoscale NREL Datasets (WTK, NSRDB)



~100 km grid resolution
daily average data
2000-2100

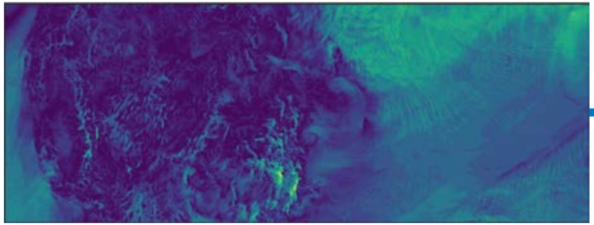
How do we bridge this gap?

~2-4 km grid resolution
5 min-hourly data
Historical

Our solution needs to be flexible enough to enable researchers to study any climate model or climate change scenario and to stay current with new climate research.

Super-Resolution for Renewable Energy Resource Data with Climate Change Impacts (Sup3rCC)

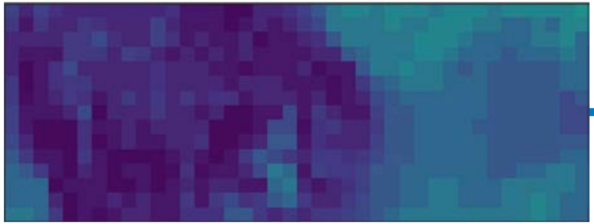
True High Res (WTK or NSRDB)



4km hourly

Coarsen high res to create training data

True Low Res (WTK or NSRDB)

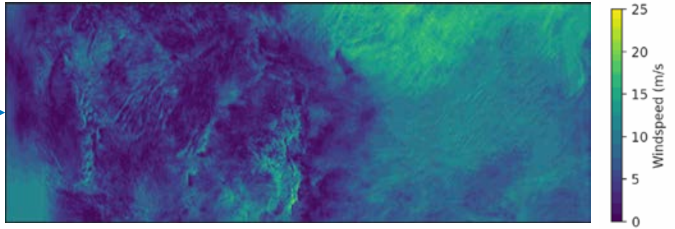


100km Daily

Discriminative Model

Generative Model

Synthetic High-Res Output



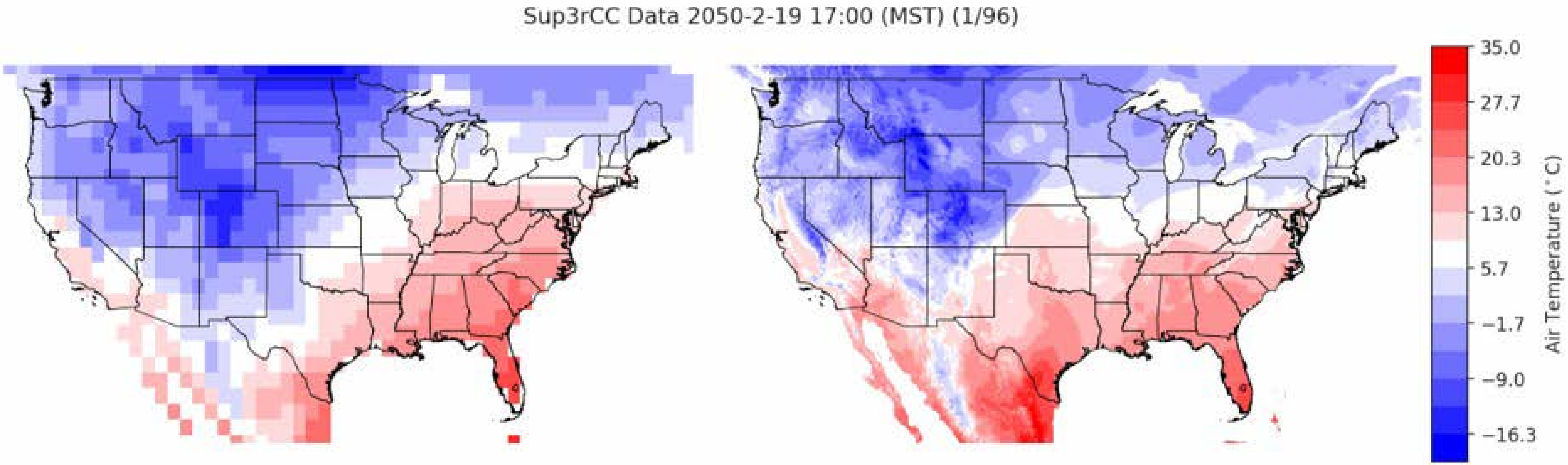
4km hourly

Benefits of Downscaling with ML:

1. Computational efficiency (10-100x faster than WRF)
2. Designed for renewables
3. Fully integrated into energy analysis software

Open-source: https://nrel.github.io/sup3r/

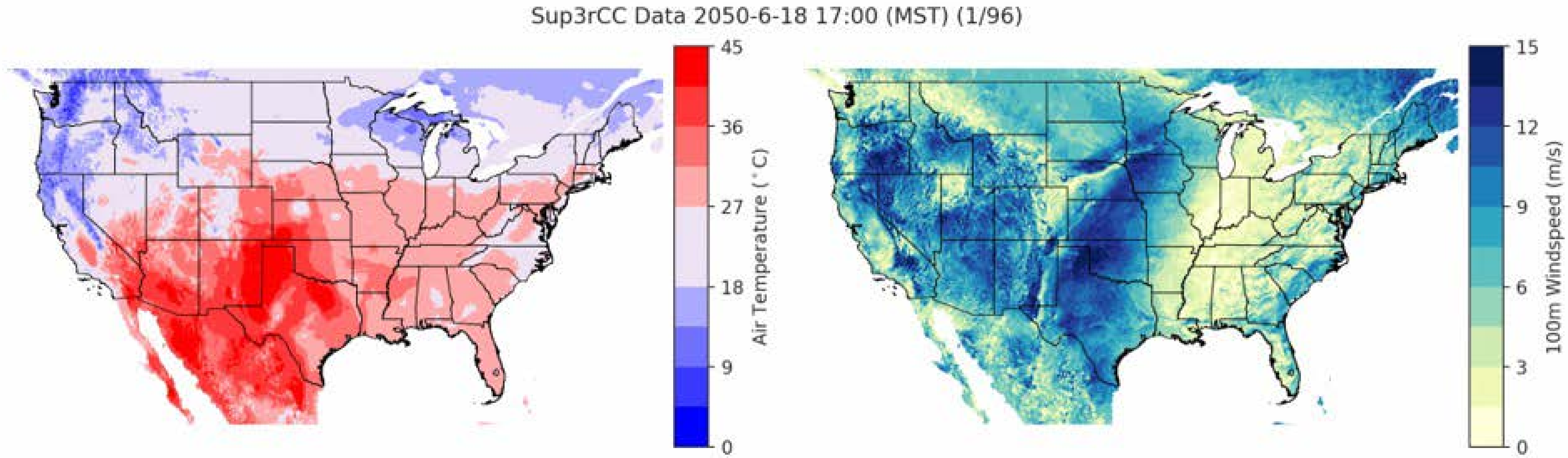
High-Resolution Spatial Features and Dynamics



- The Sup3rCC generative models (right) add high-resolution spatial features and temporal dynamics conditioned on the low-resolution GCM input (left)

Animation: https://app.box.com/s/t3jwke2mff4uk9lhu94r8eqhunhhub6o

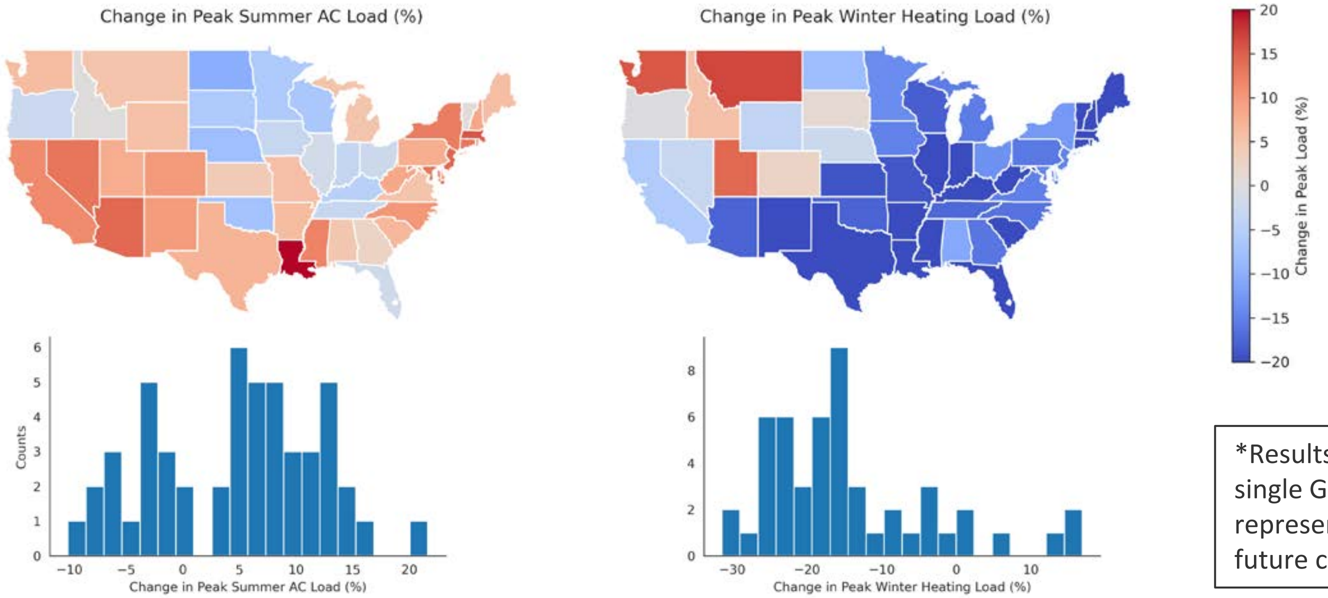
Variables are Spatiotemporally Coincident



- The Sup3rCC data includes temperature, humidity, wind, and solar irradiance variables, all spatiotemporally coincident
- Sup3rCC enables research of future energy systems with high levels of both wind and solar capacity using a single synchronous dataset

Animation: https://app.box.com/s/n0n9xr1bwabp1zolisea5vwa83j0ofle

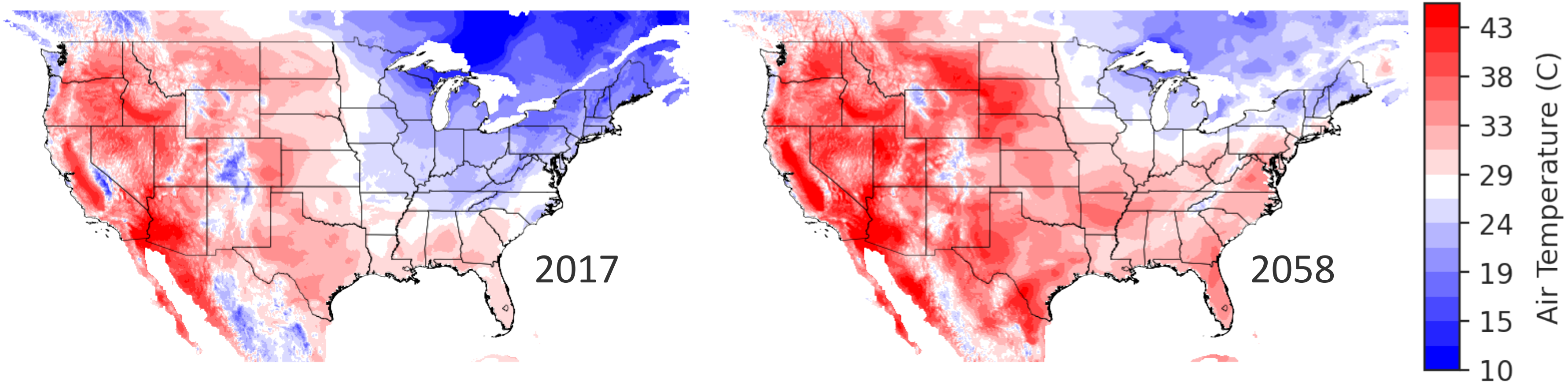
Impacts on Energy Demand



*Results are from a single GCM and only represent one possible future climate

- The high-resolution Sup3rCC temperature and humidity data can be used to estimate the impacts of climate change on future energy demand
- The load data above is based on bottom-up electrical load modeling from Evolved Energy Research for a hypothetical net-zero 2050 electrified infrastructure

Wind + Solar + Temperature Compound Events



- The maps above show snapshots during the hottest days in the West during unseasonably low wind + solar events (more than 1 stdev from baseline values) from the 2015-2024 and 2050-2059 periods

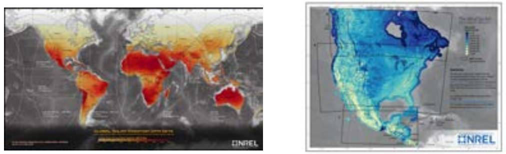
*Results are from a single GCM and only represent one possible future climate

- Future event is +1.4ºC hotter in the West (widespread, population weighted) and up to +3.3ºC hotter (localized temperature increase in Los Angeles)

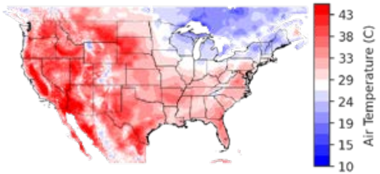
- These generative models and their output data enable a crucial capability to explore how meteorological events that stress the energy system might evolve under climate change.

How does this all fit together?

Renewable Energy Resource Data (NSRDB, WTK)



Climate Change Data (Sup3rCC)



rev

Load Data

Power System Modeling

Capacity Expansion Model (CEM)

Production Cost Model (PCM)

Resource Adequacy (RA)

Results and Insights!

Future Work

1. Open-source model + data release
2. Documentation + publishing
3. Impacts on the renewable energy supply curve
4. Coupling with buildings and bottom-up load models
5. Integration into capacity expansion, production cost, resource adequacy
6. Uncertainty quantification with large GCM ensembles

Thank you

www.nrel.gov

Grant.Buster@nrel.gov

NREL/PR-6A20-85711

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the DOE Grid Deployment Office (GDO), the DOE Advanced Scientific Computing Research (ASCR) program, the DOE Solar Energy Technologies Office (SETO), and the Laboratory Directed Research and Development (LDRD) program at the National Renewable Energy Laboratory. The research was performed using computational resources sponsored by the DOE Office of Energy Efficiency and Renewable Energy and located at the National Renewable Energy Laboratory. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL
Transforming ENERGY