Climate and Weather Impacts on Resource Adequacy

ESIG Weather Inputs Task Force

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Hay Canyon Wind Farm. Photo © Justin Sharp

Sharply Focused
Understanding Renewable Resources

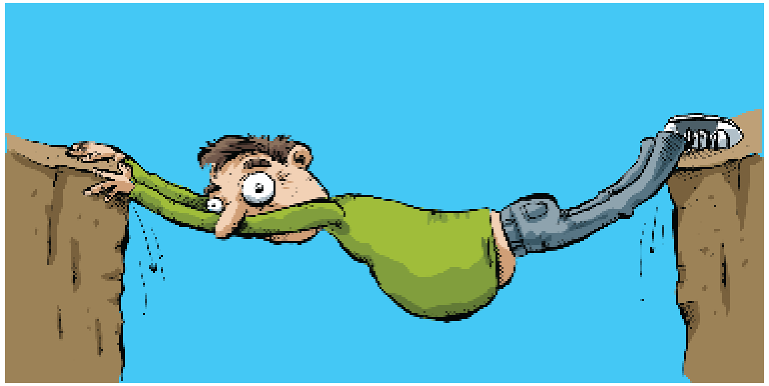
ESIG
ENERGY SYSTEMS INTEGRATION GROUP

ESIG Spring Technical Workshop
Tucson, AZ | March 29, 2023

The Energy Transition

Decarbonize by Electrifying Almost Everything

Generate with Zero Carbon Emissions



Long held opinion: Shoehorning renewables into the existing system design simply will not work!

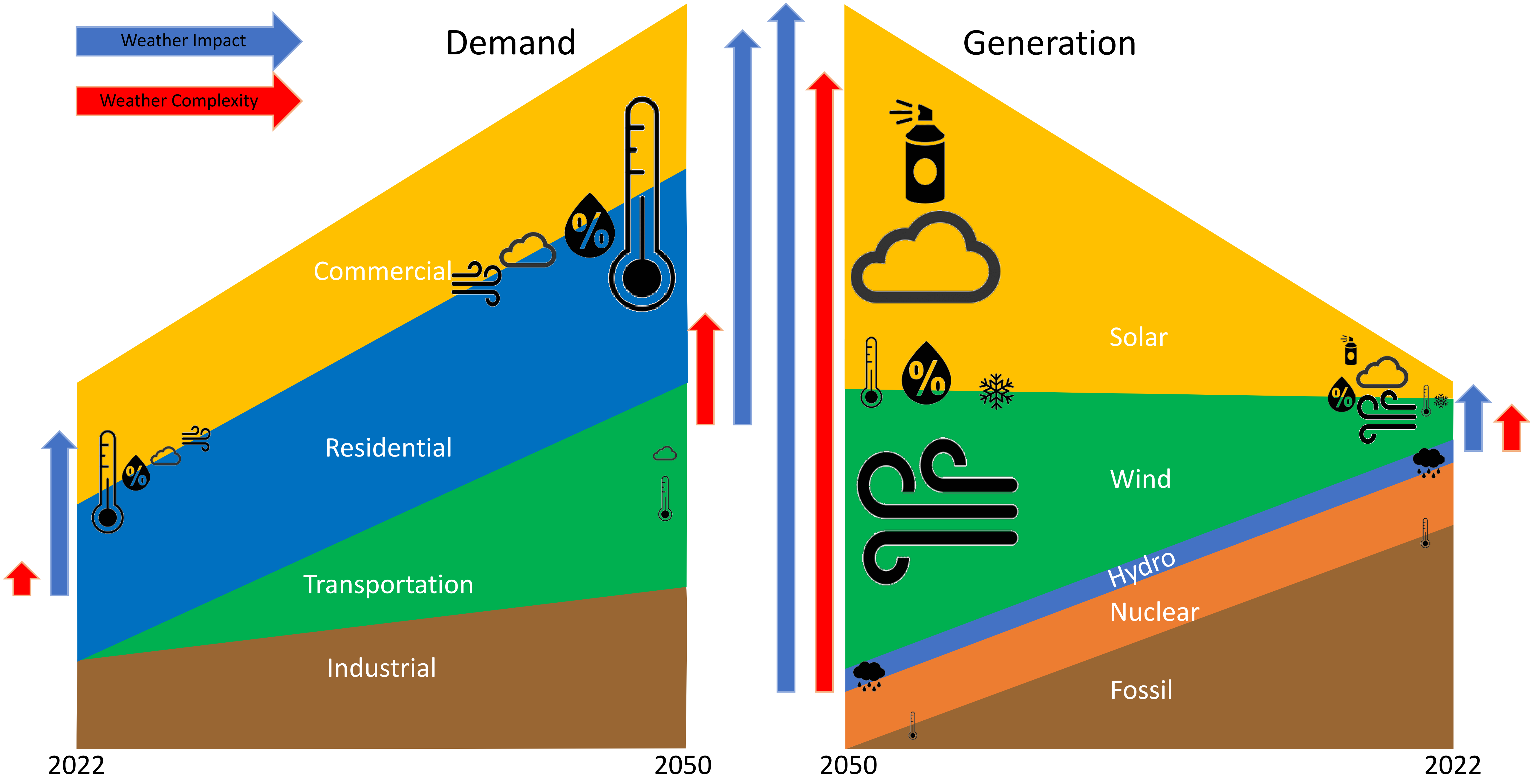
RADICAL CHANGE IS NEEDED AND IT NEEDS TO BE INFORMED
BY WEATHER AND CLIMATE ATTRIBUTES

The Electric System is Changing…RADICALLY…and it is full of uncertainty

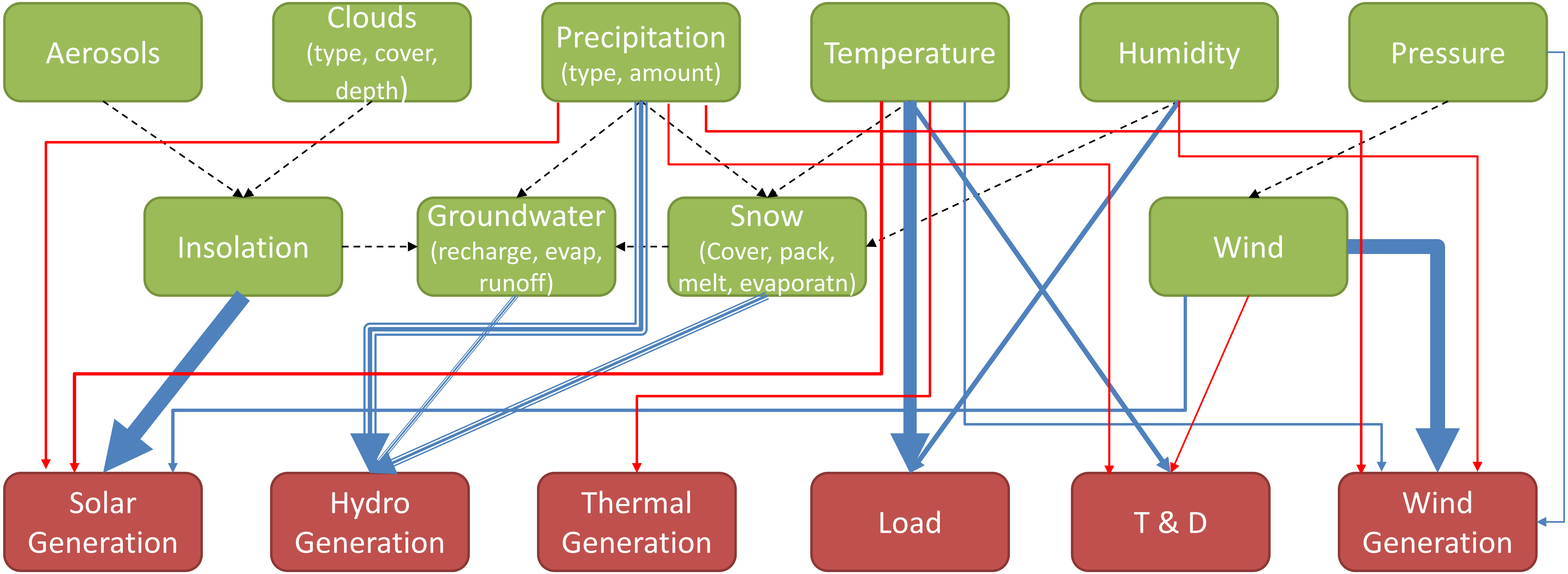
- Loads are going to evolve dramatically with deep decarbonization
- Economics and policy are driving ever larger RE shares
  - Phew! There's hope for humanity…but we've got to keep the lights on
- Future resource types, their contribution, and mix, are uncertain
  - How cheap will solar become? Will long duration storage become viable?
  - Is there the political will to deeply decarbonize?
  - How will consumption and behavior shift with technology and climate change?
- BUT WE DO KNOW A LOT ABOUT WEATHER AND (CURRENT) CLIMATE
- We MUST enable better decision making, especially for planning horizons with the variables we do know a lot about
  - Understand the system evolution…work together…build better system models
  - **Procure/create the right data for power systems modeling and use it appropriately**

- Use this knowledge to ADAPT AND EXPAND THE TRANSMISSION GRID, DEPLOY STORAGE, AND STRATEGICALLY PLACE GENERATION to minimize risk
- The impact of weather and the definition of "extreme weather" is shifting
  - The Evolving Role of Extreme Weather Events in the U.S. Power System with High Levels of Variable Renewable Energy
  - Abstract: https://www.osti.gov/biblio/1837959 Full Report: https://doi.org/10.2172/1837959

The Evolving Weather - Energy Nexus



Weather and Climate System Interactions with Electric System Components Are Becoming Much More Complex and MUST be Properly Quantified



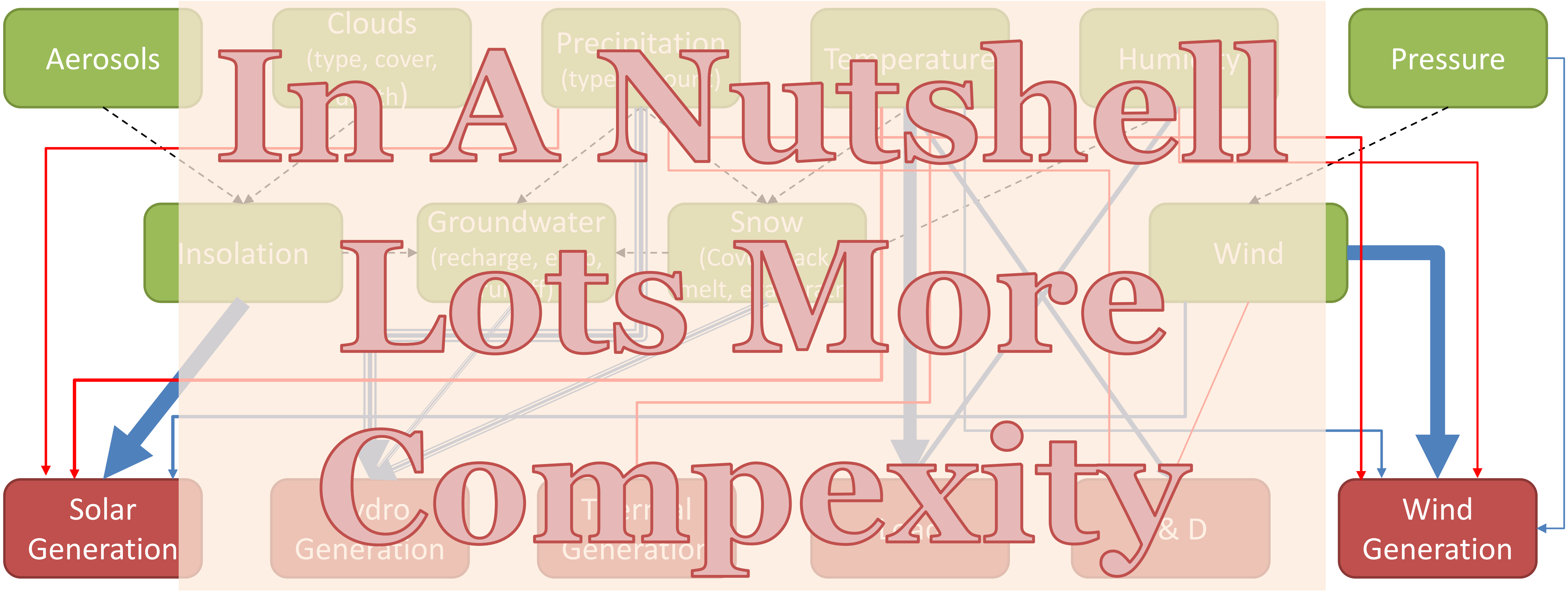
All environmental variables are interdependent. These are some of the strongest internal links

Climate system -> electric system dependency with typical magnitude approximated by line width

Dependency strength is highly variable depending on asset type and location

Dependency importance may be highly amplified by specific weather and climate conditions

Weather and Climate System Interactions with Electric System Components Are Becoming Much More Complex and MUST be Properly Quantified



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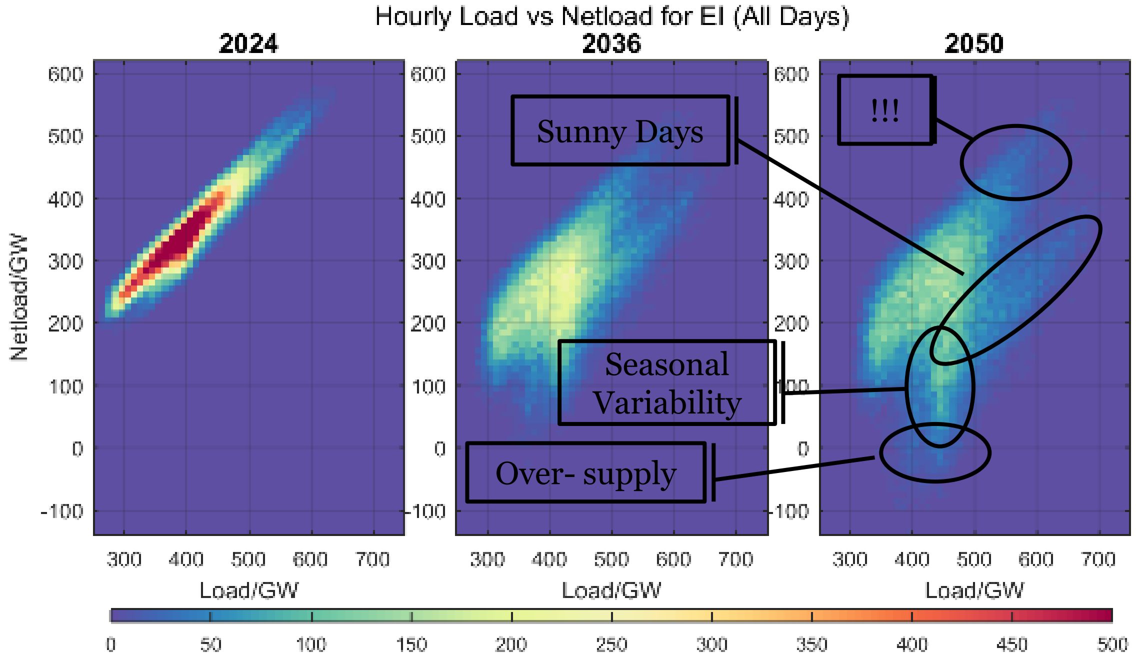
Changes in Supply Side Risk Profile

- Weather becomes the predominant driver of supply and demand balance
- Risk shifts from peak demand, to peak demand net of renewables.
- Most of the time the system will have wider margins, becoming over-supplied as penetration increases
- High demand with low renewable resources will become as impactful as peak demand and then more so

NREL Extreme Weather Events
Project Capacity Buildout

Year	Thermal	Hydro	PV	Wind	Storage
2024	703.3	88.3	113.2	87.1	14.5
2036	669.3	88.3	403.4	257.5	14.8
2050	704.9	88.3	629.6	325.4	17.7

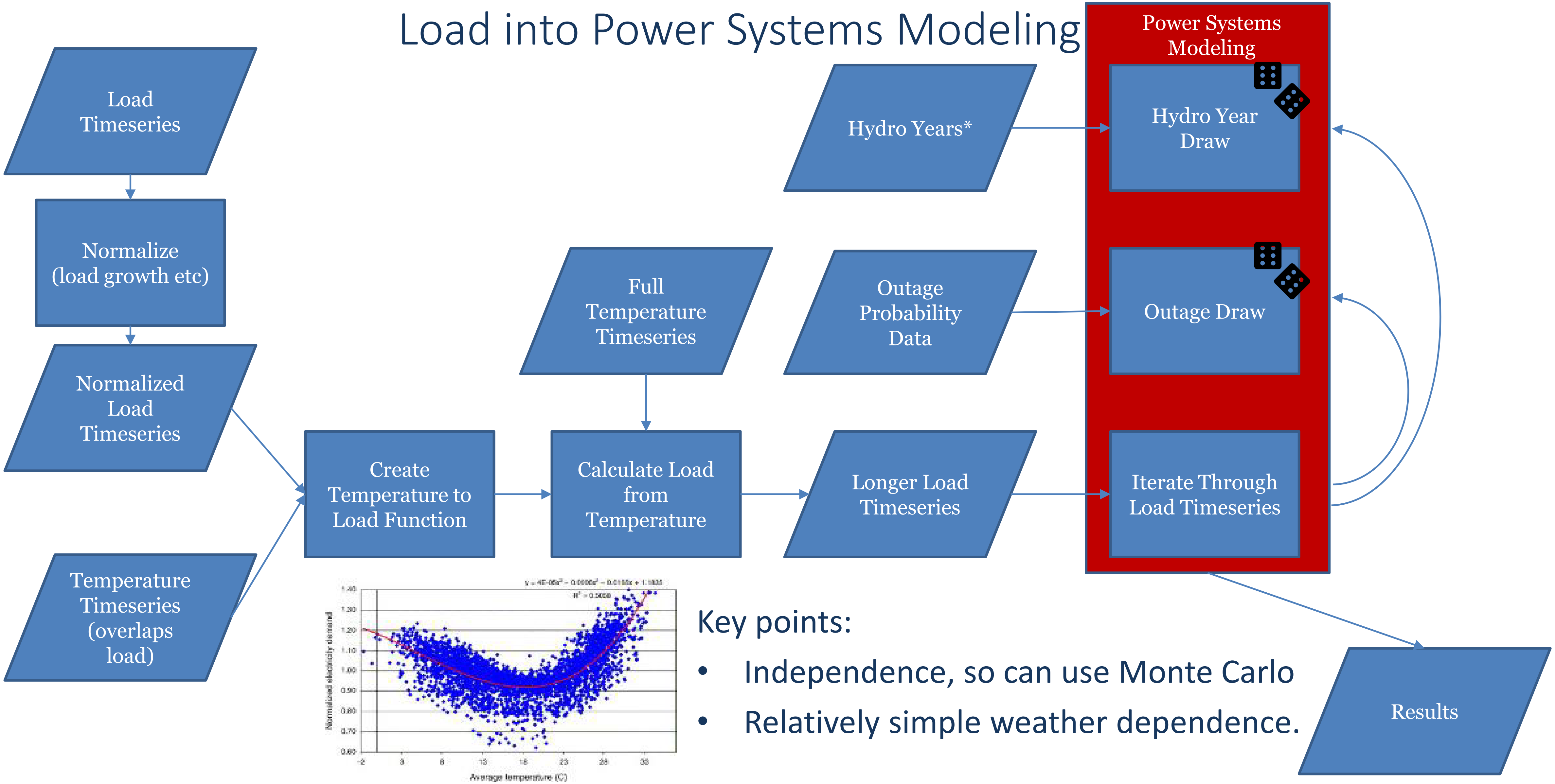
Netload = load – renewables
Solar/Wind generation estimated for portfolios for weather years 2007-2013 using coincident NSRDB/WIND TK data.



Hours/pixel (total hours = 8760*7 = 61320)

See [The Evolving Role of Extreme Weather Events in the U.S. Power System with High Levels of Variable Renewable Energy (Technical Report) | OSTI.GOV]() for details.

Illustrative Example of Current Incorporation of Weather Impacting Load into Power Systems Modeling

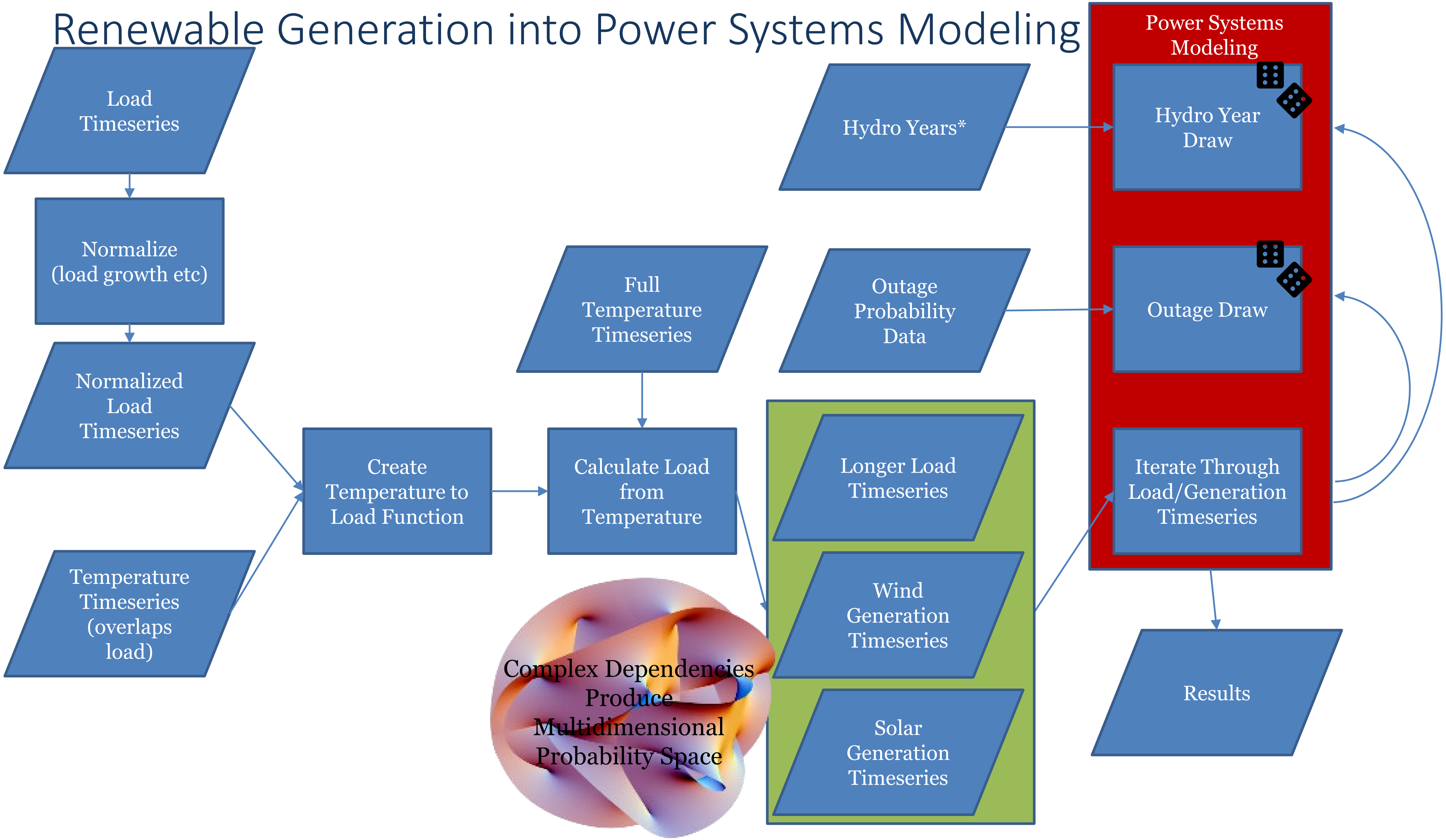


Key points:

- Independence, so can use Monte Carlo
- Relatively simple weather dependence.

*Hydro years is illustrative only. Can iterate across other constraints. Nesting method can vary.

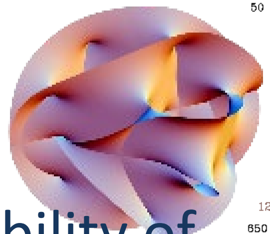
Illustrative Example of Incorporation of Weather Impacting Load and Renewable Generation into Power Systems Modeling

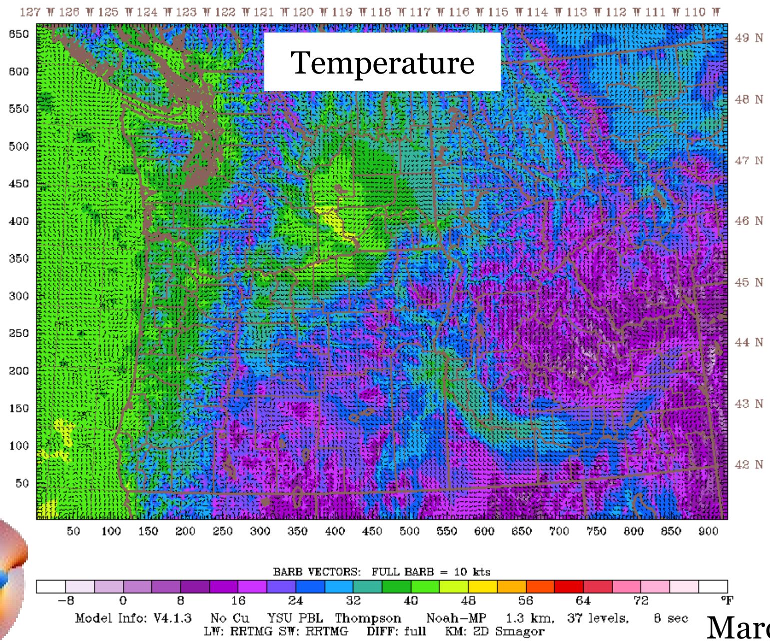


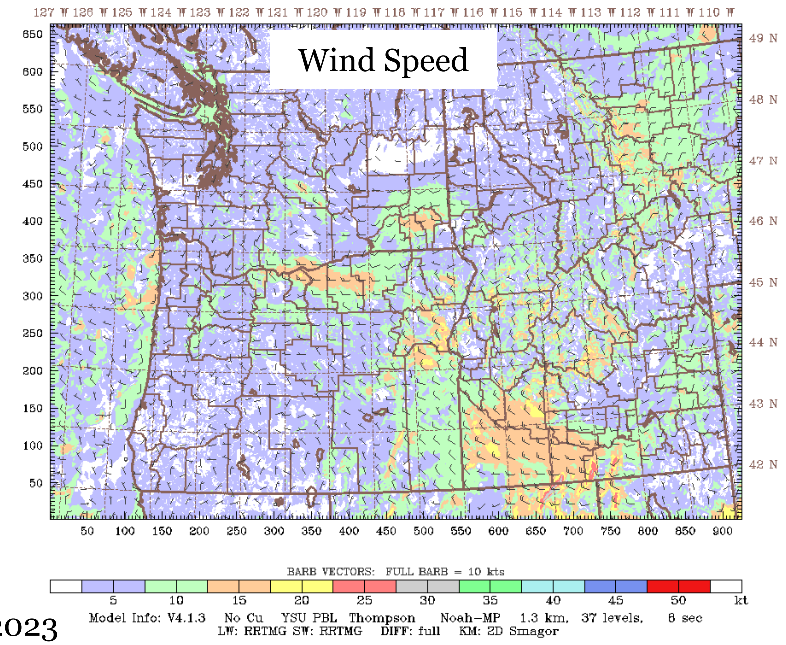
Longer Load Timeseries

Wind Generation Timeseries

Solar Generation Timeseries

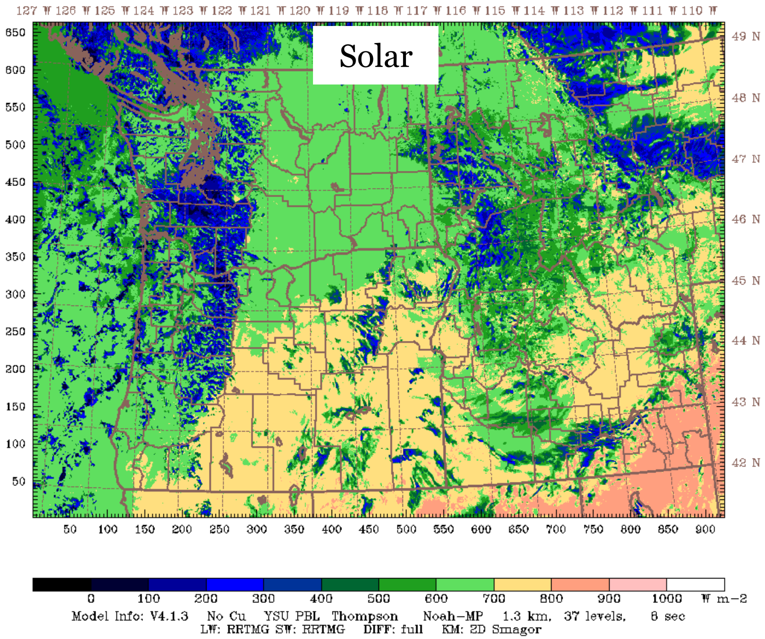






11 PDT
March 26, 2023

- Complex variability of variables impacting load, wind, and solar, coupled with their interconnectivity in time and space yields complex, yet organized probability distributions.



Accurately Modeling Power Systems with Increasing VRE and Storage

- We need to estimate the renewable generation at an appropriate aggregation level for the same weather pattern that is driving load, and we need to do it chronologically
- Two approaches:
  - Bottom up: Producing a reasonable estimate of generation at every possible location for wind and solar plants and aggregate to the required level
    - Requires detailed data sets that have been carefully validated and shown to be accurate
  - Top down: Create a model relating existing generation and weather datasets (e.g. using ML). This is the typical operational forecasting method.
    - Simpler to implement, hard to implement accurately do due to lack of plant data
    - Requires extrapolation of existing generation to new plants to model new capacity
    - Limited to level of aggregation for which generation data is available

Audience Participation Time

- How many people in the room have conducted power systems modeling studies, and/or used their outcomes for decision making or other work?
- How many you know where the weather inputs used for generation estimates in the modeling studies you've been involved in come from?
- How many of you have validated the accuracy of the weather data that underpins these studies, or at least read detailed validation reports that detail the accuracy of the data
- How many of you have looked specifically at accuracy during periods of low resource?

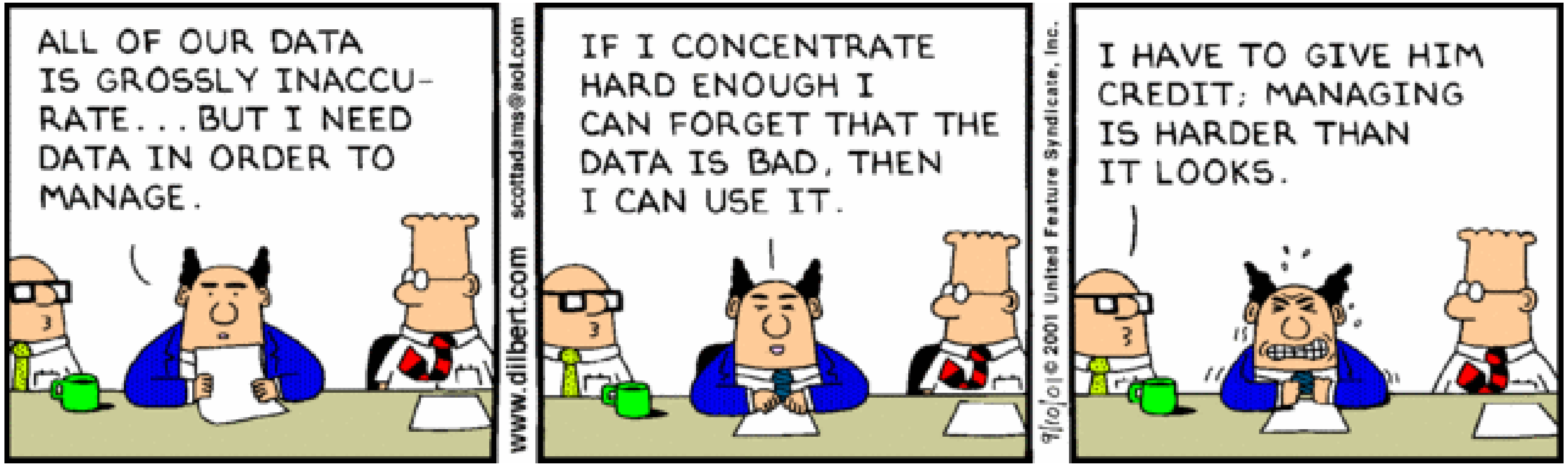
Radical Hypothesis

Historical generation estimations used in power systems modeling are currently less accurate than operational generation forecasts.

This is partly because plant data is available and used for training/validation of operational forecasts and partly due to more attention being paid to forecasting.

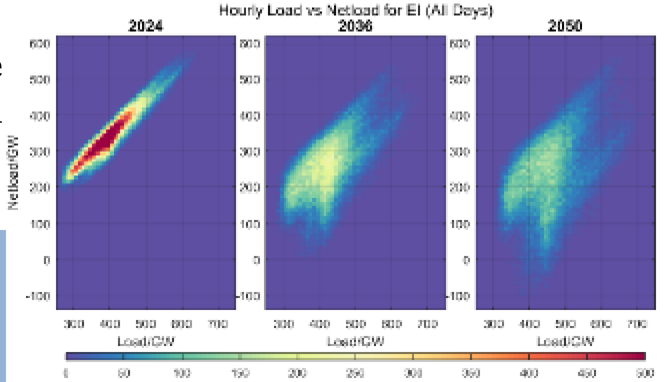
The Big Picture – Collective* Denial

- The data we have is insufficient for the task at hand. Garbage In = Garbage Out



- Creating a better dataset is possible. It is not a trivial side project, but the cost is small compared to mistakes in the $trillions transition
- Industry collaboration and cooperation is essential and low hanging fruit.

*Guess where this data is from



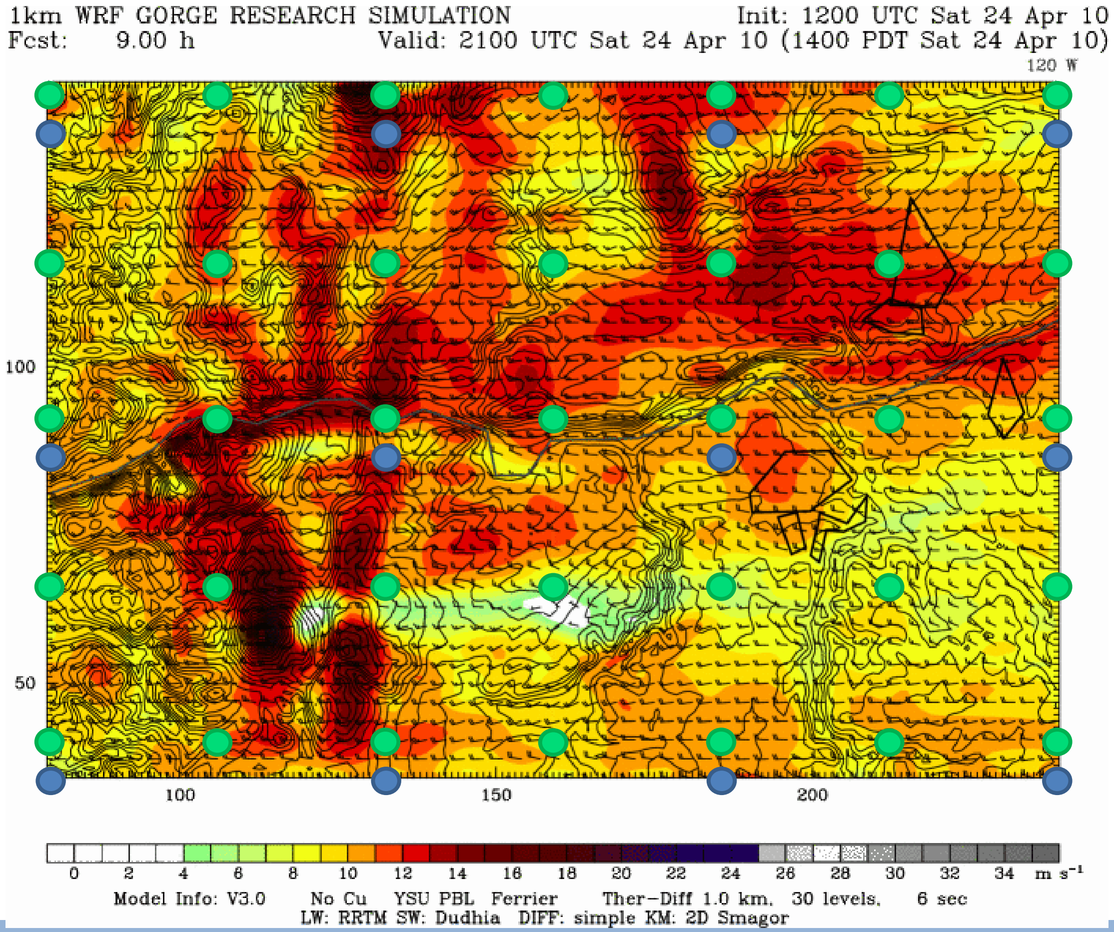
Now I've Got Your Attention…What are the Challenges?

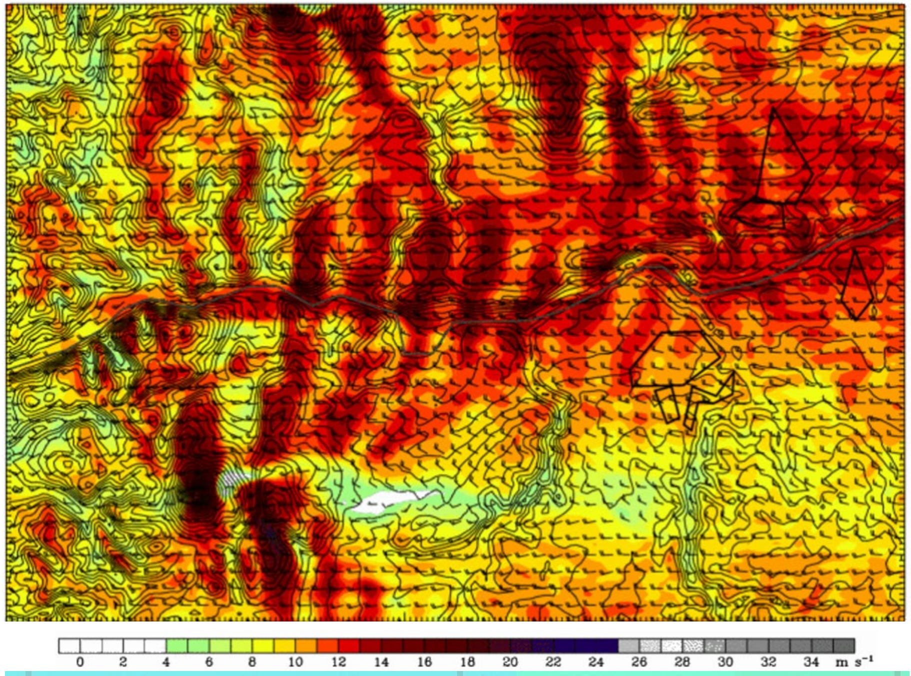
- Weather input validation and statistical correction is difficult to impossible:
  - Need to estimate generation in locations where no meteorological or generation data is available
  - Lack of sector cooperation: ground truth data is not even available at existing VRE generation sites
- Meteorological data being used as a black box resource with observation level quality
  - Lack of understanding by end-users of meteorological data origins and limitations
  - Often there is little or no interaction with a meteorologist
- Meteorologists not questioning how power systems practitioners utilize the data they are asked to provide
  - "Here's the data you need…" with an assumption that engineers know, or will validate, data limitations
- Lack of validation of weather data in the context of weather scenarios that matter the most
  - Validation tends to be of average errors at a handful of locations. Little or no validation of tail events.
  - As far as I can tell we are mostly flying blind…I'm not being alarmist…I'm telling it how I see it.
- Silos everywhere. We have to get out of them. Including at DOE!

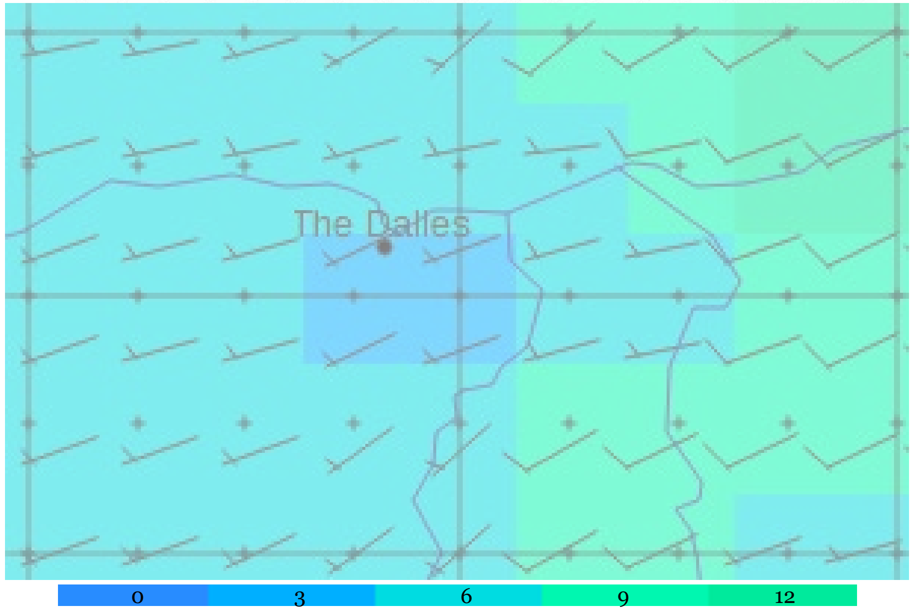
Get out of the silos…meteorology is becoming central

Simple Example 1: Resolution/Fidelity

- The grid scale doesn't just define the fidelity of the data presented. It defines the type of weather phenomena that can be modeled



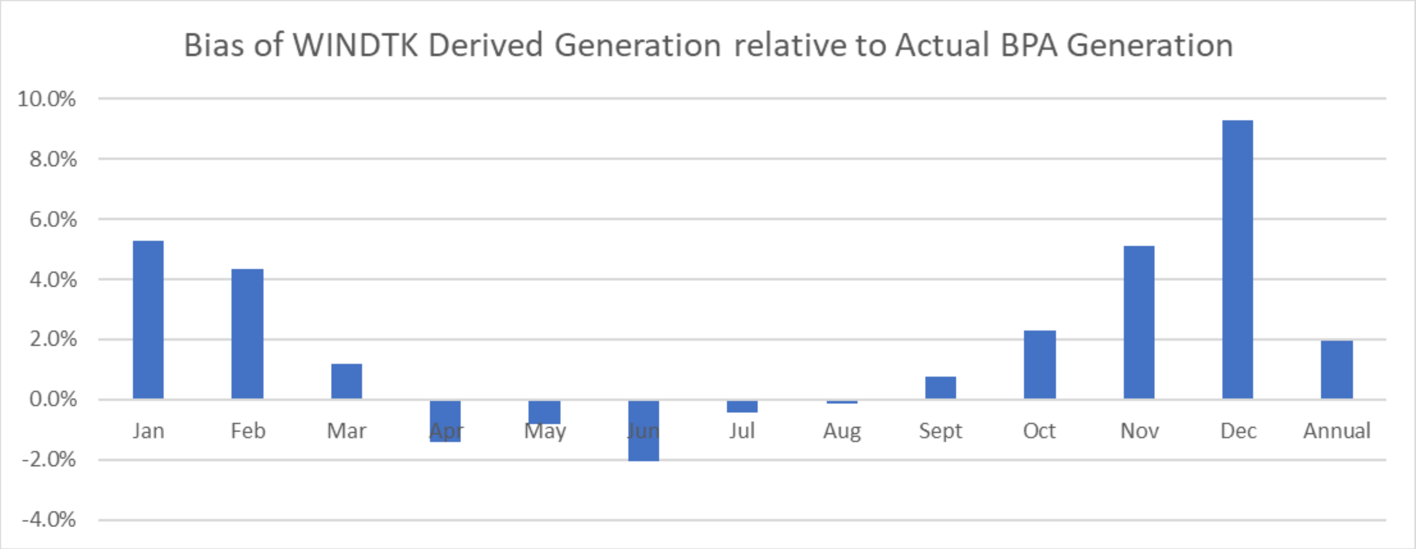




Simple Example 2: Validation

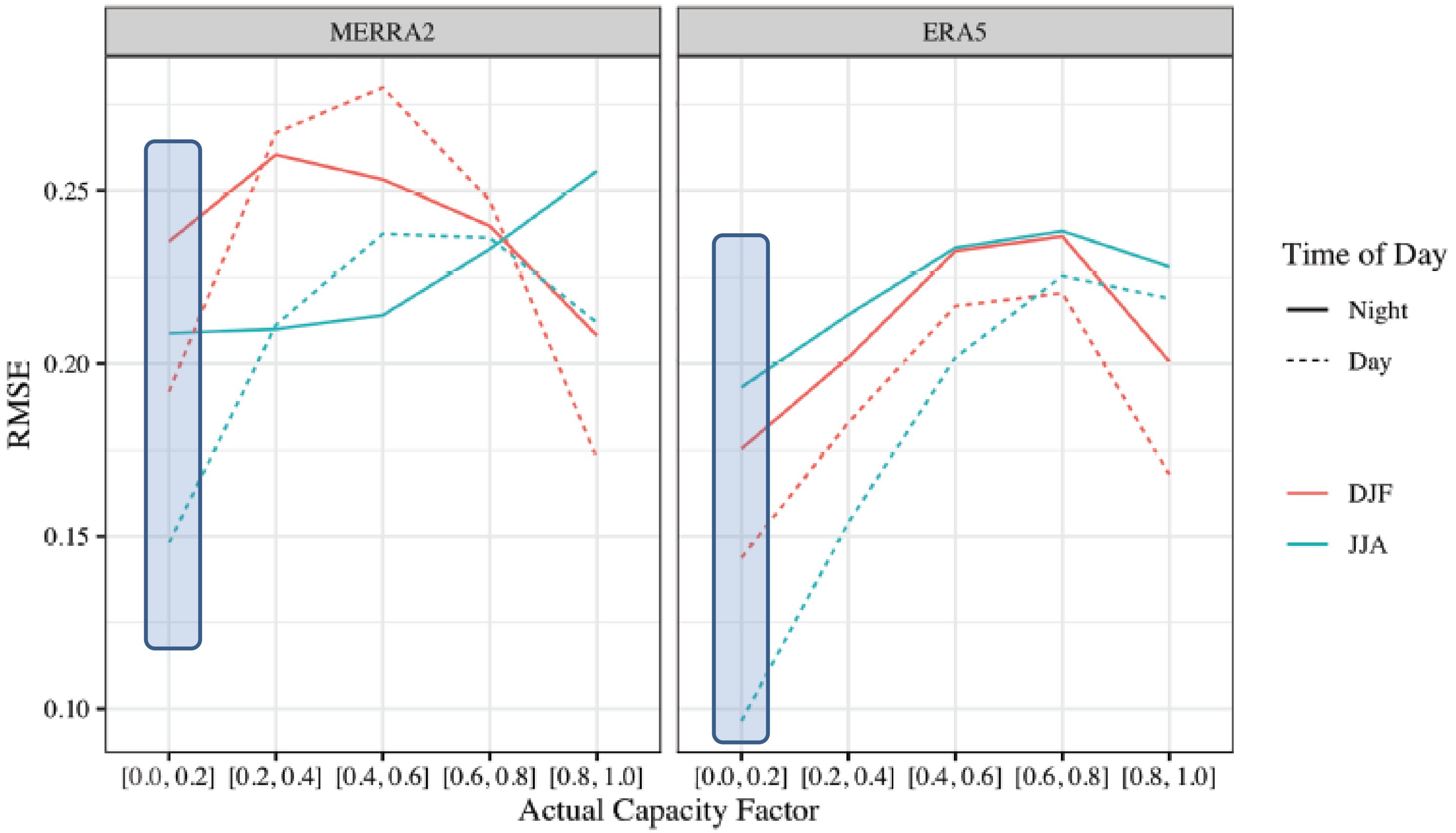
- We must validate everything. Not just the averages, and distributions, but the tails
- The distribution of coincident tail events MUST be close to reality
- Example:
  - WINDTK data in the BPA area
  - Wind resource in BPA BA is notoriously difficult to predict with NWP => WFIP2 Project
    - Complex terrain that needs a minimum of 1.33 km resolution to resolve
    - Stable boundary layer issues in the wintertime.

These biased low wind speed events frequently coincide with high load events due to regional mesoscale meteorology



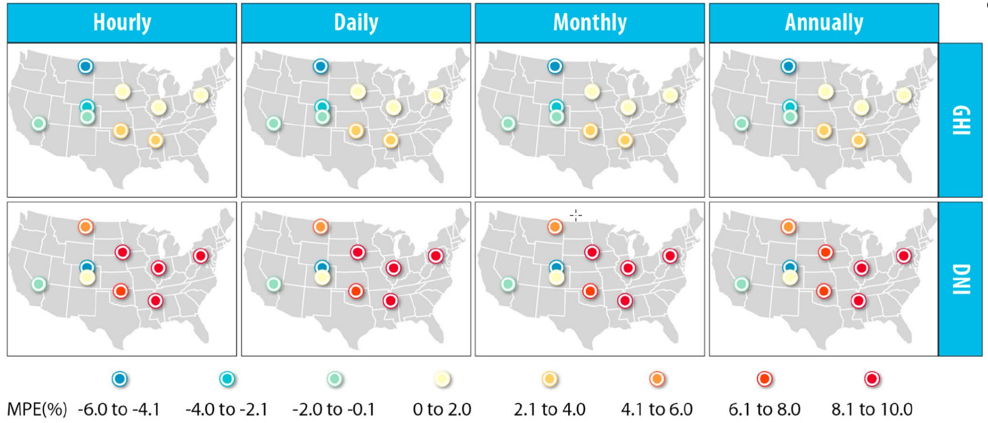
Tail event deviations can be >7x. e.g. BA wide generation of 3% and model based estimates of 23%!

Simple Example 2: Validation (continued)



Average RMSE as a function of recorded CF bins for winter and summer divided into nighttime (8–1 h before sunrise) and daytime (1–8 h after sunrise) averaged across over 100 ERCOT windfarms over 7-years.

Figure from Davidson & Millstein (2022): Limitations of reanalysis data for wind power applications



NSRDB validated* against a handful (literally) of observations, because there simply aren't many quality surface solar measurements available. Note mean percentage error is significant on an hourly and even daily basis, especially for DNI. Despite not being created for this purpose, NSRDB is broadly used as the solar insolation input to estimate solar generation for PS modeling, generally without reference to data input uncertainty

*Sengupta et al (2018): The National Solar Radiation Data Base (NSRDB); Renewable and Sustainable Energy Reviews. *(Figure from paper)*

Takeaways

- The data we have is insufficient for the task at hand.
  - We’re basically flying blind. We have some maps but they’re out of date or don’t show the right information
  - Weather data is a foundational driver of power systems analysis. Its accuracy cannot be ignored.
  - Urgent need for comprehensive data characterizing the weather driven facets of current and future supply and demand
- Creating better data is possible. It is not a trivial side project, but the cost is small compared to mistakes in the $trillions transition
  - Weather input data will never be perfect. The **limitations must be understood** so that appropriate margins can be built in.
  - Data must be produced on an **ongoing basis** and **validated** against as many pertinent observations as possible.
  - The data needs to be **transparently produced**, **openly available**.
  - Data **uncertainty** must be known and **clearly communicated** including the ability to represent the tails of the net-load distribution
- Industry collaboration and cooperation is essential and is the low hanging fruit.
  - Generators must share meteorological and availability normalized data. Ideally it would be public and transparent, but it can be done under NDA.
  - Engineers and meteorologists must work together. Currently we have an old map, and the people reading it don't understand the language it is written in. It looks like English, but it is model English, not weather observation English.

But There Are Some Good Datasets Out There, Right? The State Of Play

- There are some good datasets, but none of them are designed for, or meet the requirements needed for comprehensive power systems modeling for the energy transition

	Spatial Resolution	Temporal Resolution	Length	Continuously Extended	Correct Variables/ Levels	Coincident and Coherent	Validated/ Uncertainty Quantified for VRE Use	Detailed Documentation	Future Proofed	Availability/ Ease of Access	Curation and Advice
MERRA2	~60 km	Hourly	1980-present	Yes	Yes/No	Yes	No	Yes	Maybe		Basic
ERA5	~30 km	Hourly	1959-present	Yes	Yes/No	Yes	No	Yes	Yes		Good
HRRR	3 km	15 min	2014-present	Yes	Yes/No	Yes/No	No	Yes	Yes		Basic
WIND Toolkit	2 km	5 min	2007-2014	No	Yes/Yes	Yes	Yes	Yes	No		Basic
WTK-LED	2 km/4 km	5 min	3 yr/20 yr	No	Yes/Yes	Yes	??	?	No		
NSRDB	4 km/60 km	30 min	1998-present	Yes	Yes/No	Sort of	Yes	Yes	Yes		Basic
CERRA	11/5.5 km	???	???	?	?	?	?	?	?		
CONUS404	4 km	Hourly/15 min precip	1980-2021	No	?	Yes	?	?	?		
BARRA	12 km/1.5 km	???	???	?	?	Yes	?	?	?		
Public Observing Networks	Non-uniform, variable density	1 hr or less	Variable	Yes	Yes/No	Maybe	N/A	Varies	Yes		Basic
Renewable Energy Project Data	Non-uniform, variable density	1 hr or less	Variable	Varies	Yes/Yes	Yes	Yes	Varies	Varies		None
Proprietary Statistically Derived VRE Shapes	Non-uniform, variable density	Hourly	Variable	N/A	Yes/Yes	No	Partial	See foot note	No		None

- More details coming soon in ESIG Weather Inputs for Power Systems Modeling. Stay tuned.