The Need for a National Power System Planning Weather Dataset

Justin Sharp, Ph.D.

Your assumptions are your windows on the world. Scrub them off every once in a while, or the light won't come in.

Alan Alda, actor, writer and director

Hay Canyon Wind Farm. Photo © Justin Sharp

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ESIG Markets and Meteorology Workshop
Denver, CO | June 14, 2023

Motivation: The Energy Transition

THE ELECTRIC SYSTEM IS CHANGING

…RADICALLY…

AND IS FULL OF UNCERTAINTY

THE SECTOR WILL NEED TO EVOLVE

ITS METHODS ACCORDINGLY

ESIG

Findings included in seminal consensus-based reports from the ESIG Rethinking Resource Adequacy initiative

The quality of power system studies becomes increasingly dependent on characterization of weather

Methods must evolve to more completely incorporate weather data

Meteorology is Becoming Central

Decarbonize by Electrifying Almost Everything

Generate with Zero Carbon Emissions

← Fuel Supply Knowledge Gap →

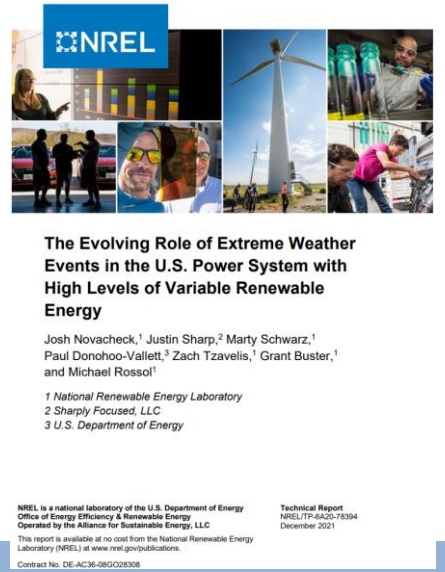
RISKS ARE SHIFTING

WEATHER DEPENDENCE AND WEATHER COMPLEXITY ARE INCREASING

NREL Transforming ENERGY

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)



A Paradigm Shift is Needed

Decarbonize by Electrifying Almost Everything

Generate with Zero Carbon Emissions

AND IT MUST BE INFORMED

BY WEATHER AND CLIMATE ATTRIBUTES

We Urgently Need Better Data For This Purpose!

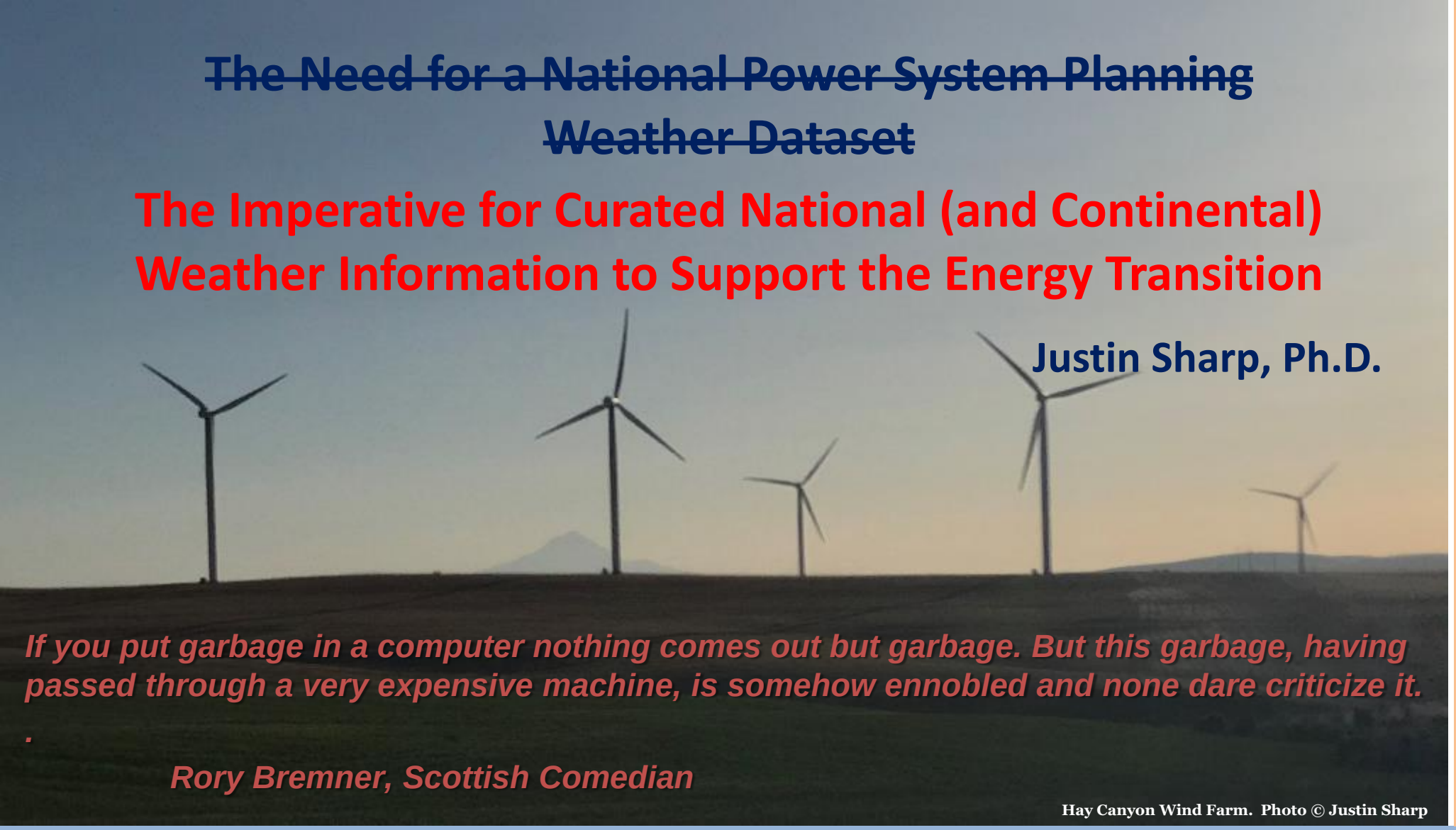
(And to make sure data past and future is used appropriately)

This is detailed in the forthcoming ESIG Taskforce report: "Weather Input Datasets for Power System Modeling: A Needs Assessment and Guide to using Existing Data"

~~The Need for a National Power System Planning Weather Dataset~~

The Imperative for Curated National (and Continental) Weather Information to Support the Energy Transition

Justin Sharp, Ph.D.



If you put garbage in a computer nothing comes out but garbage. But this garbage, having passed through a very expensive machine, is somehow ennobled and none dare criticize it.

.

Rory Bremner, Scottish Comedian

Hay Canyon Wind Farm. Photo © Justin Sharp

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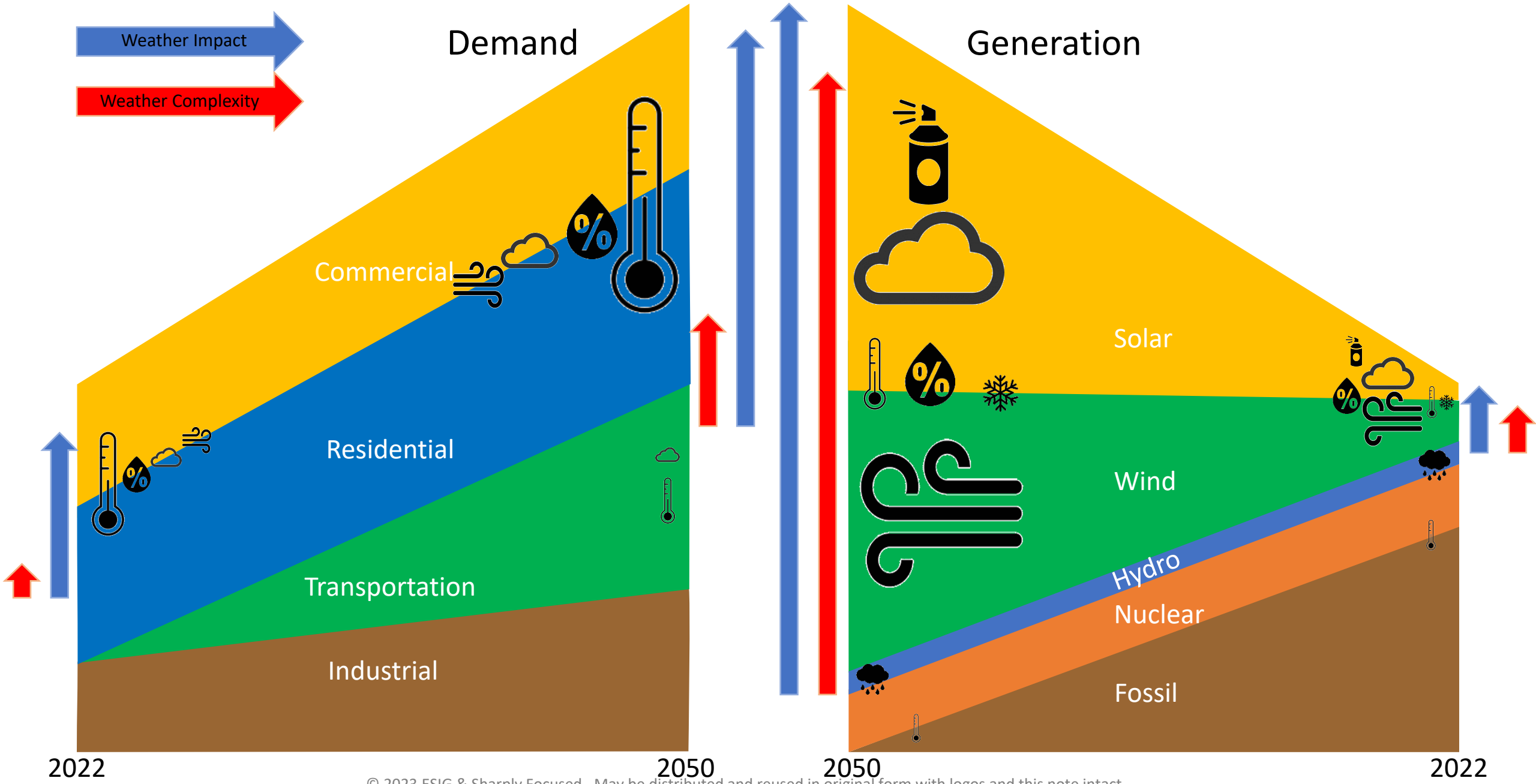
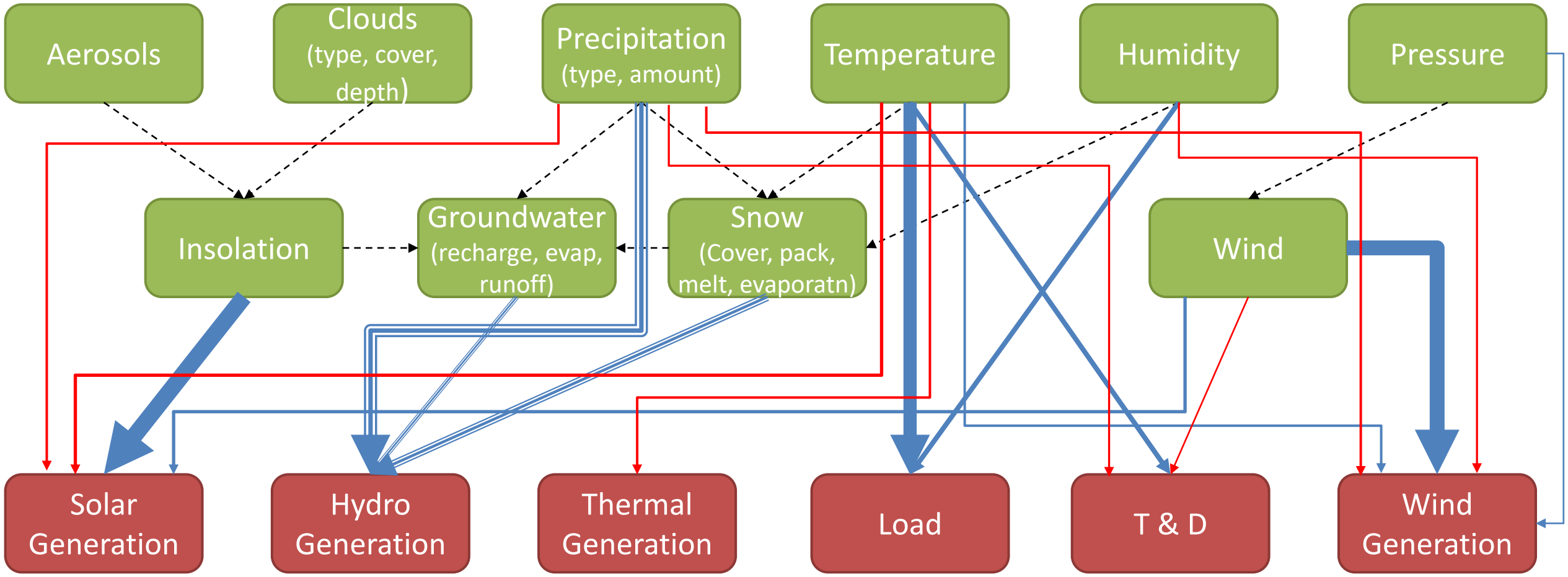
Weather Information for Power System Planning

- ✓What is the energy weather nexus?
- How it the nexus changing? Why does it change the type of information we need?
- There's gobs of weather data out there. What's wrong with the data we have?
- Ok. So, what do we need?
- What will it cost?

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

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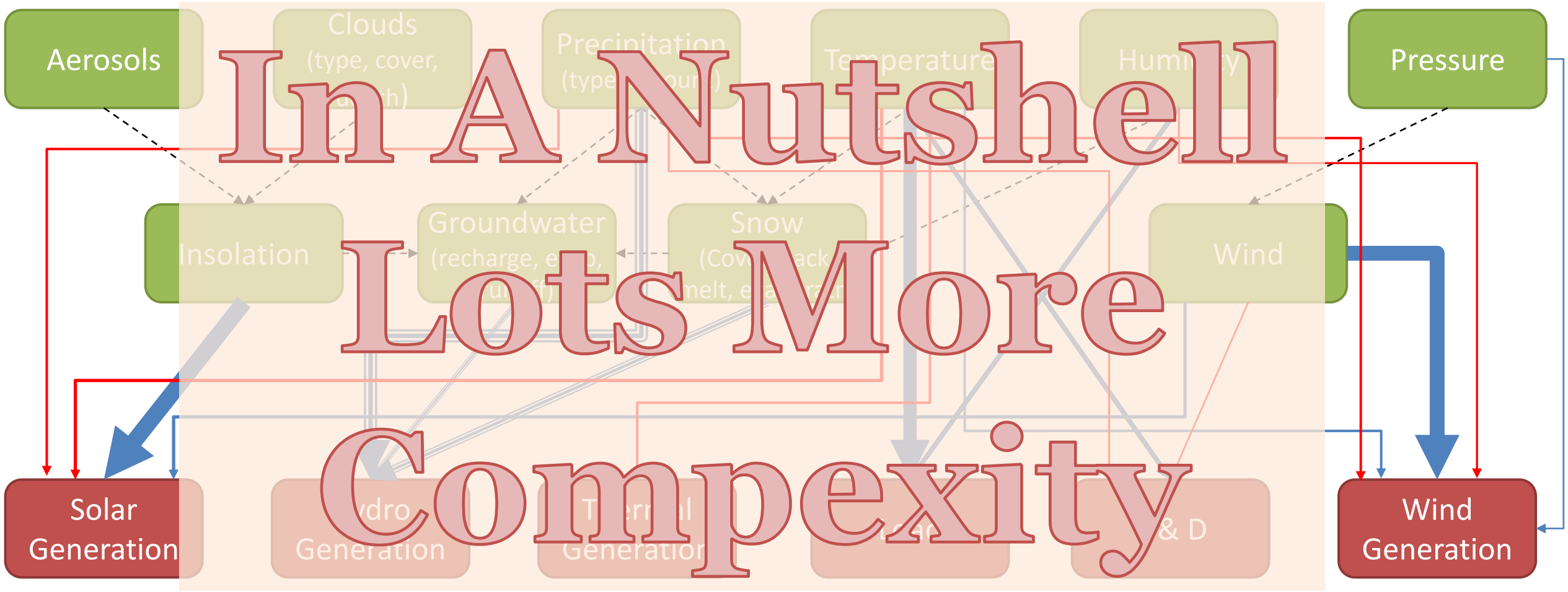

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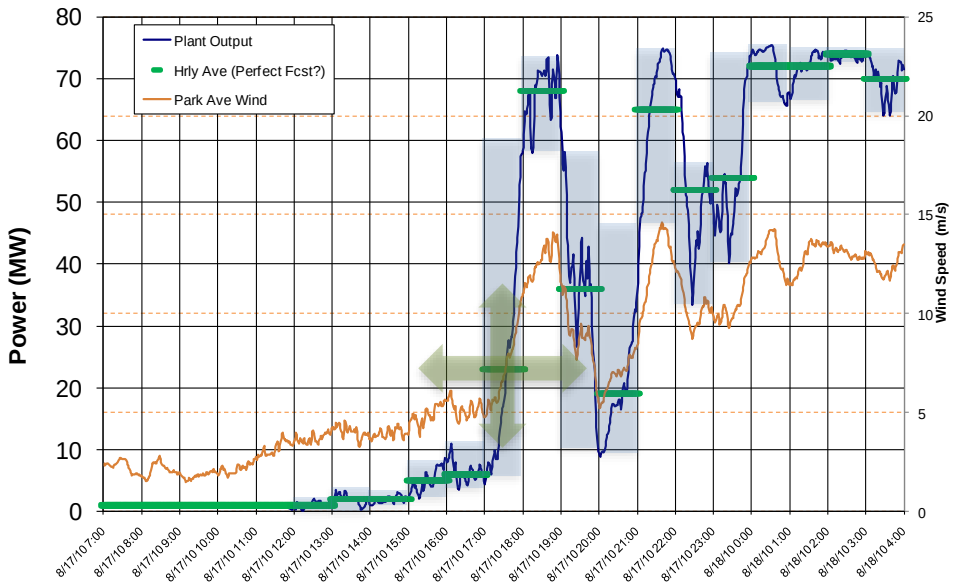
Weather Dependence Must Be Managed/Mitigated



Variability and Uncertainty

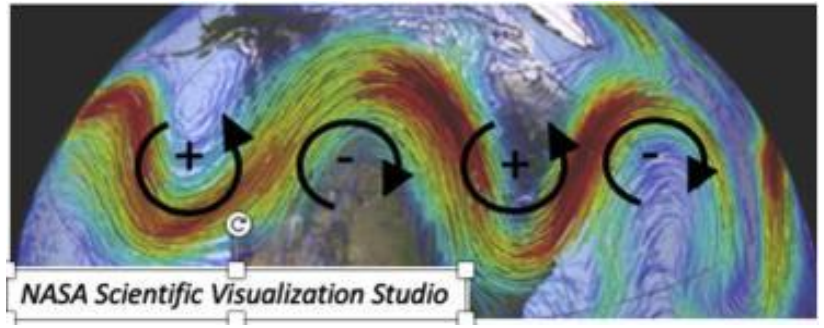
- Mostly due to weather at high RE penetration
- Operational forecasts reduce uncertainty
- Forecasts cannot reduce variability. Planning success depends characterizing and addressing variability ahead of operations.

Ad-hoc Mitigation

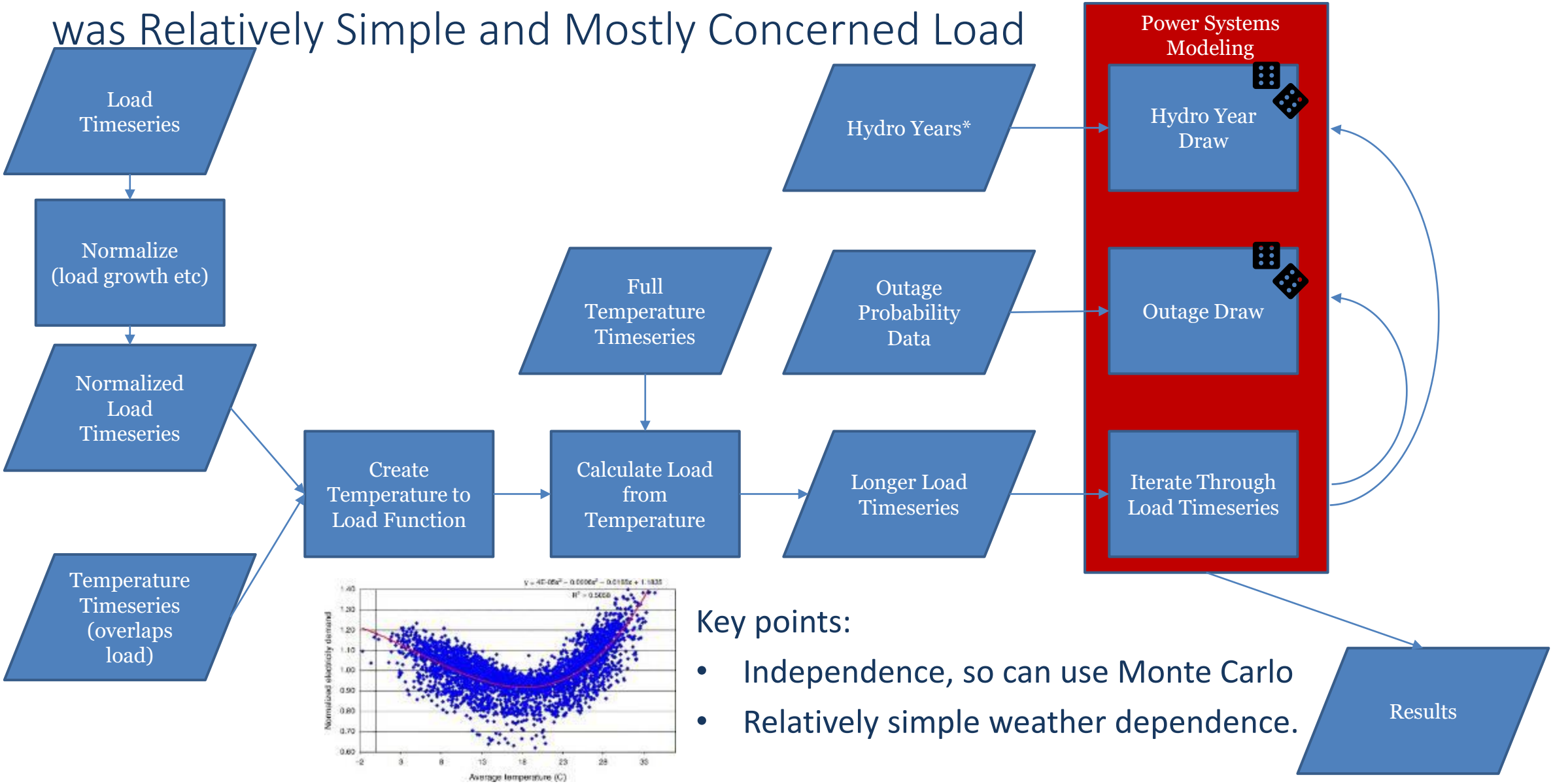
- Energy Storage/P2G
- Overbuilding/fossil backup
- Not efficient or cost effective.
- May not meet policy goals.

Informed Mitigation

- Recognizes continental scale
- Build T&G accordingly
- Requires high-quality, high-resolution, meteorological data
  - Current data is inadequate (pun intended) for the job.



Power System Models Have Always Incorporated Weather but Treatment was Relatively Simple and Mostly Concerned Load

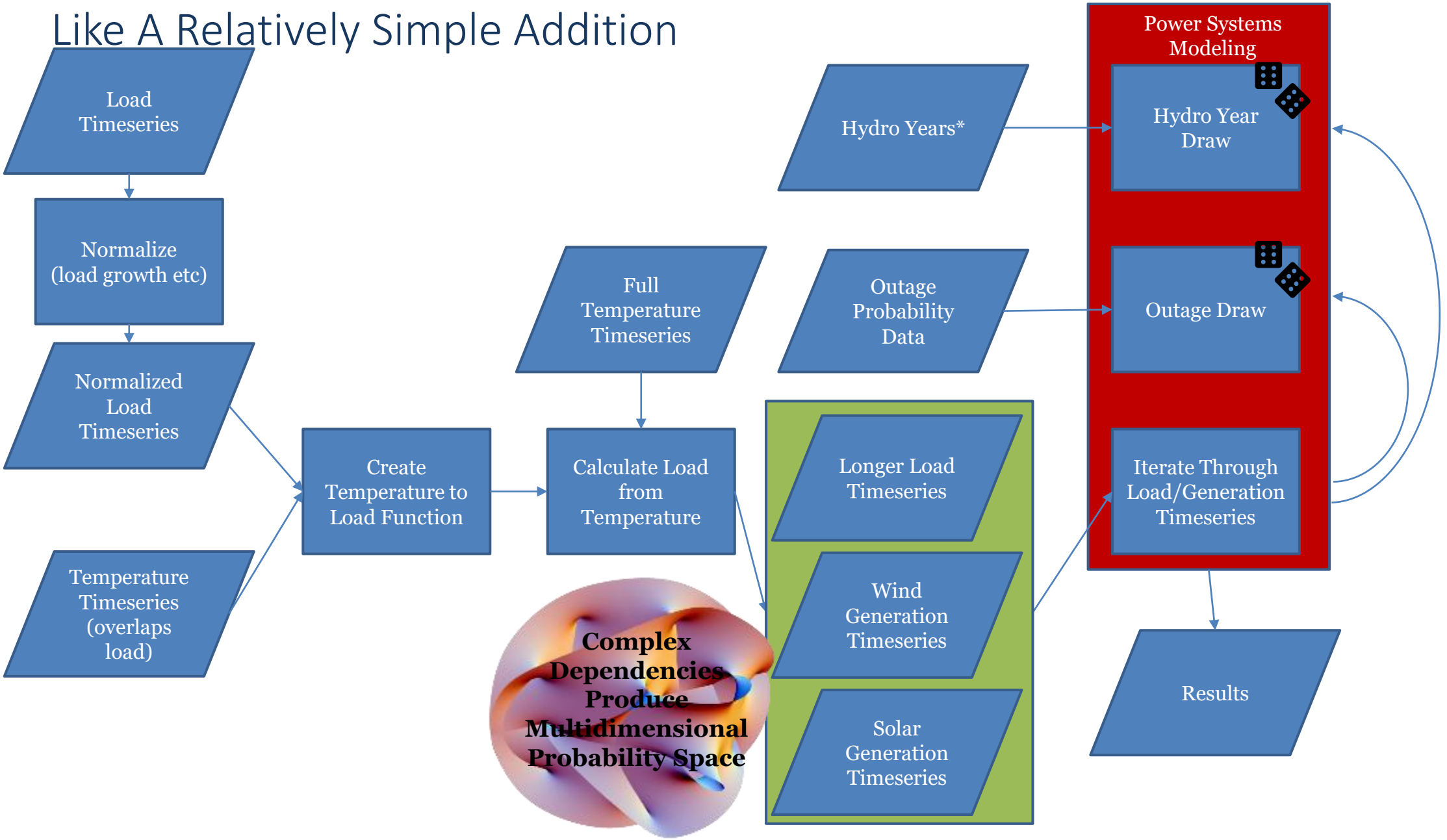


Key points:

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

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

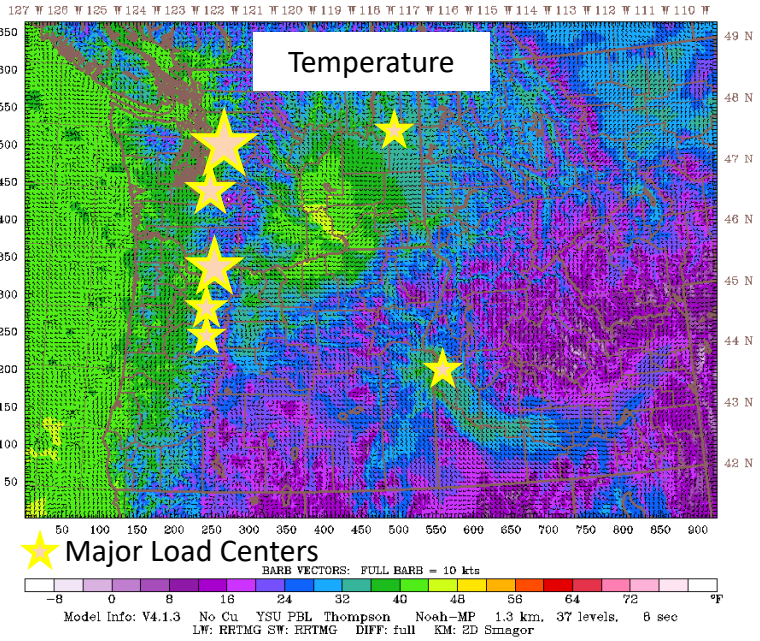
At First Glance Adding Wind, Solar and Storage seems Relatively Seems Like A Relatively Simple Addition

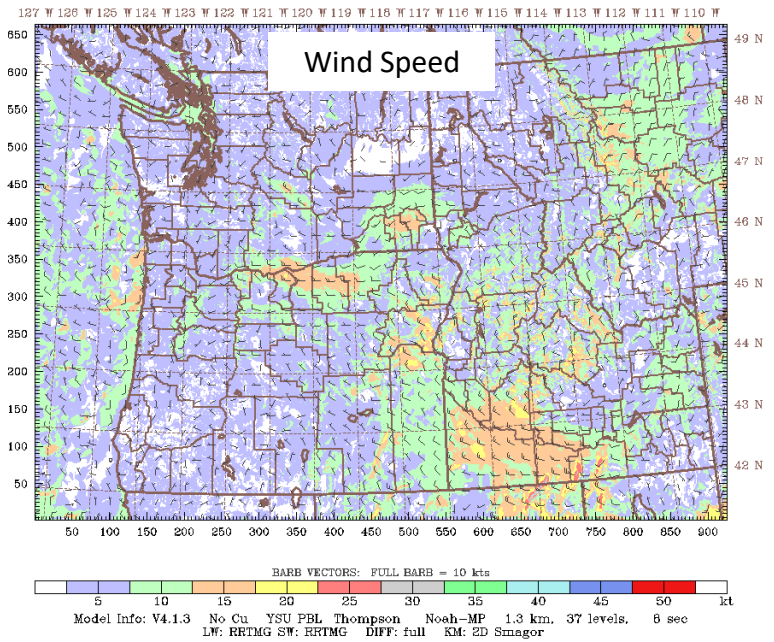


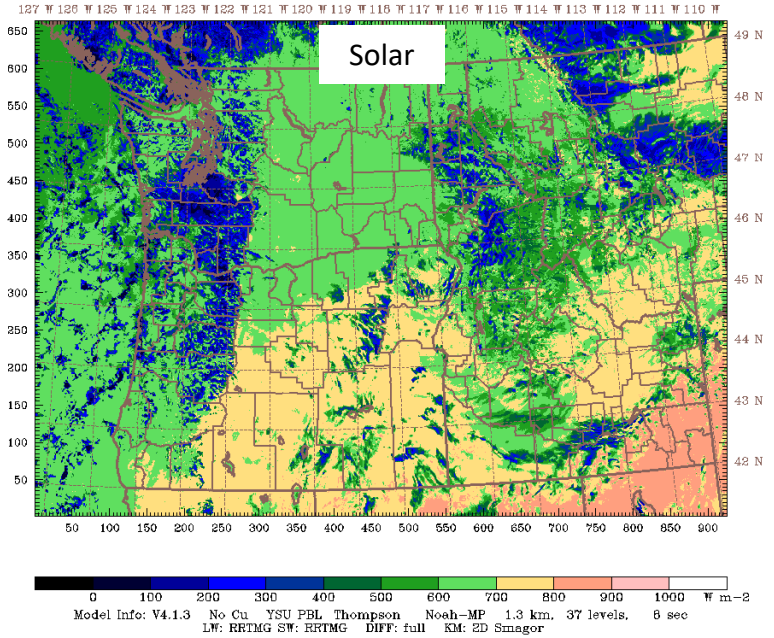
Longer Load Timeseries

Wind Generation Timeseries

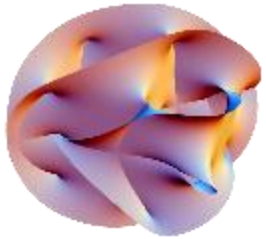
Solar Generation Timeseries







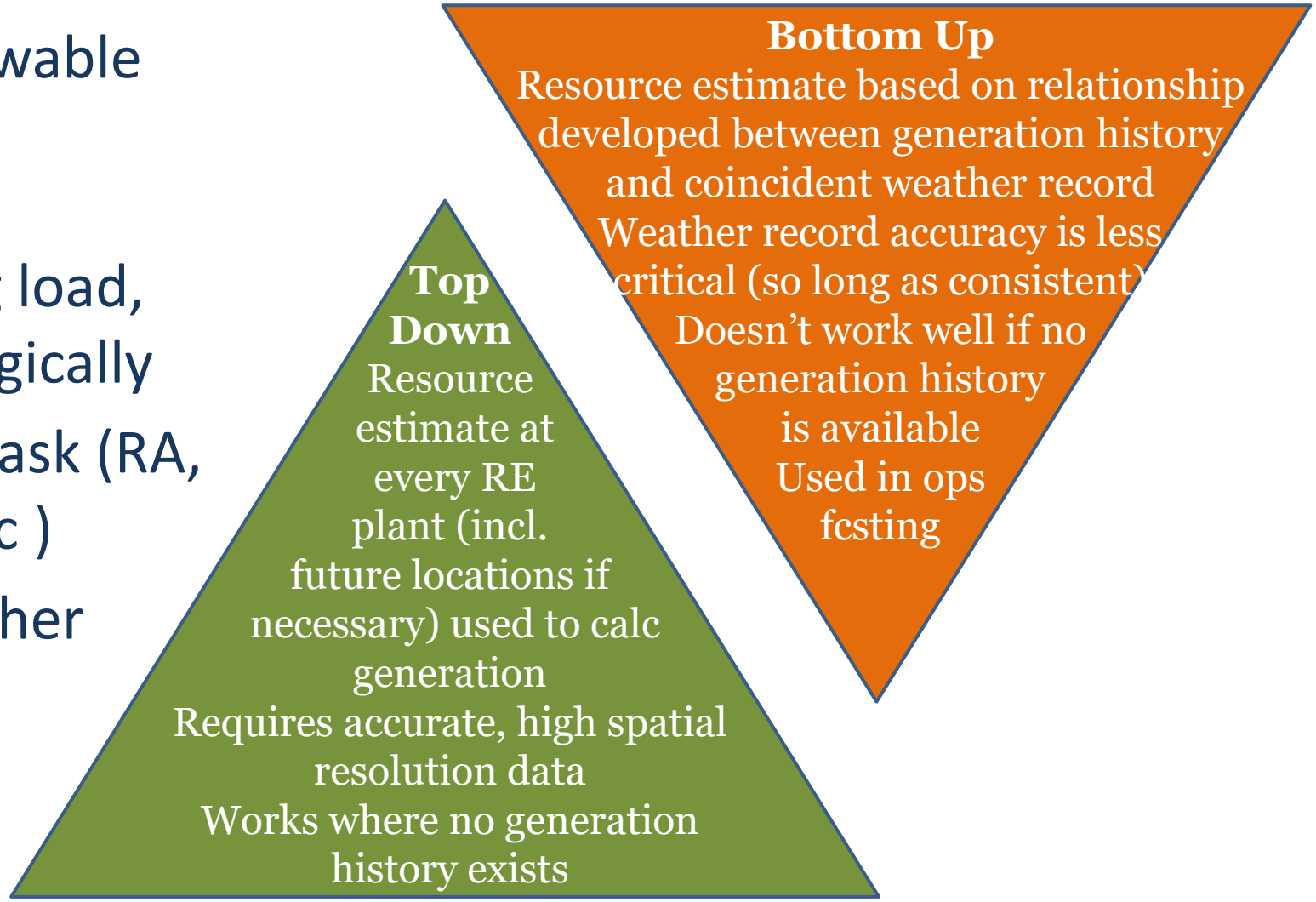
- Complex variability of variables impacting load, wind, and solar, coupled with their interconnectivity in time and space yields complex, yet organized probability distributions
- DERs and storage further complicate things
- Other weather impacts on hydro/thermal/VER generation, and on T&D add yet another layer.



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

- Details depend on analysis task (RA, Capacity Expansion, PCM etc)
- Consider other G/T&D weather dependent drivers where important



But We Produce All This Data and Use it in Operations

Radical Hypothesis

Historical generation estimations used in power system 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.

What Are The Requirements of Weather Inputs for Power Systems Analysis?

- Representative of Actual Weather
- Coincident, Physically Consistent Weather Variables
- Sufficient Resolution (<=2 km, <=15 min)
- Chronological

Physical Requirements

- Covers Multiple Decades with Consistent Method
- Validated and Uncertainty Quantified
- Periodically Refreshed
- Regularly Extended

Relevance Requirements

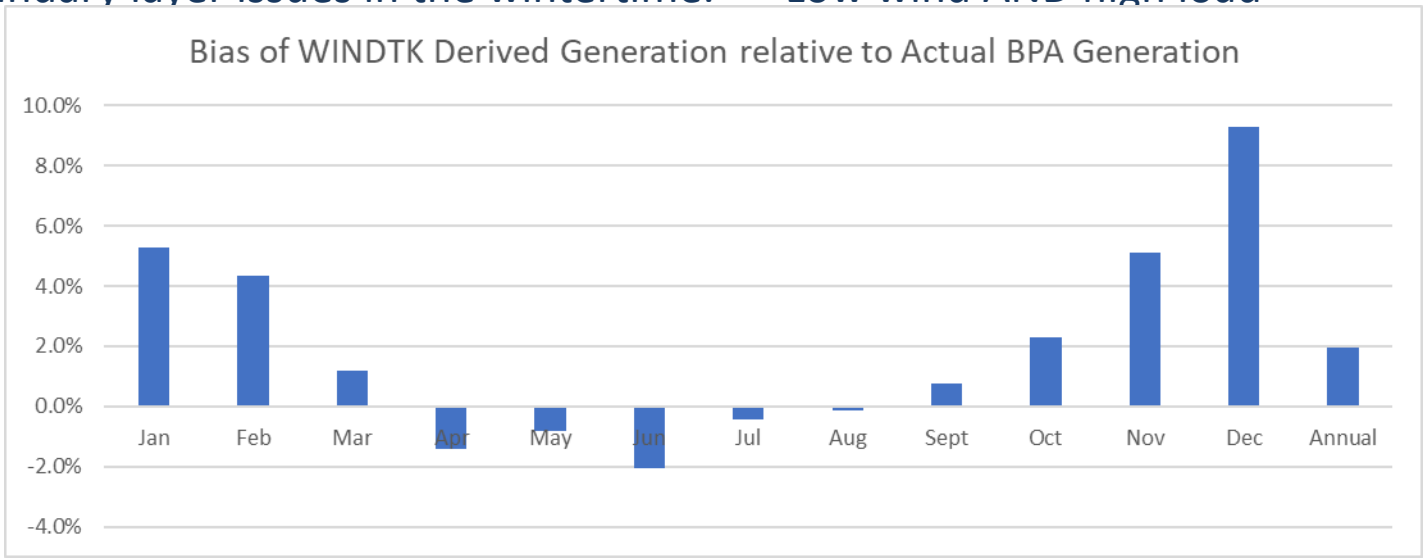
- Expertly Curated
- Publicly Available and Easily Accessible
- Transparently Documented

Usability Requirements

What's Needed: Use Case Specific Validation

- We must validate according to the use case. E.g. For RA, the distributions, and especially the tails, matter more than the averages
- 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. => Low wind AND high load

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

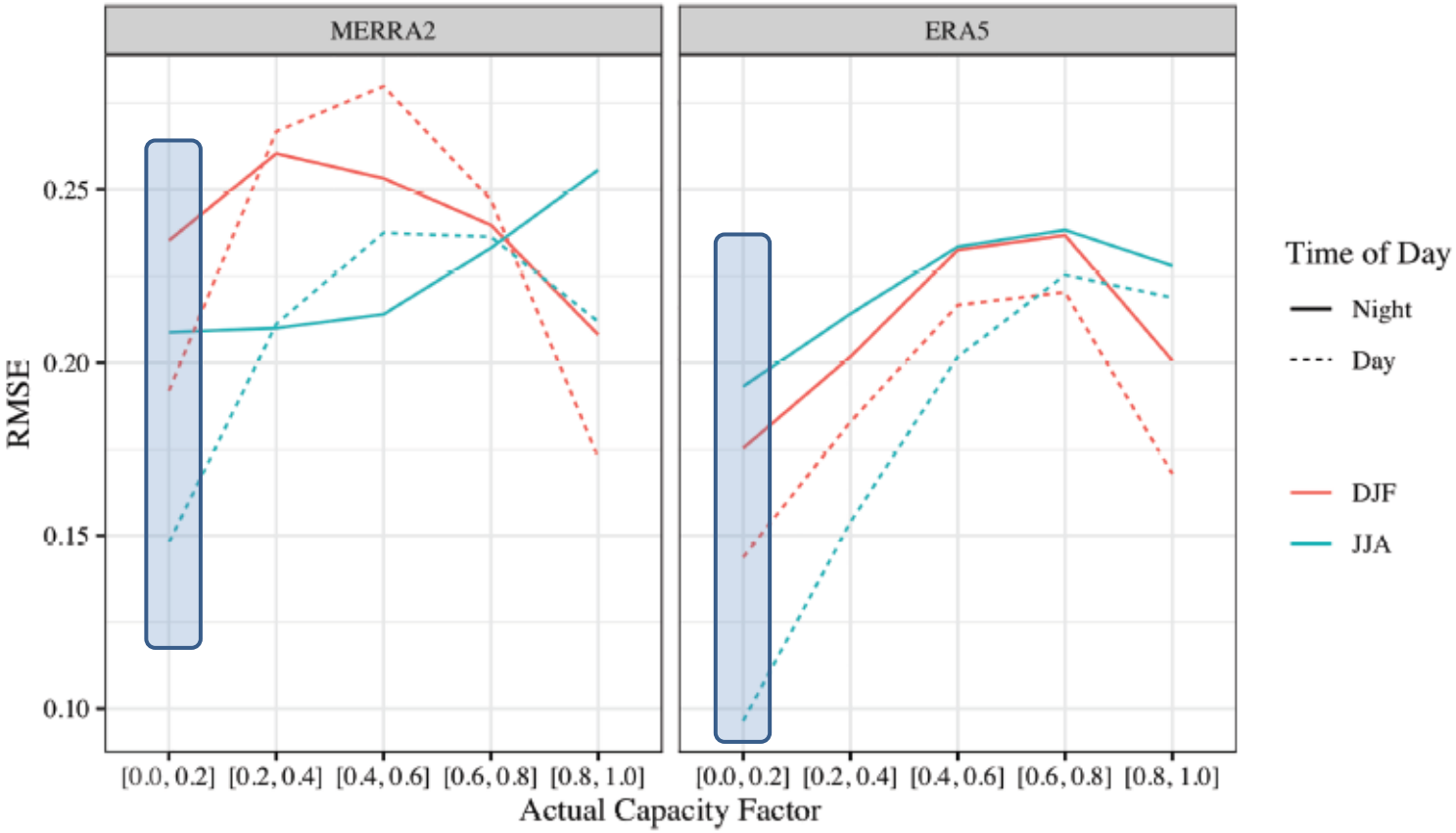


Tail event deviations can be >7x.
e.g. BA wide generation of 3% and model-based estimates of 23%!

What is Needed: Comprehensive Industry Wide Data Transparency and Sharing

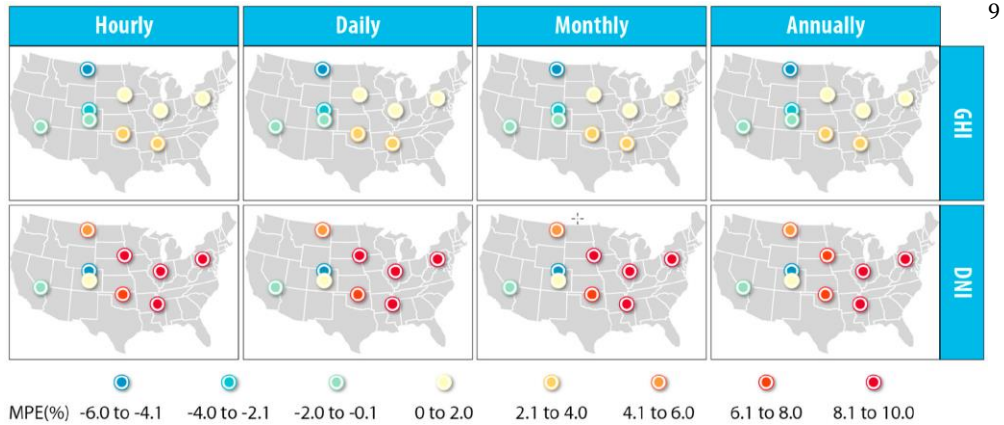
- What: Meteorology data, generation data, availability data
- Why: Valuable untapped resource with little proprietary value but huge socialized sector value
- Use: NWP initialization and nudging, NWP validation and bias correction, generation estimation, validation and bias correction
- ERCOT is leading the way. Others should follow ASAP

When Validated How Bad Is The Existing Data?



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

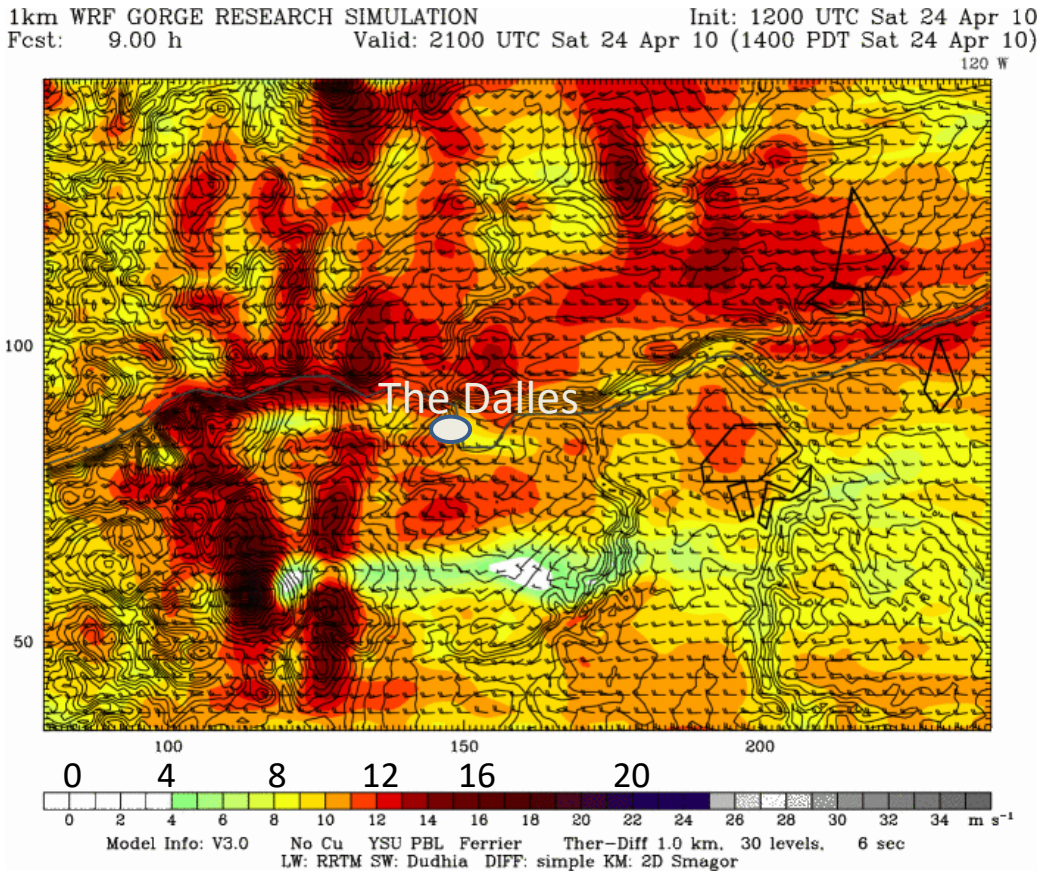


NSRDB validated* against a handful (literally) of observations, because there simply aren't many quality surface solar measurements available. Note mean percentage error is significant on an hourly and even daily basis, especially for DNI. Despite not being created for this purpose, NSRDB is broadly 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)*

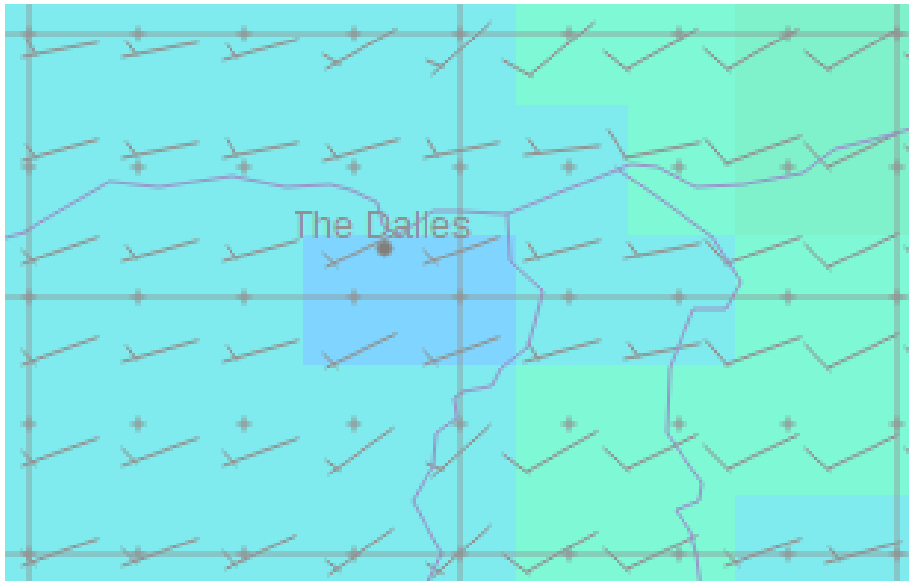
Note the errors at low CF's (boxed). These matter the most for resource adequacy studies.

What is Needed: Behavioral Change and Trans-disciplinary Coordination



- Treating NWP model data as black box data is a recipe for disaster!
- Both meteorology and power systems are complicated. Let's stop assuming we understand each other's specialties and work more closely to meet each other's needs.

1 km WRF Forecast and ERA5 Reanalysis (~30 km) Valid Around the Same Date and Time



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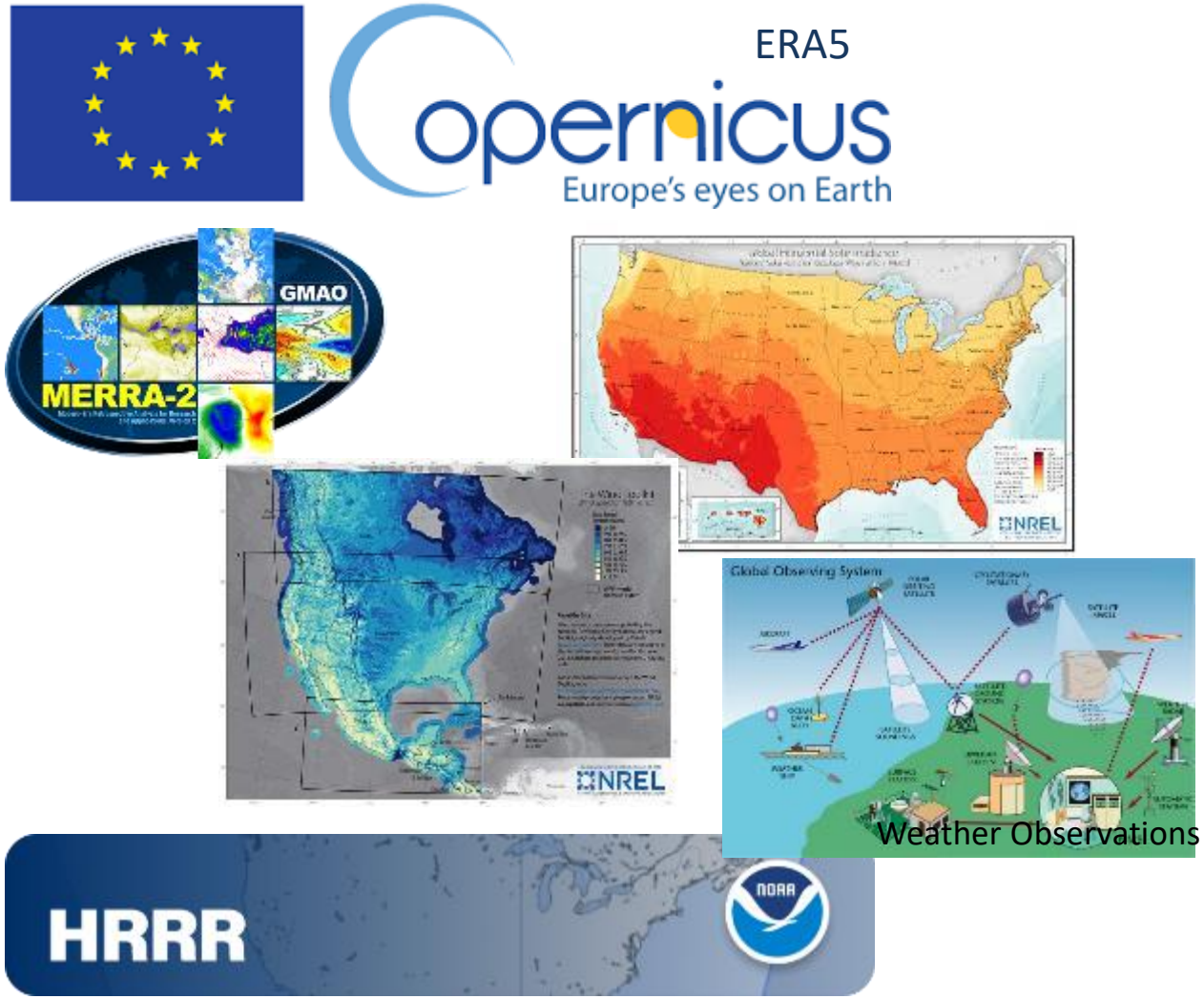
What About The Data Available Today?



The data currently available to the sector (on left) is not adequate for the task at hand. Main issues are one or more of the following:

- Insufficient spatial or temporal resolution
- Insufficient time history
- Insufficient validation
- Distributions don't match reality especially for extreme events
- Sometimes proprietary and opaque
- Not coincident or physically consistent
- Archaic or not extended to present date
- Non-static modeling platforms

Why does it matter?

- You can't correctly predict the wind and solar generation if the weather data isn't good. Sometimes, you'll be WAY off.
- Load estimation is also more difficult

A Closer Look at the Data Available Today

- Observations:
  - Closest representation of truth
  - Too sparse, and requires rigorous QC
  - And/Or Proprietary
- ERA5 (~30 km) (and MERRA2, ~60 km):
  - Longest, most complete consistent time series
  - Easy to use
  - Too low resolution for generation estimates
- WIND TK (2 km, 5 min/hourly):
  - Resolves most physical phenomena
  - Includes forecast database
  - Some temporal seams
  - Outdated model, esp. not great for solar
  - Only 2007-2013 using same set up. 2014 available using different configuration.
- NSRDB (4 km, 30 min):
  - Based on satellite observations and a physics based model
  - Continuous and consistent since 1998
  - Not originally designed for integration studies
  - Non-solar fields are misleading interpolations of MERRA2
- HRRR (3 km, 15 min):
  - Resolves most physical phenomena
  - Data from operational forecast archive
  - Model configuration inconsistent in time
- Data from proprietary models:
  - Opaque and often unscientific in basis

Common Issue: Lack of validation and examination of use case applicability

General Issues with Today's Methodologies

- Provided for offline reference reading!
- Model data (even reanalysis data) is NOT the same as observations
  - Ability to represent features is limited by resolution.
  - LARGE deviations can exist between model data and reality
  - Models have limitations and weaknesses. These are understood by NWP experts but not by general data users
- Model data is being used as a black box
  - Gridded data is easily accessible and easy to use
  - Therefore, it is very attractive to data hungry users
  - But see bullet#1…users must understand the limitations and the impacts on downstream results
- Lack of validation:
  - Model data contains many (often millions) of data points.
  - There is very little validation of any of these points
  - Mostly because there are few observations available (but see below)
  - Validations are not targeted to RA needs (e.g. low resource periods)
- Lack of observations for validation, bias correction and generation estimation
  - Model data MUST be validated, and uncertainty quantified
  - Models will always be imperfect. Ground truth allows sophisticated bias correction to be applied
  - Generation data allows sophisticated models to be used to estimate generation time series from past met. Data
  - **The rapid build out of wind and solar means this data is available. But it is currently proprietary. This must change.**

How Do We Get To What We Need?

- Power systems experts need to working with NWP experts to ensure there is crystal clear requirements specifications. Meteorologists must be transparent about what is and is not possible
- Three routes. Analyze cost benefit FIRST before expending large amount of effort.
- All require a comprehensive set of observations from industry. Start with ERCOT if we can't get them anywhere else.
  - Reanalysis + obs + machine learning (cheapest, my gut tells me it will be insufficient)
  - Moderate resolution NWP + GAN Downscaling (promising but needs validation)
  - High resolution NWP (will definitely work but still won't be perfect)

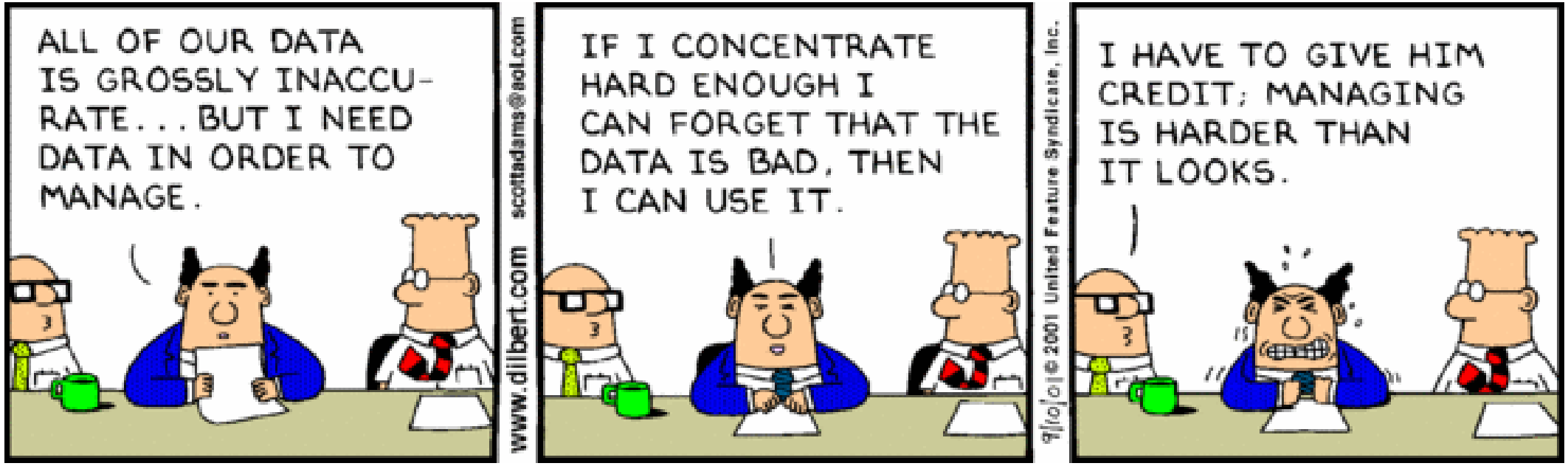
How Much Will It Cost/How Long Will It Take?

Rough ballpark estimates for highest cost 1-km CONUS option back to 1990 based on polling vendors specializing in high volume NWP work

- Compute costs: Initial: $8-15 M. Ongoing $1-2 M/yr including storage
- People: Initial history: $1-2 M. Ongoing NWP: $300-500K/yr. Validation, dissemination, curation: $400-700K/yr
- Total for 1990-2035: $30-55M
- Includes overhead but not profit.
- Probably conservative but detailed analysis is needed.
- Time: Six months on CPU for first 33 yrs. 1 ½ year project
- Investment to decarbonize the grid by 2035: $330-740B[1]
- Less than 0.01%. The potential cost of flying blind is…???

OR

[1] NREL 2022: https://www.energy.gov/eere/articles/nrel-study-identifies-opportunities-and-challenges-achieving-us-transformational-goal



- 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.

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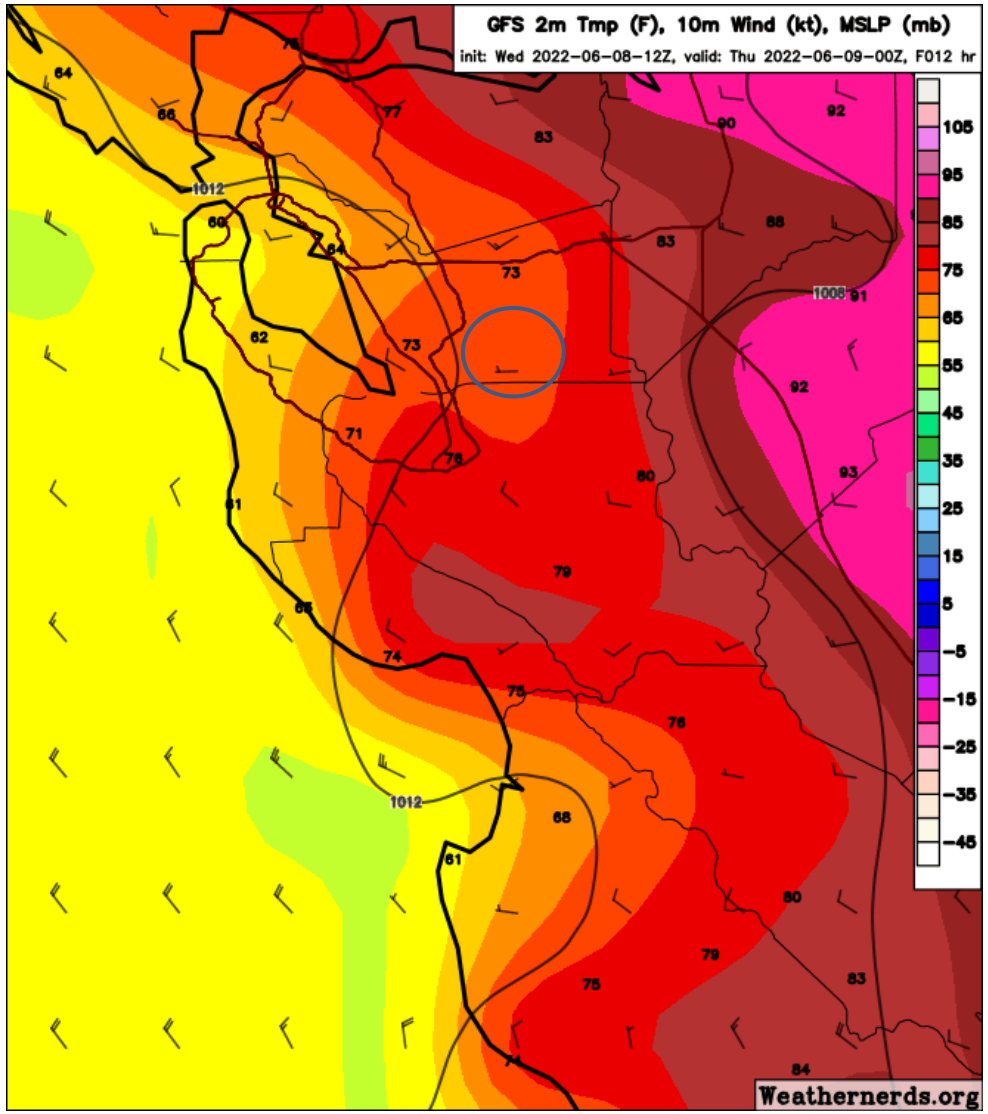
Not All Data is Created Equal: Weather Inputs Requirements for Power Systems* Should Provide Data That…

- …has spatial and temporal scales relevant to the system being modeled. See example on right.
  - Accurately capture the resource drivers and their variability
  - Capture the uncertainty in forecasts of the resource drivers
  - Do the same for drivers of system load



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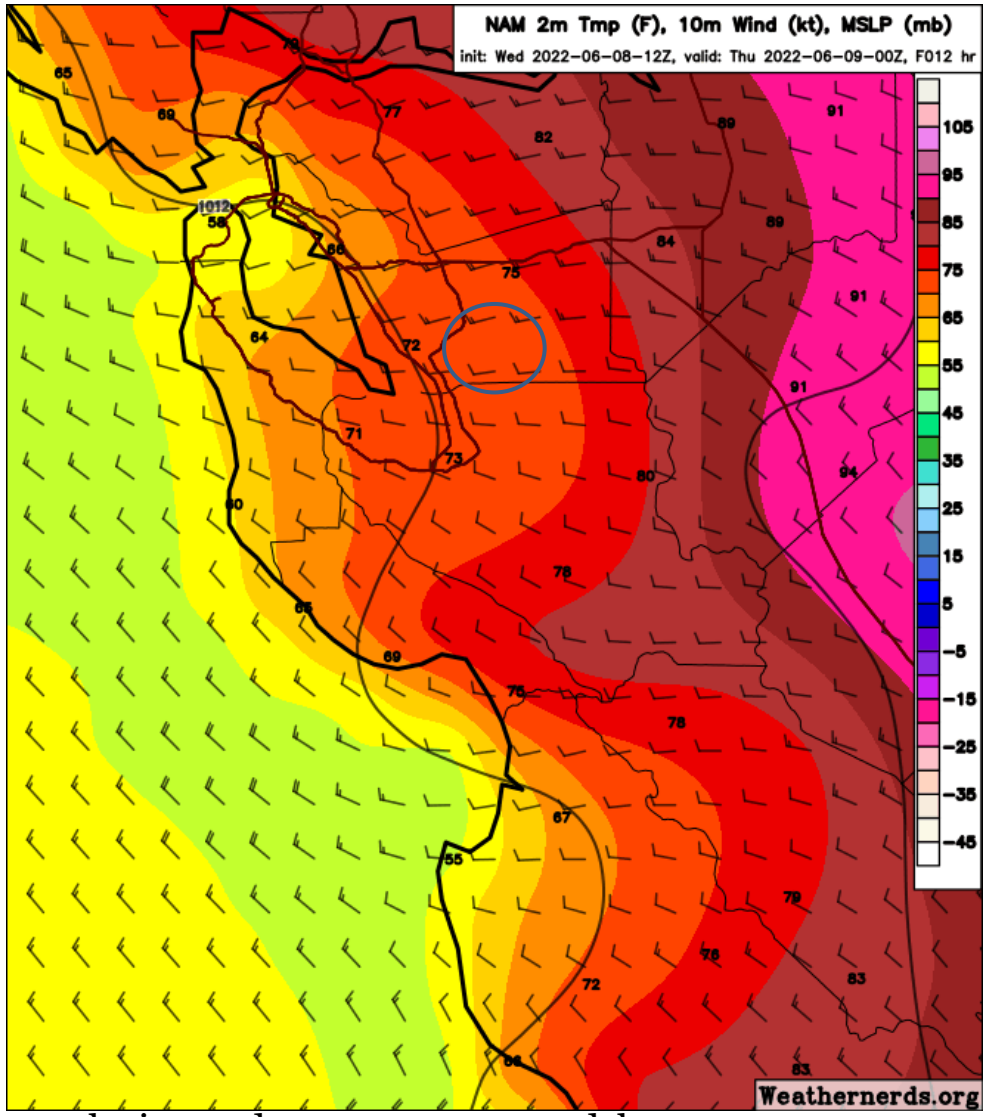
- …is concurrent and physically consistency
  - All variables represent the same time chronology and be dynamically consistent
  - How important is chronology and dynamic consistency?
    - NSRDB and WINDTK, and example on the right provide synchronous variables but they may lack dynamic consistency



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- …provides a 30+yr, updated time history with a consistent model framework throughout
  - Model and data quality/quantity consistency to avoid systematic bias changes