Weather and Climate Intelligence for an Increasingly Weather Dependent Grid

A Summary of the ESIG Weather Inputs Task Force Report and Proposed Next Steps

Justin Sharp
Technical Leader

Avista DPAG
December 3, 2024

Support and content provided by:

ESIG ENERGY SYSTEMS INTEGRATION GROUP

GridLAB

Sharply Focused Understanding Renewable Resources

EPRI Load Forecasting Initiative

LOAD FORECASTING

Improved load forecasts at operational and planning timescales* will drive more efficient investment decisions and better grid performance.

EPRI launched a 24-month initiative (ending in Q4 2025) to address critical needs in load forecasting that will work across three areas:

01 Industry Coordination
Enable knowledge-sharing and collaboration among utilities, ISOs/RTOs, etc.

02 Long-Term Forecasting (Planning)
Develop methodologies and guidance to incorporate new load drivers

03 Short-Term Forecasting (Operations)
Develop methodologies and guidance to mitigate changes in forecast accuracy

Website: msites.epri.com/LFI

*we are defining "planning timescales" as >1-year ahead

Acknowledgements/Disclaimer:

The report and its companion documents were output from the ESIG Weather Inputs Task Force project. I'd like to acknowledge the help of all the members of the task force especially to those contributed to the writing and those who provided deep review and comments.

The project was convened and supported by ESIG. Additional funding was provided by GridLab and Sharply Focused.

ESIG ENERGY SYSTEMS INTEGRATION GROUP

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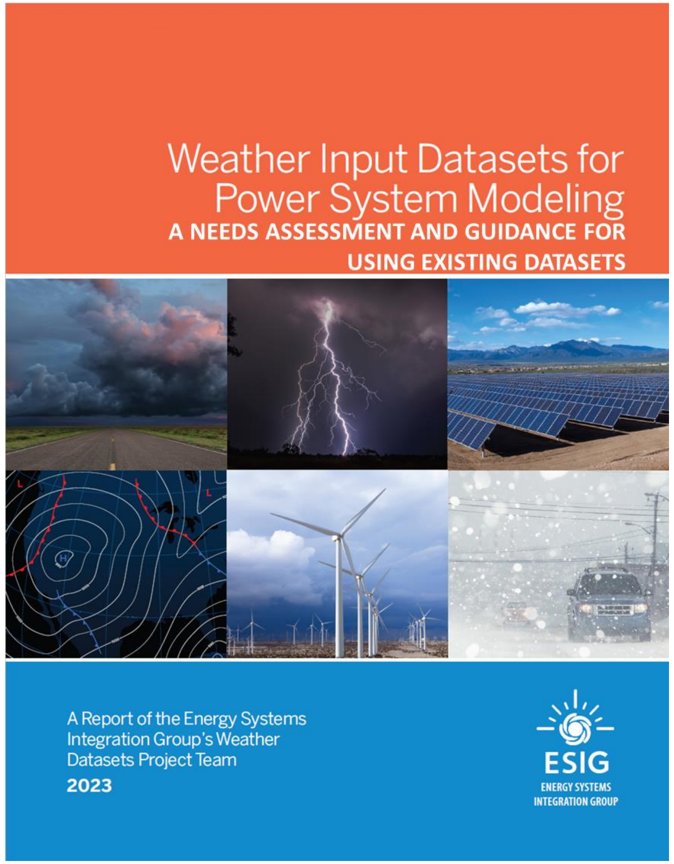
Sharply Focused
Understanding Renewable Resources



[Report Landing Page]

- [Executive Summary]
- [Main Report]
- [Summary Report]
- [Meteorology 101]

Scan for report landing page

While largely objective, some of this presentation represents my own views, some of which may not necessarily be the official views of task force members or member organizations.

EPRI

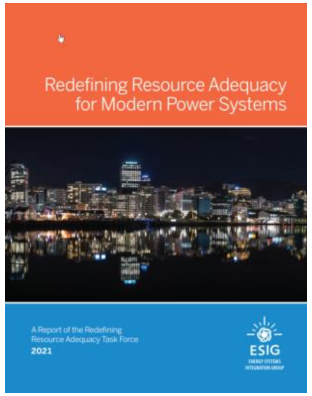
Motivation: The Energy Transition

THE ELECTRIC SYSTEM IS CHANGING

…RADICALLY…

AND IS FULL OF UNCERTAINTY

THE SECTOR HAS TO EVOLVE ITS METHODS ACCORDINGLY


Redefining Resource Adequacy for Modern Power Systems

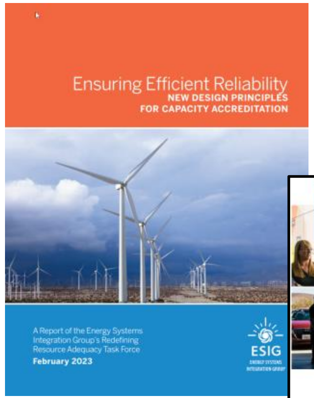
A Report of the Redefining Resource Adequacy Task Force

2021

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. Analysis must incorporate weather more comprehensively

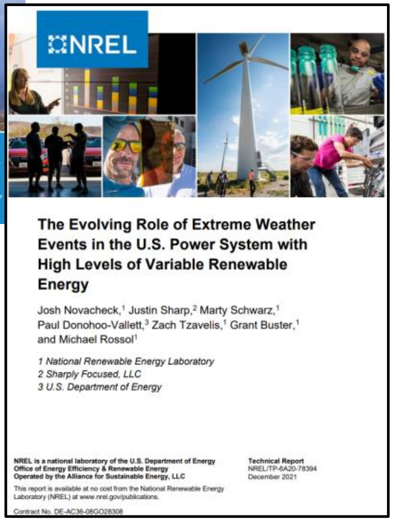

Ensuring Efficient Reliability

NEW DESIGN PRINCIPLES FOR CAPACITY ACCREDITATION

A Report of the Energy Systems Integration Group's Redefining Resource Adequacy Task Force

February 2023

ESIG


NREL

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

Josh Novacheck,[1] Justin Sharp,[2] Marty Schwarz,[1] Paul Donohoo-Vallett,[3] Zach Tzavelis,[1] Grant Buster,[1] and Michael Rossol[1]

1 National Renewable Energy Laboratory
2 Sharply Focused, LLC
3 U.S. Department of Energy

NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency & Renewable Energy Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-6A20-78394
December 2021

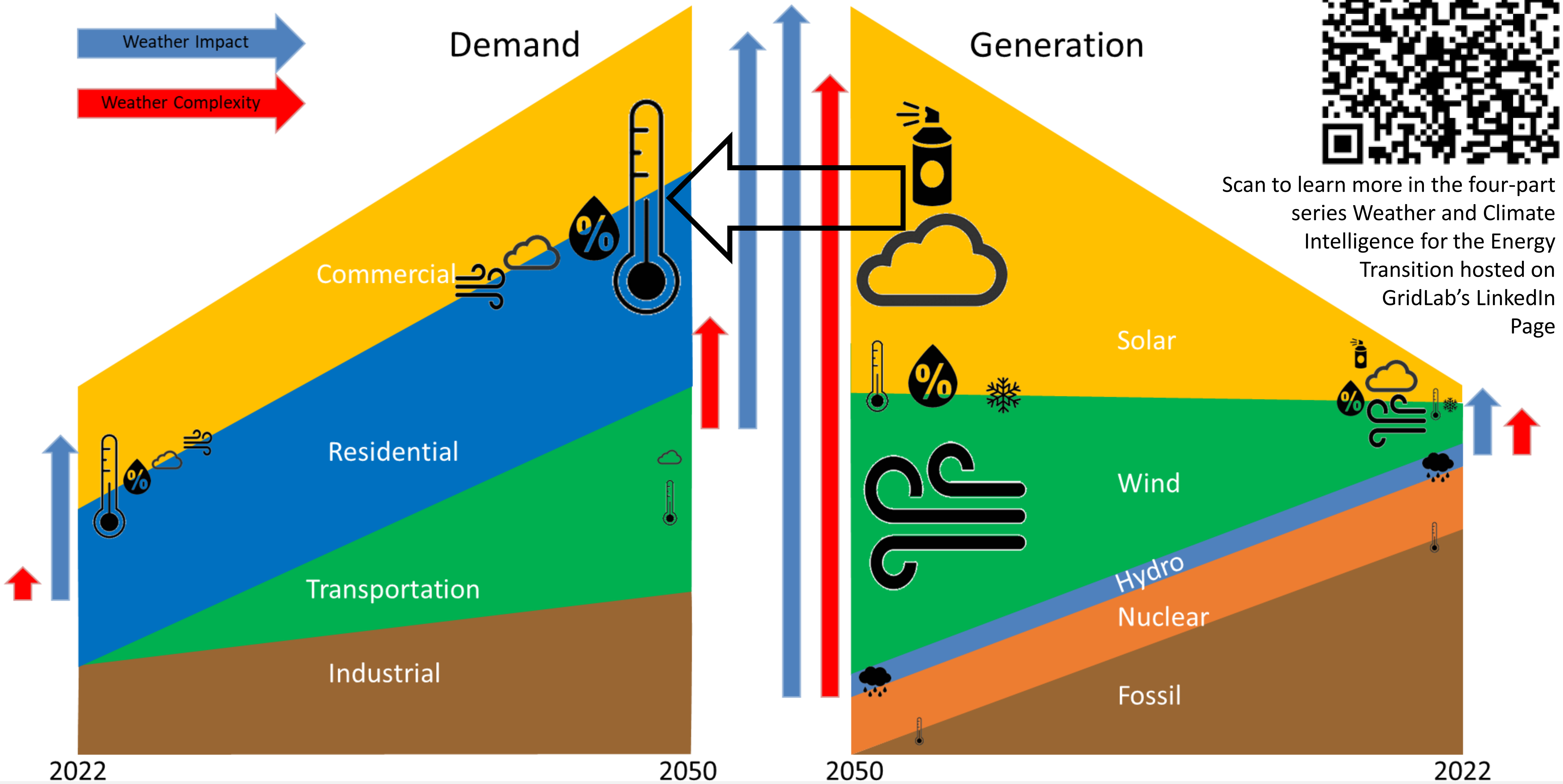
Sharply Focused
Understanding Renewable Resources

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)

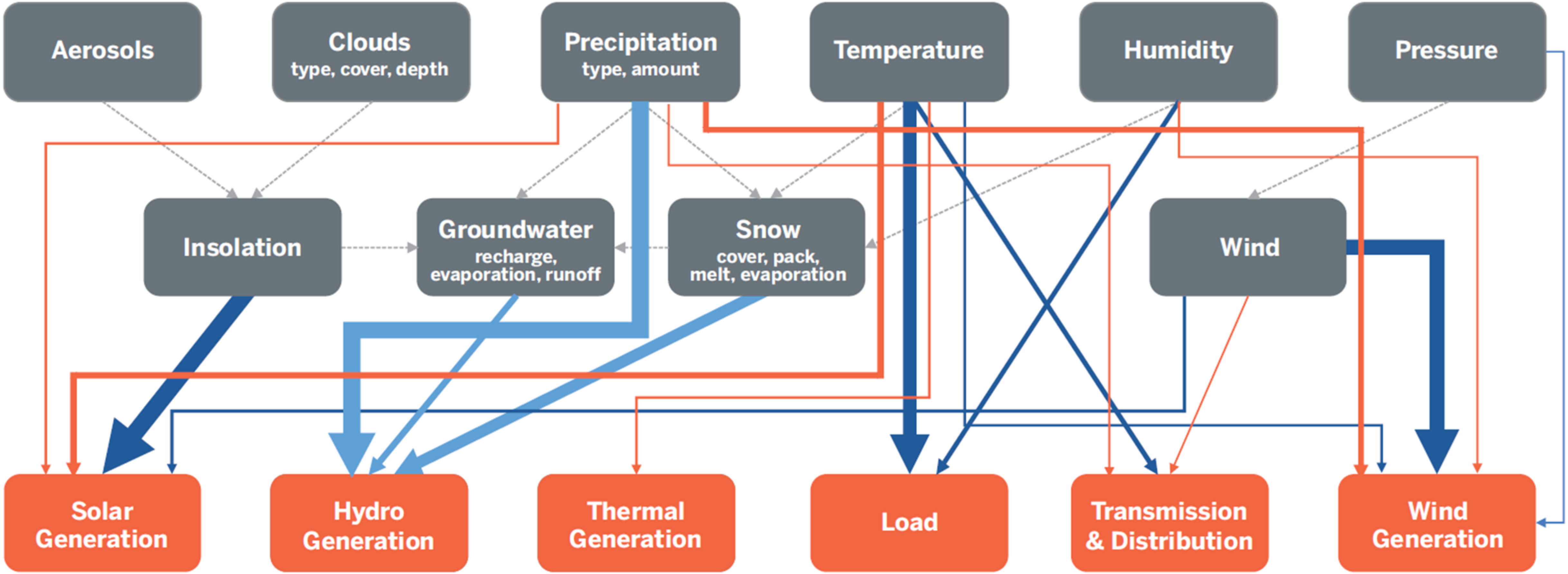
EPRI

The Evolving Energy – Weather Nexus



Scan to learn more in the four-part series Weather and Climate Intelligence for the Energy Transition hosted on GridLab's LinkedIn Page

Electricity System Weather-Dependence

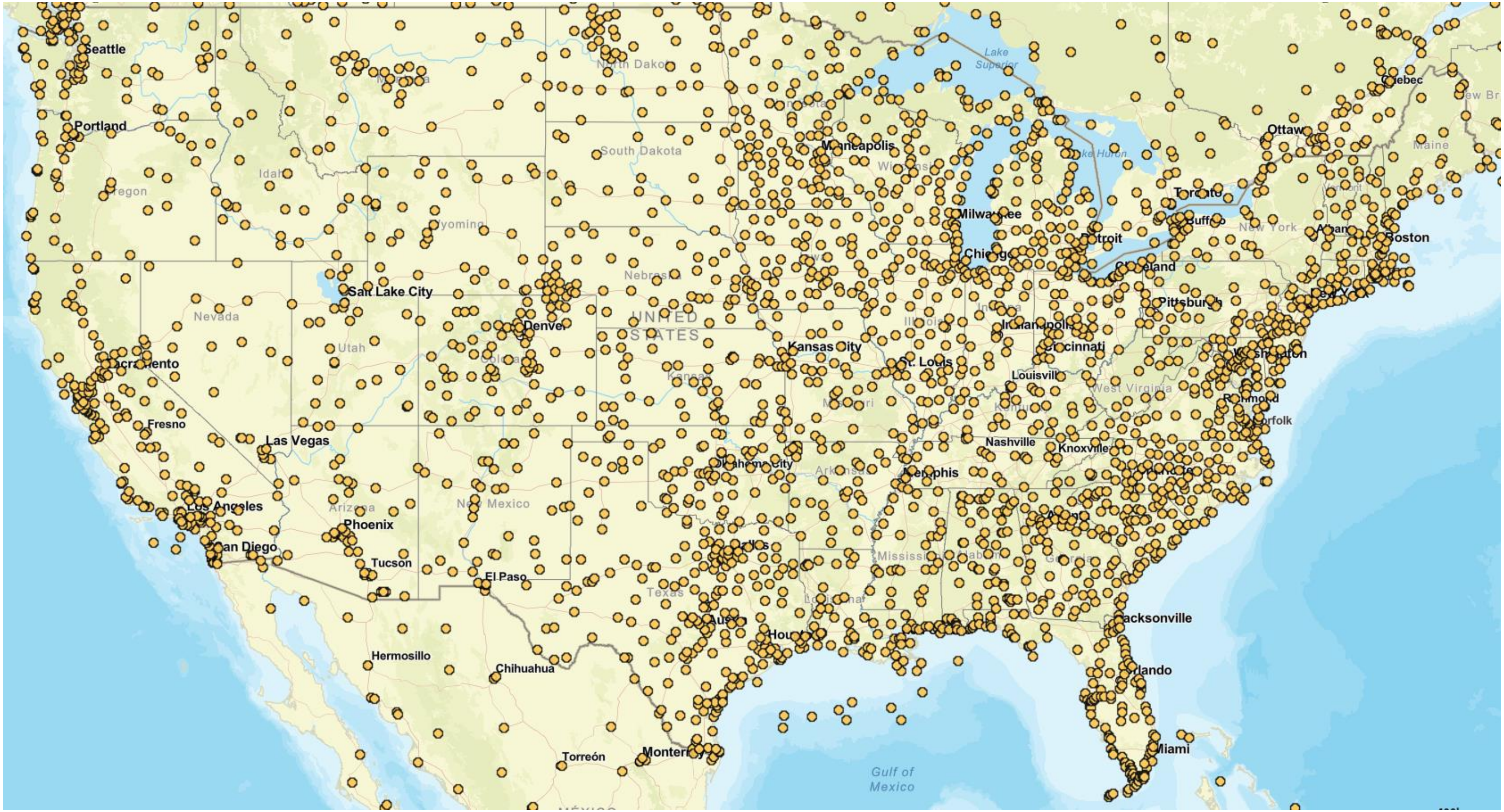


Typical magnitude is approximated by the thickness of the lines.

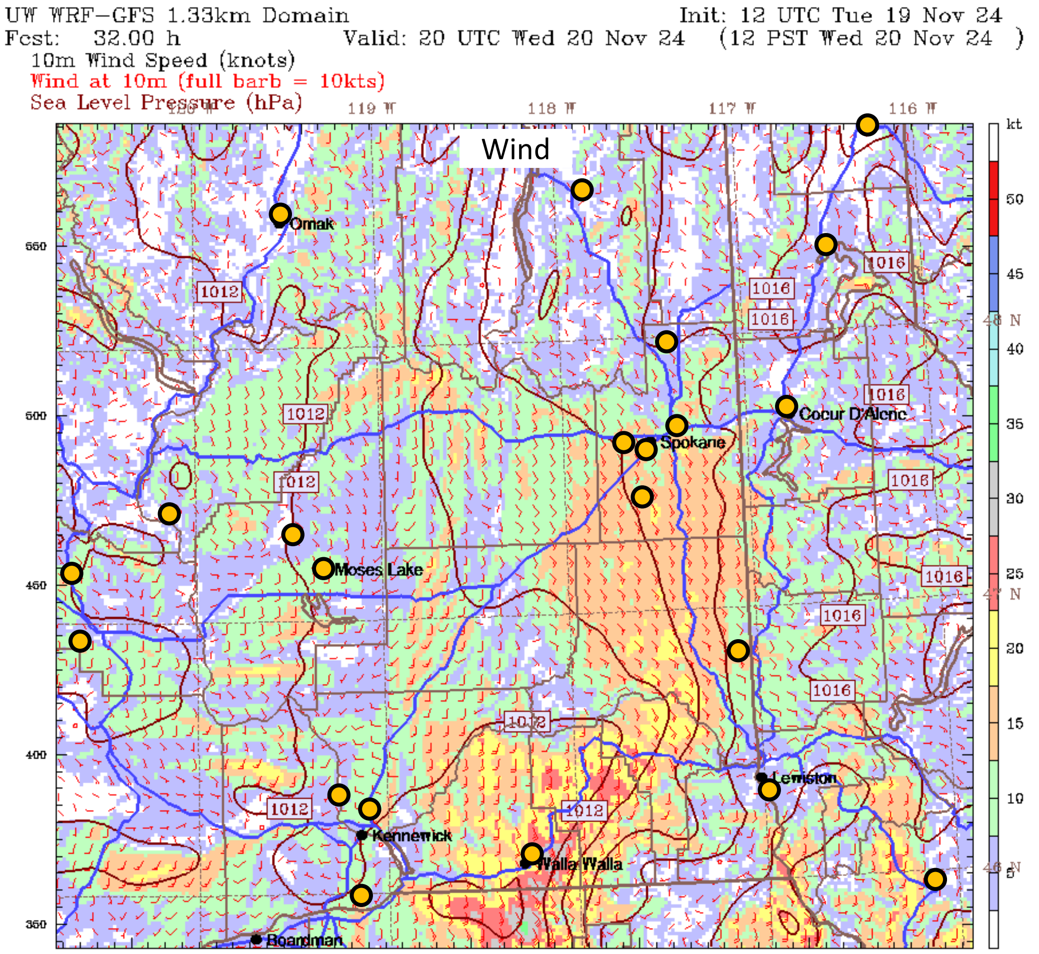
- While all environmental variables are interdependent, these are some of the strongest internal links.
- Dependence of the electricity system on the climate system.
- Strength of dependence is highly variable and depends on asset type and location.
- Degree of dependence can be greatly amplified by specific weather and climate conditions.

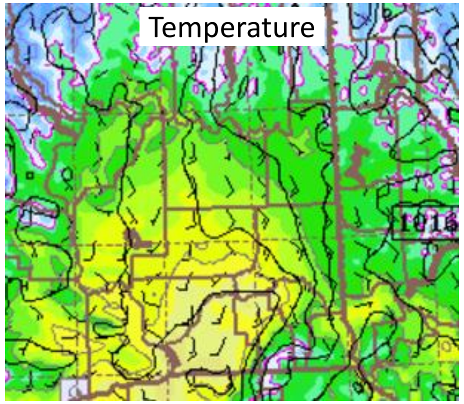
Source: ESIG Weather Data for Power System Planning
https://www.esig.energy/weather-data-for-power-system-planning/

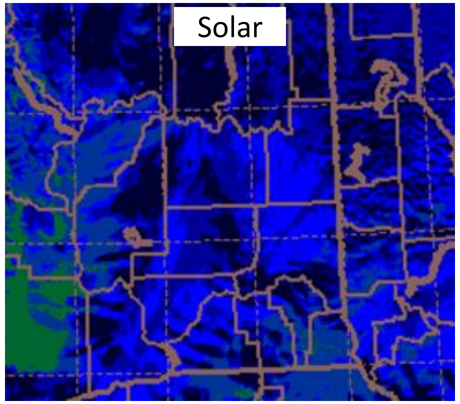
Active High-Quality Public Weather Observations



- Power system models have always incorporated weather
  - Treatment mostly concerned with impact of temperature on load, and sampling of hydro years
  - Data needed from urban areas (with plenty of observations), and existing streamflow measurements
- Obs. of weather impacting wind and solar output are not widely available and MUST BE SYNTHESIZED
  - Fields vary rapidly across short distances and times, and are needed for remote areas
  - Observations are sparse, have a short history, and where they exist they are mostly **proprietary**
- The complex interaction between variables impacting load, wind, and solar MUST now be considered, and must be coincident and physically consistent (in time and space),and chronological.
- The interconnectivity in time and space yields complex, yet organized, multi-dimensional probability distributions that must be realistic for accurate power system analysis.
- DERs/storage and other weather impacts on G,T, and D add more layers of complexity.







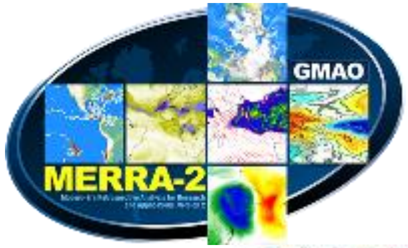
The Main Attributes of Time Series Data Necessary to Meet General Power System Modeling Needs

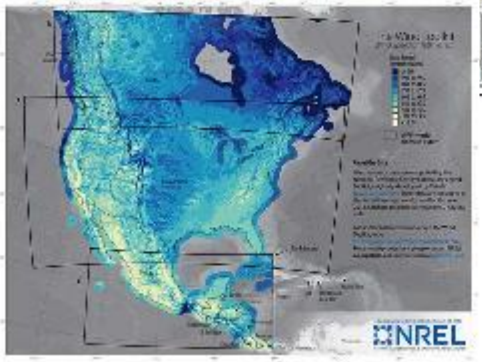
Source: ESIG Weather Data for Power System Planning https://www.esig.energy/weather-data-for-power-system-planning/

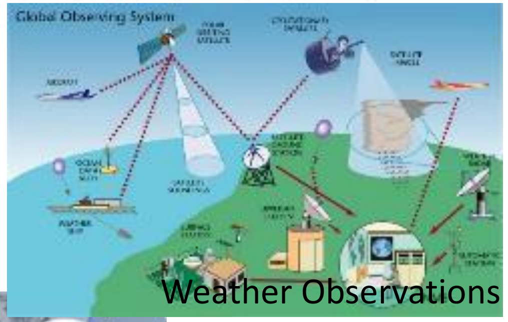
Including the necessary variables	Include the necessary variables at sufficient spatio-temporal resolution and accuracy to reflect actual conditions that define the generation potential at current and future wind/solar sites and temperature at load centers
Covering multiple decades with ongoing extension	Cover multiple decades with consistent methodology and be extended on an ongoing basis to capture the most recent conditions and allow climate trends to be identified
Coincident and physically consistent	Are coincident and physically consistent, in space and time, across weather variables
Validated	Are validated against real conditions with uncertainty quantified
Documented	Are documented transparently and in detail, including limitations and a guide for usage
Periodically refreshed	Are periodically refreshed to account for scientific and technological advancements
Available and accessible	Publicly available, expertly curated, and easily accessible

Existing Weather and Climate Data is Inadequate for Comprehensive Analysis of Modern Power Systems

ERA5







The biggest issues are one or more of the following:

- Insufficient validation and uncertainty quantification (true for all datasets)
- Insufficient spatial or temporal resolution
- Insufficient time history/lack of ongoing extension
- Distributions that don't match reality, especially for extreme events
- Data use from non-static modeling platforms
- **A lack of knowledge of the limitations of current datasets and the downstream impact of biases and inaccuracies**

Why does this matter?

- You can't correctly predict supply and demand if the weather data isn't good. Sometimes, you'll be WAY off.
- Coincident weather data is need to assess compound risks to generation, transmission and distribution.

The Data We Have Today

The data currently available to the sector (on left) is not adequate for the tasks at hand. No single dataset meets all the needs. Mixing and matching causes physical consistency issues.

TABLE 2
Summary of Current Power System Modeling Weather Input Data Sources

	Spatial Resolution	Temporal Resolution	Length	Continuously Extended	Correct Variables/ Levels	Coincident and Coherent	Validated/Uncertainty Quantified for Power System Use	Detailed Documentation	Future-Proofed	Availability/ Ease of Access	Curation and Advice	Region Covered
MERRA-2[a]	~60 km	60 min	1980–present	Yes	Yes/No	Yes	No		Probably		Basic	Global
ERA5[b]	~30 km	60 min	1940–present	Yes	Yes/No	Yes	Some		Yes		Good	Global
HRRR[c]	3 km	15 min	2014–present	Yes	Yes/No	Yes/No	No		Unideal		Basic	U.S.
WIND Toolkit[d]	2 km	5 min	2007–2014	No	Yes/Yes	Yes	Yes		No		Basic	Various
WTK-LED[e]	2 km/4 km	5 min	3 year/ 20 year	No	Yes/Yes	Yes	Not yet	Not yet	No	Unknown, dataset not yet available		Various
NSRDB[f]	4 km/ 60 km	30 min	1998–present	Yes	Yes/No	Solar only	Yes		Yes		Basic	Most of globe
CERRA[g]	11 km/5.5 km	60 min	1980–present		No/Yes	No solar	Yes		Possibly		Basic	Europe
CONUS404[h]	4 km	60 min/ 15 min (precip)	1980–2020	No	Unknown/ Probably	Yes	Not the intended use					Continental U.S.
BARRA[i]	12 km/ 1.5 km	60 min	1990–2019	No	Yes/ Probably	Yes				Fee-based		Australia/ New Zealand
Public Observing Networks[j]	Non-uniform, variable density	1 hr or less	Variable	Yes	Yes/No	Mostly	Varies. Not for power systems	Varies	Usually	Usually easy	Varies	Global
Renewable Energy Project Data[k]	Non-uniform, variable density	Usually minutes	Variable but rarely more than 10 years	Varies	Yes/ Usually	Yes	Usually	Varies, but usually poor	Varies	Usually poor	Usually none	Very limited
Proprietary Statistically Derived VRE Shapes[l]	Non-uniform, variable density	Usually hourly	Variable. Rarely reliable long records.	Varies	Usually incomplete	No	Partial	See note	No		None	Very limited

■ Fully Met ■ Close to Being Met ■ Partially Met ■ Met in a Very Limited Way ■ Not Met at All ■ Not Enough Info. for Determination

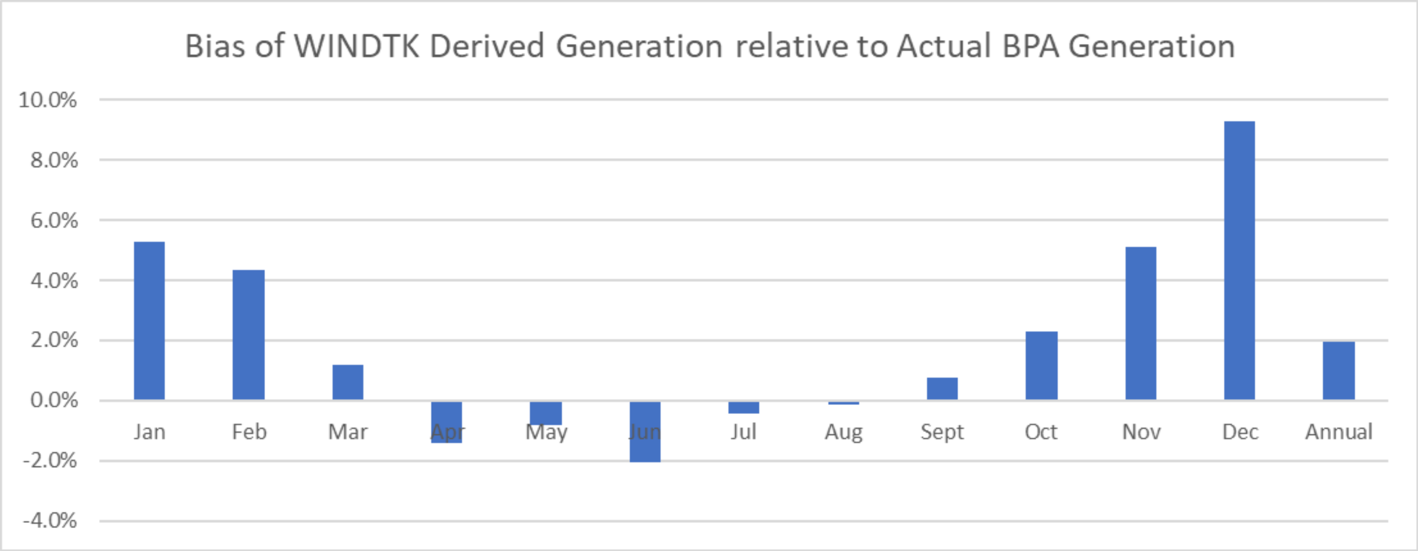
Summary of the most applicable datasets globally that are (or can be) used to provide weather inputs for power system analysis tasks, especially for providing estimate of site-level generation, and concurrent weather-driven load and generation outage risks. The degree to which the needs of each column heading are met is estimated with color coding. See documentation for each dataset for all details. Footnotes on next page. P76, main report.

Source: Energy Systems Integration Group

How Bad is it Really? A 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 here:
  - WINDTK data in the BPA area.
  - Wind resource in BPA BA is notoriously difficult to predict with NWP => WFIP2 Project
    - Complex terrain in the region needs a minimum of 1.33 km resolution to resolve. More on this later.
    - 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%!

Don’t We Produce This Data and Successfully Use it in Operations?

Yes, we do. Which leads to the radical statement that:

Historical supply and demand estimations used in power system planning analysis are often less accurate than forecasts used in operations!

Why? Proprietary plant datasets are available and used for training/validation of operational forecasts, more attention is paid to them, and we only need data for next few days, versus for the last few decades.

Our Weather "Intelligence" is Inadequate

Producer(s)

Create initial and ongoing gridded archives

Bias correction

Ongoing generic R&D

Gridded Weather Data

- Physically consistent weather variables
- Multi-decadal, historical and future
- **Not coordinated with sector needs**
- **Insufficient resolution for general power systems use**

Users

End-use application of data

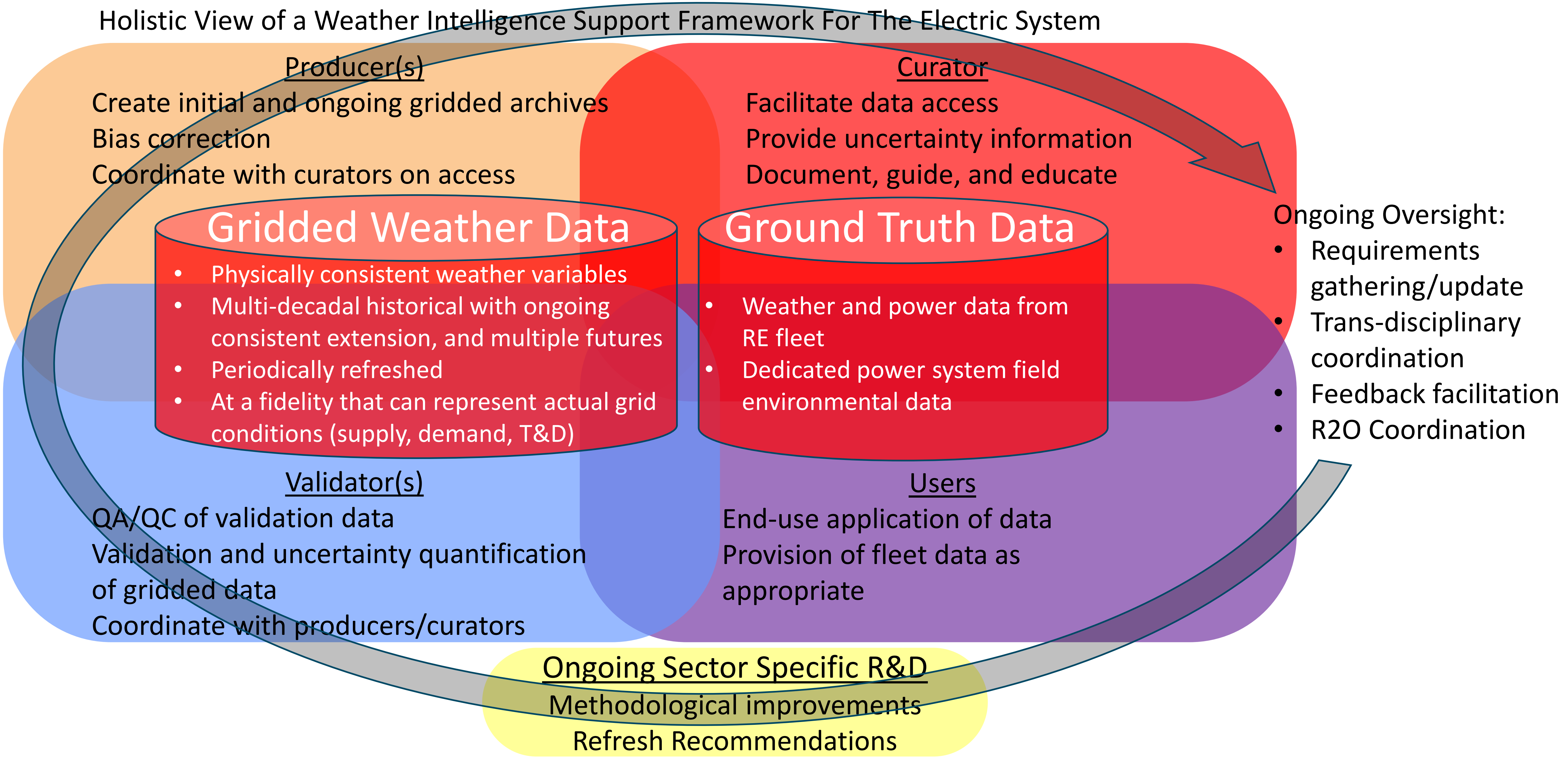
We are transitioning to a much more weather dependent electric system:

- Demand is becoming much more weather dependent
- Wind and solar are instantaneously defined by weather
- Other infrastructure is at increasing risk from weather

Yet, our weather intelligence isn't even close to adequate

- Uncoordinated, lacking vision and leadership
- Not created with sector needs in mind

We Need Vision, Investment & Leadership



Weather Dependence and Complexity are Increasing Rapidly

Weather/Climate Are Becoming Central

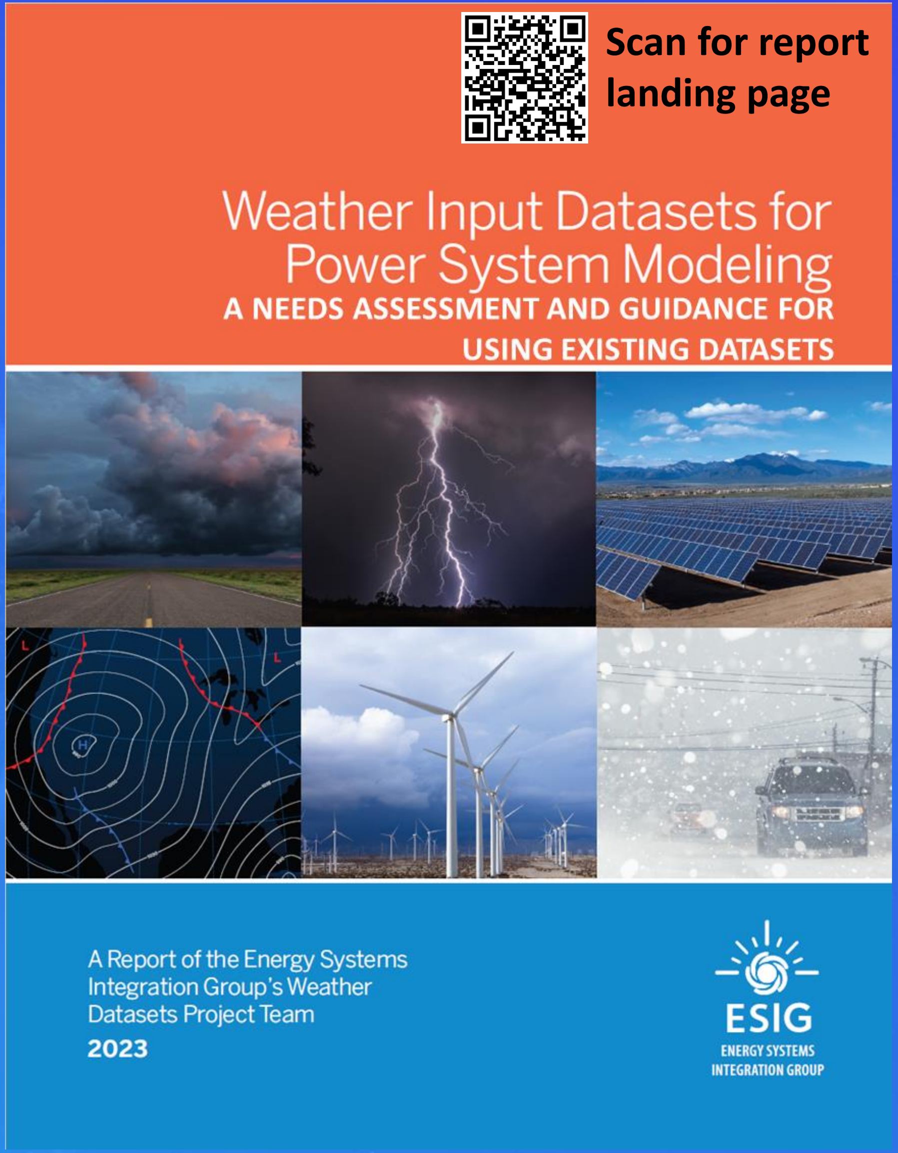
<u>Yet We Are Largely Flying Blind</u>

There is an Imperative for Dedicated, Accurate, and Expertly Curated Weather Information to Support the Energy Transition!

The risks resulting from inaction:

- Reliability issues tied to renewables
- Inefficient system design and planning

<u>Risk $$$'s are orders of magnitude higher than task investment $'s</u>



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Analysis of our increasingly weather dependent system must be data driven

How do we mitigate the current shortcomings of available data?

One solution is to fly blind and largely ignore the problems and hope they wash out in the analysis. This is often the current practice.

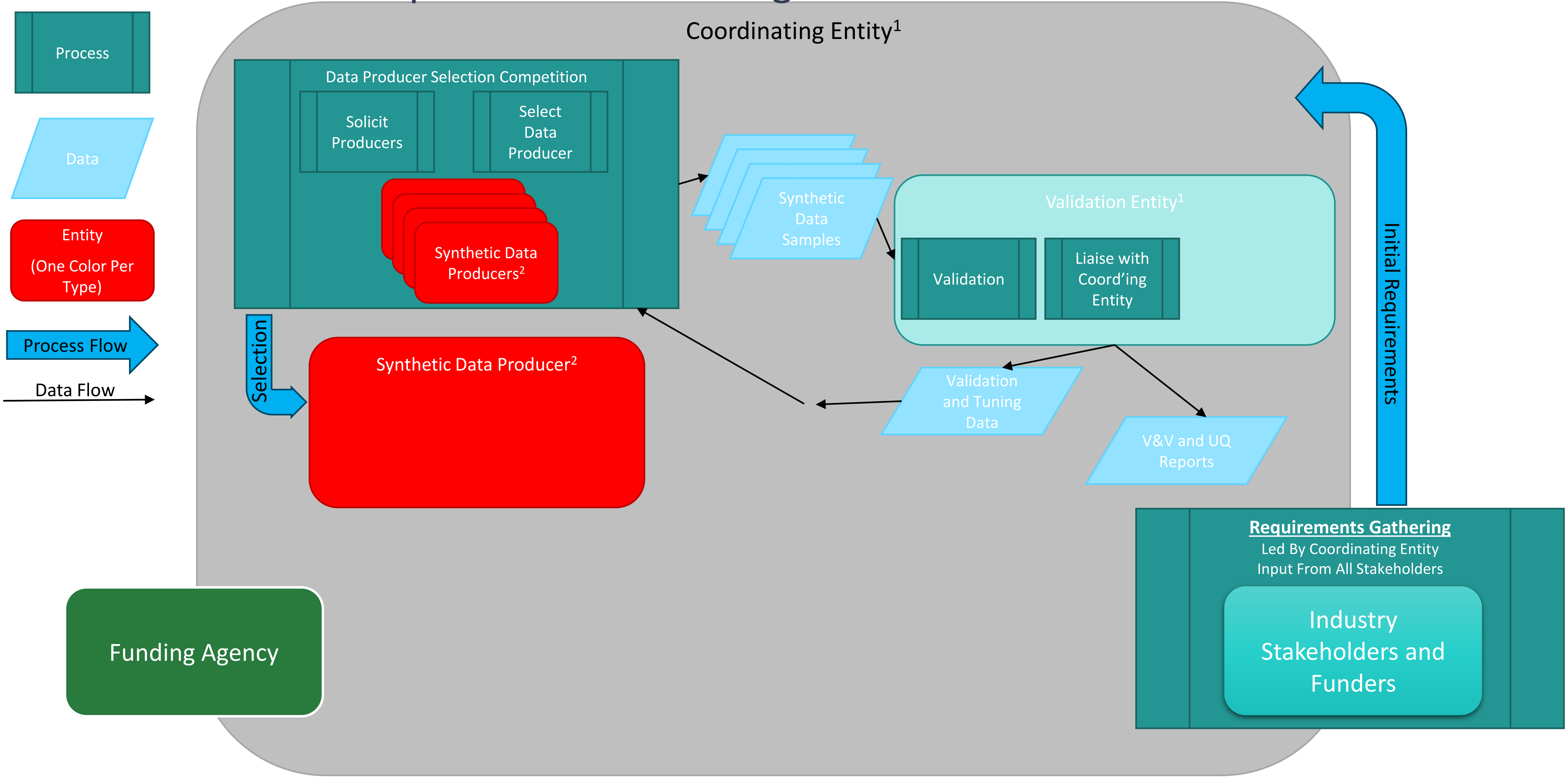
Garbage In = Garbage Out

Learn more in the four-part video series Weather and Climate Intelligence for the Energy Transition produced by Sharply Focused for GridLab and hosted on GridLab's LinkedIn Page

There are achievable, better options.
I'll take you through a (methodologically agnostic) proposed approach.

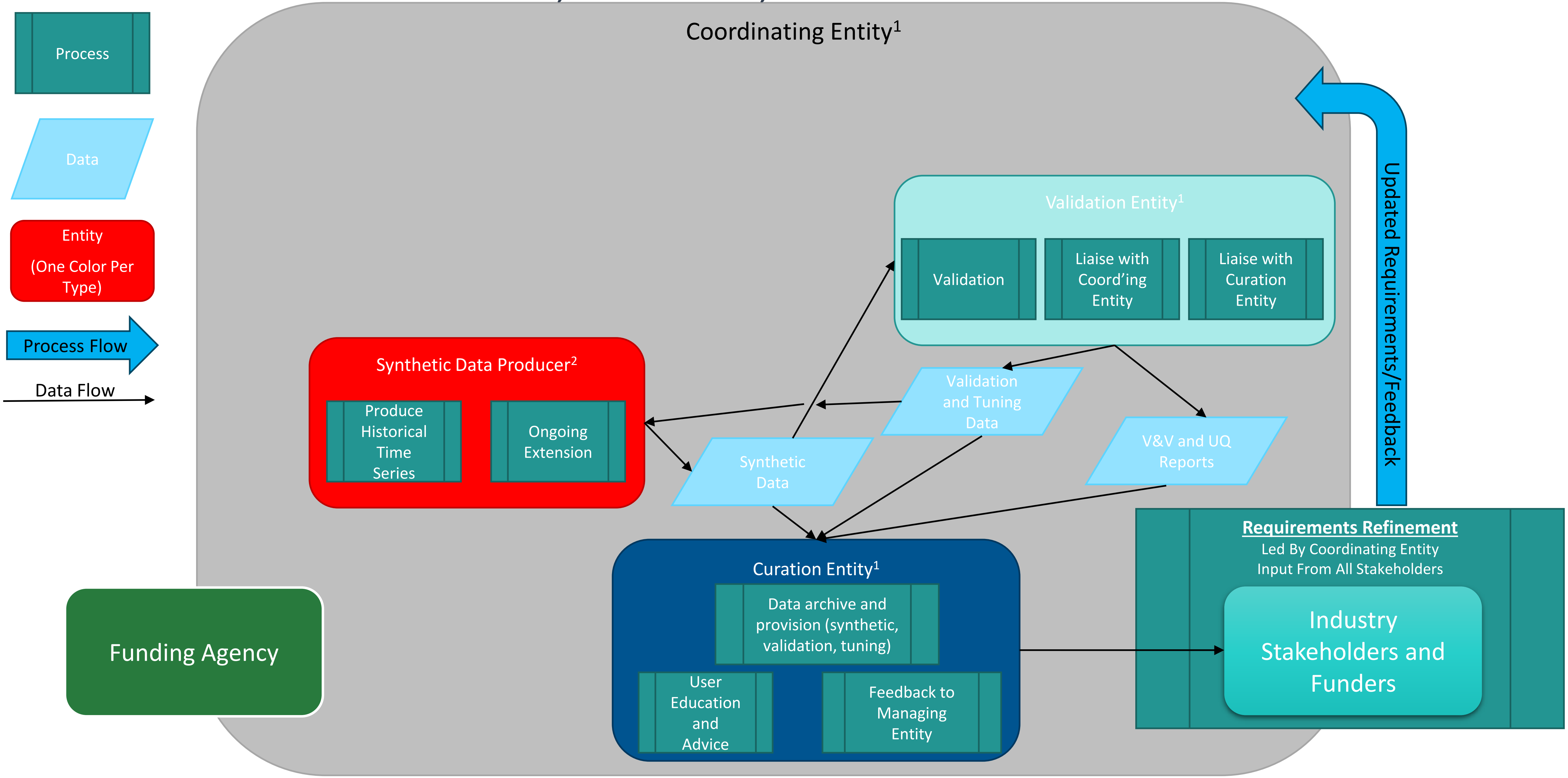
EPRI

Requirements Gathering and Selection Process



[1]May all be the same organization. [2] Should *not* be the same organization; creates a conflict of interest.

Production, Validation, and Curation Processes



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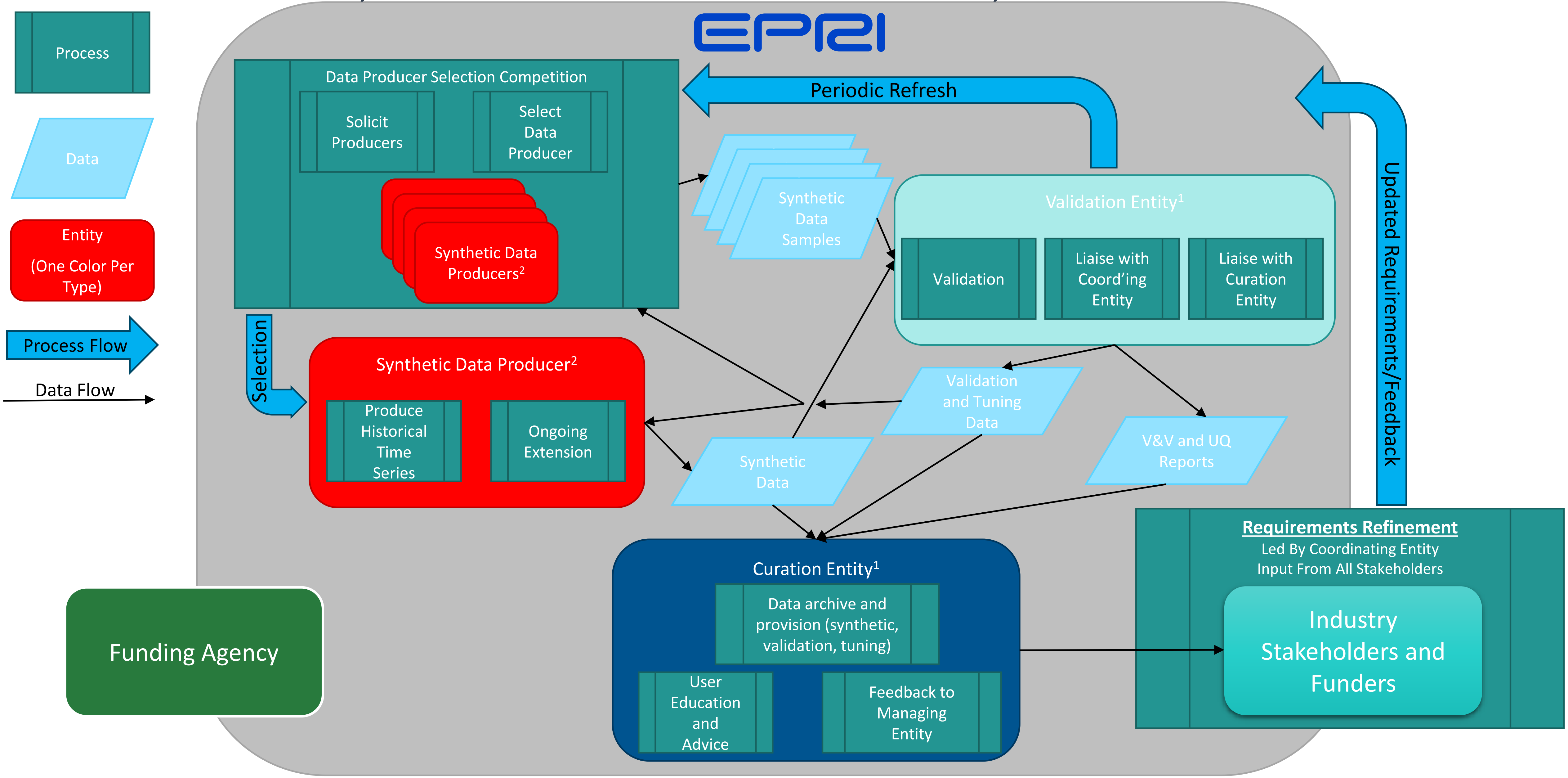
Production, Validation and Curation Processes, with Periodic Refresh



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How Much Will It Cost?

<u>**Rough**</u> figures based on costs for high volume NWP work for high-cost case (1-km CONUS NWP) back to 1990, extended continually to 2035 with extensive validation.

- Selection process with comprehensive validation and comparison to existing datasets: $2-3M
- Initial dataset production: $8-15 M. Ongoing $1-2 M/yr. Includes all storage
- Initial dissemination and curation tasks: $1 M. Ongoing: $400-700K/yr. Management: $200K/yr
- Validation and uncertainty quantification: $500K/yr + Cost to Acquire Measurements
  - LEVERAGING THE RE BUILDOUT IS IMPERATIVE (as is standardization)
  - Consider cost sharing the physical assets to incentivize cooperation
  - Industry support level and validation thoroughness ultimately sets the cost
- The value of an observational network to support data production and validation needs detailed cost-benefit analysis. <u>In the AI world, quality ground truth data is king</u>.

OR

Custom 1990-2035 Climate Dataset for Electrification: $35-70M + validation hardware costs

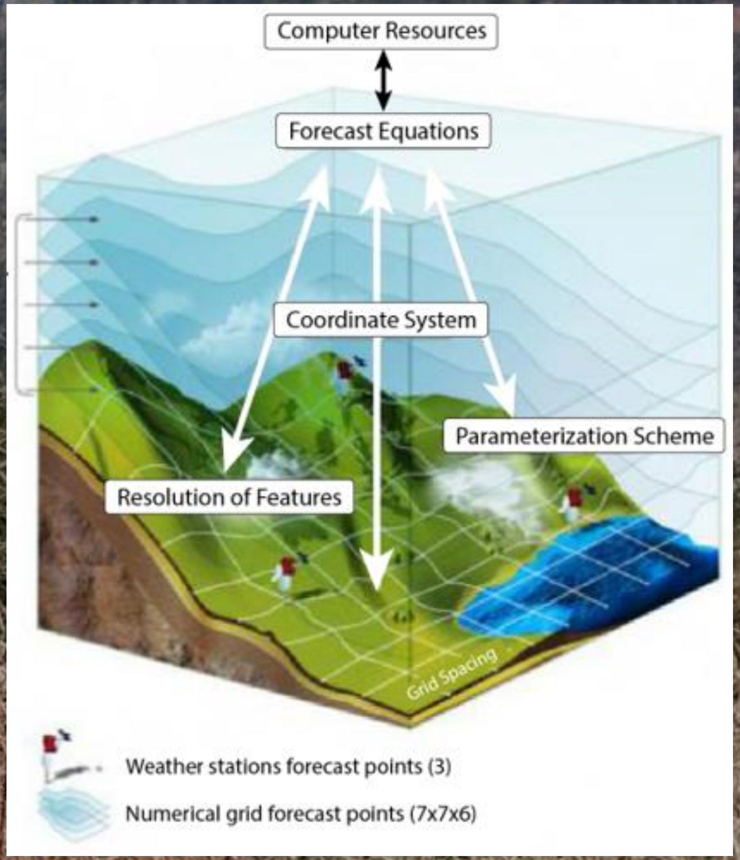
Expected grid decarbonization investment by 2035: $330-740B[1]

<u>**The "map" costs < 0.01% of expected investment. The potential cost of flying blind is…???**</u>

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

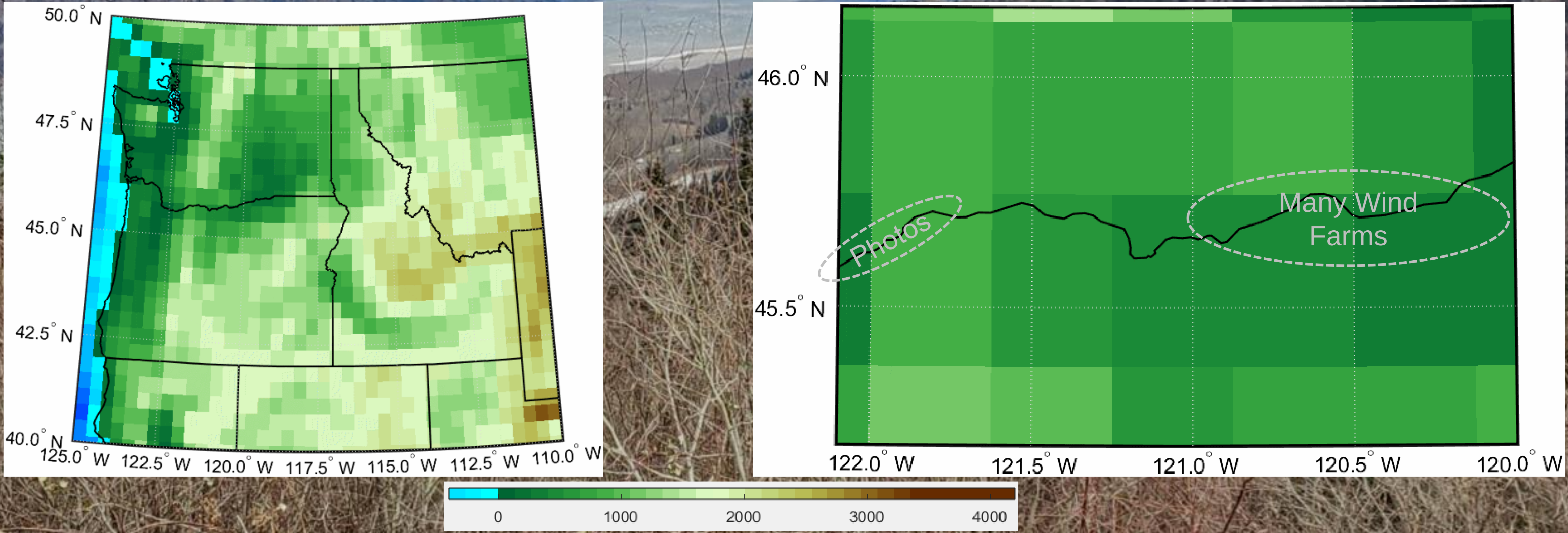
Getting into the Weeds

All Data Is Not Created Equal
The Impact of Grid Spacing

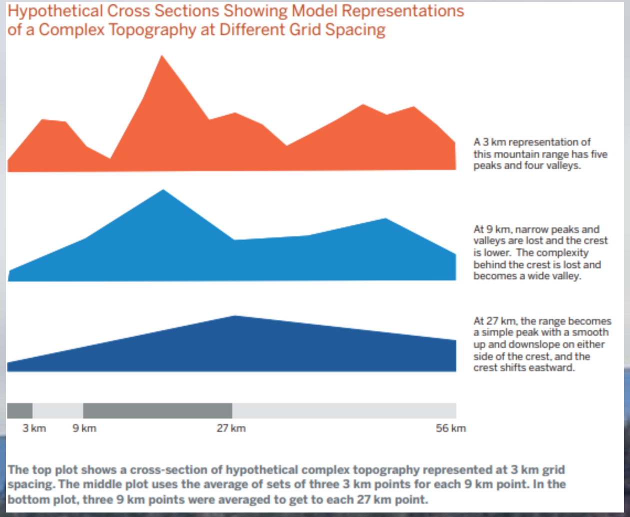


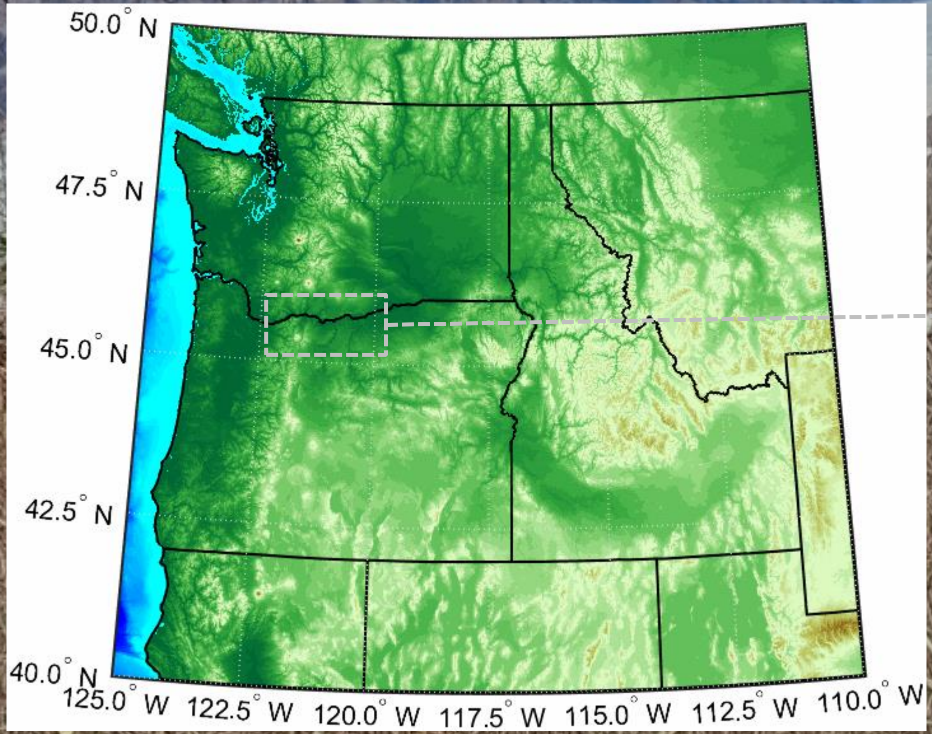
Representation at 30 km Grid Spacing (About the same as ERA5)

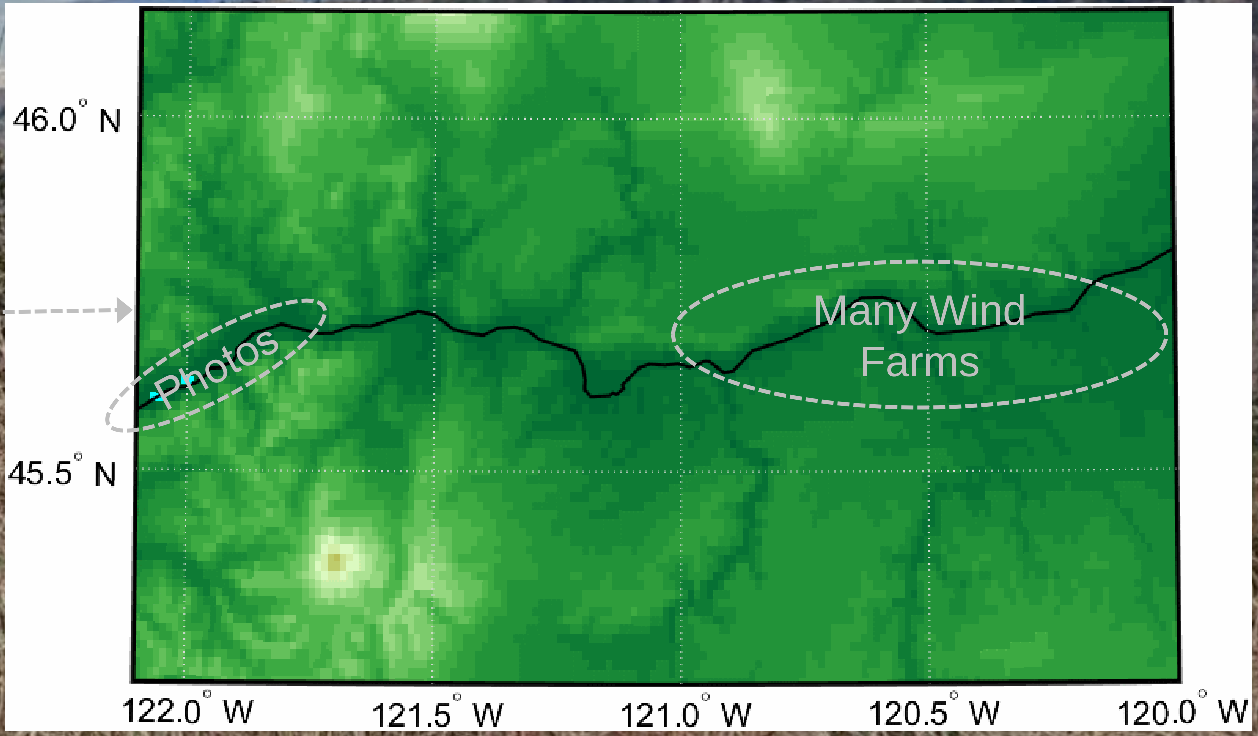
30 km Grid Spacing (~ERA5)



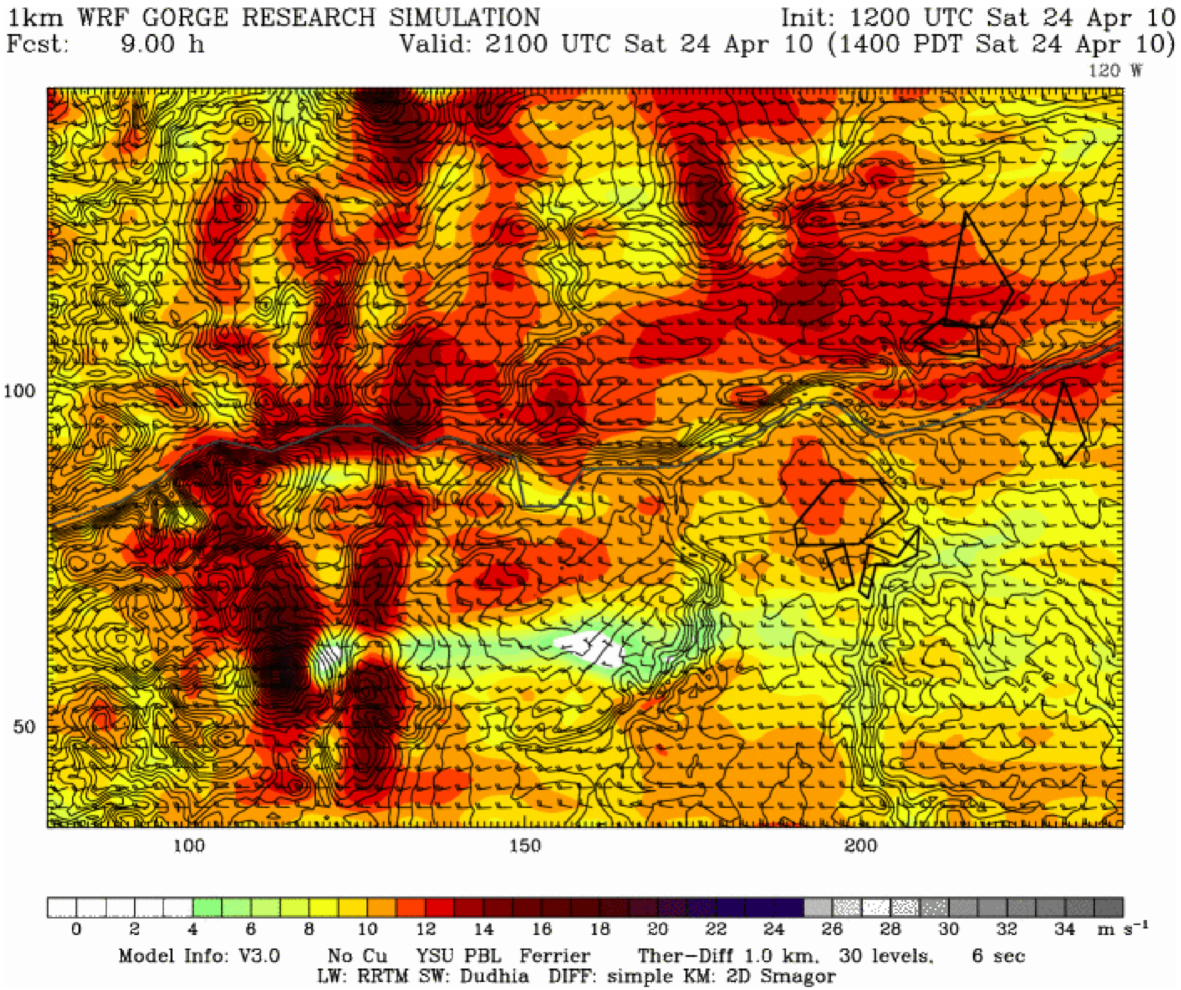
Representation at 1 km Grid Spacing (The WIND Toolkit has 2 km Resolution)

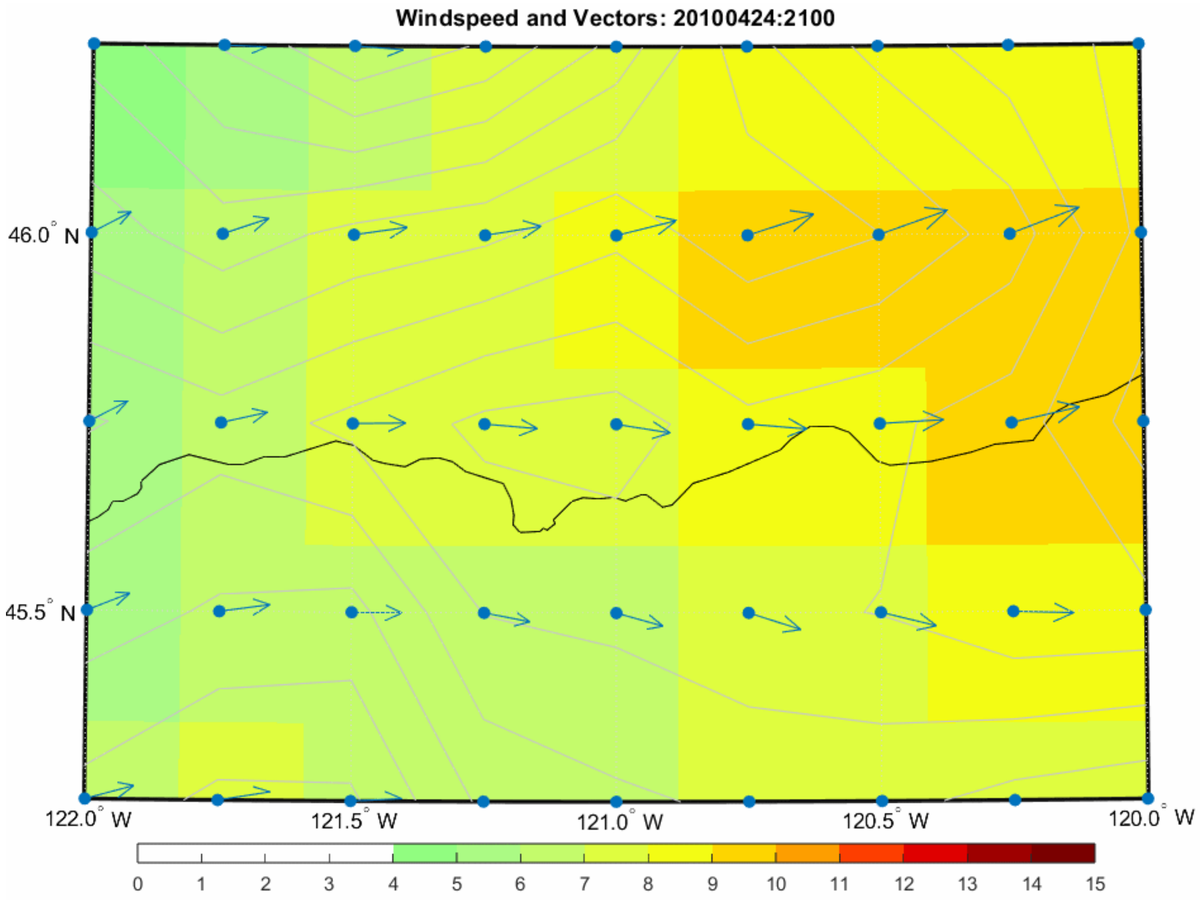






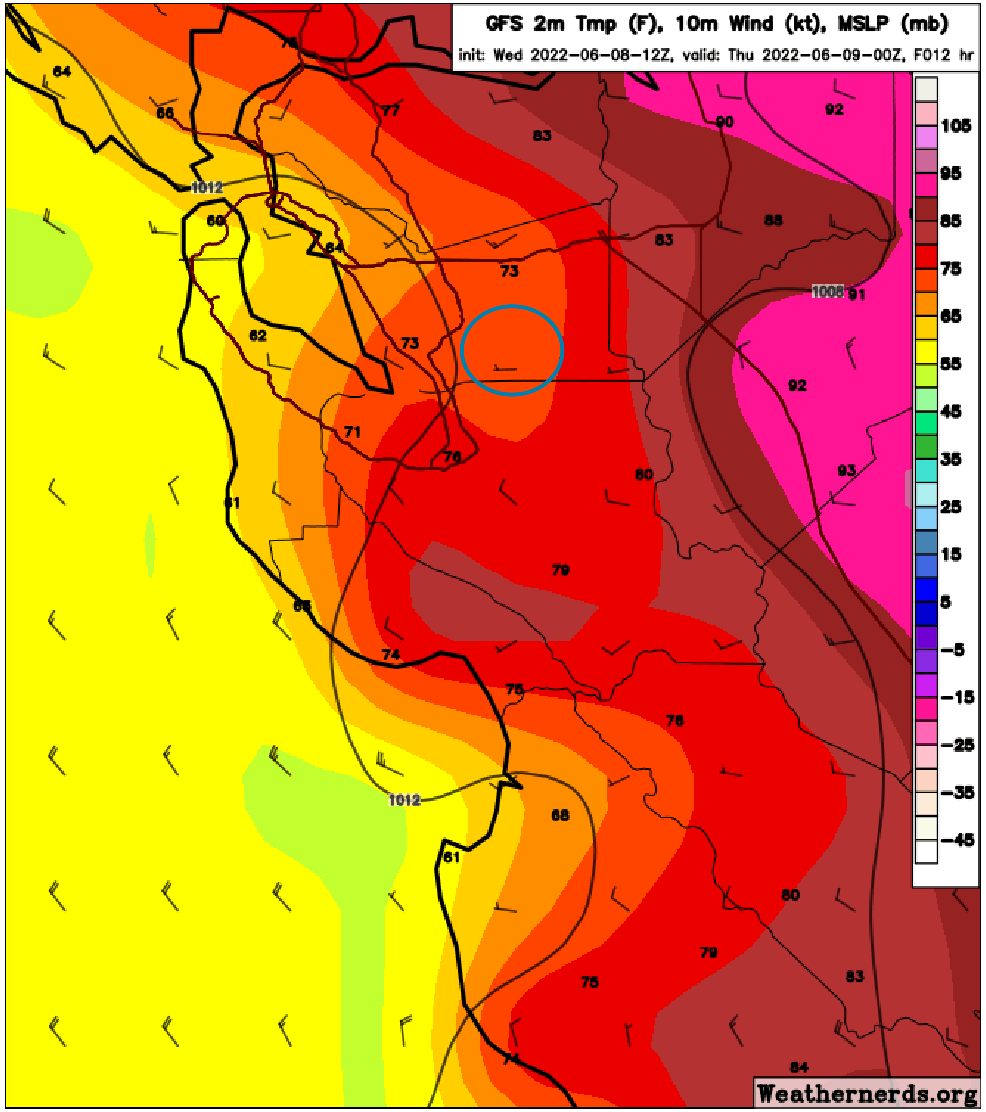
An Example of Resolution Impacts





Weather datasets For Power Systems Should…

- …have 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 estimates of the resource drivers
  - Do the same for drivers of system load
- …



Not All Data Is Created Equal. Model Data ≠ Observations

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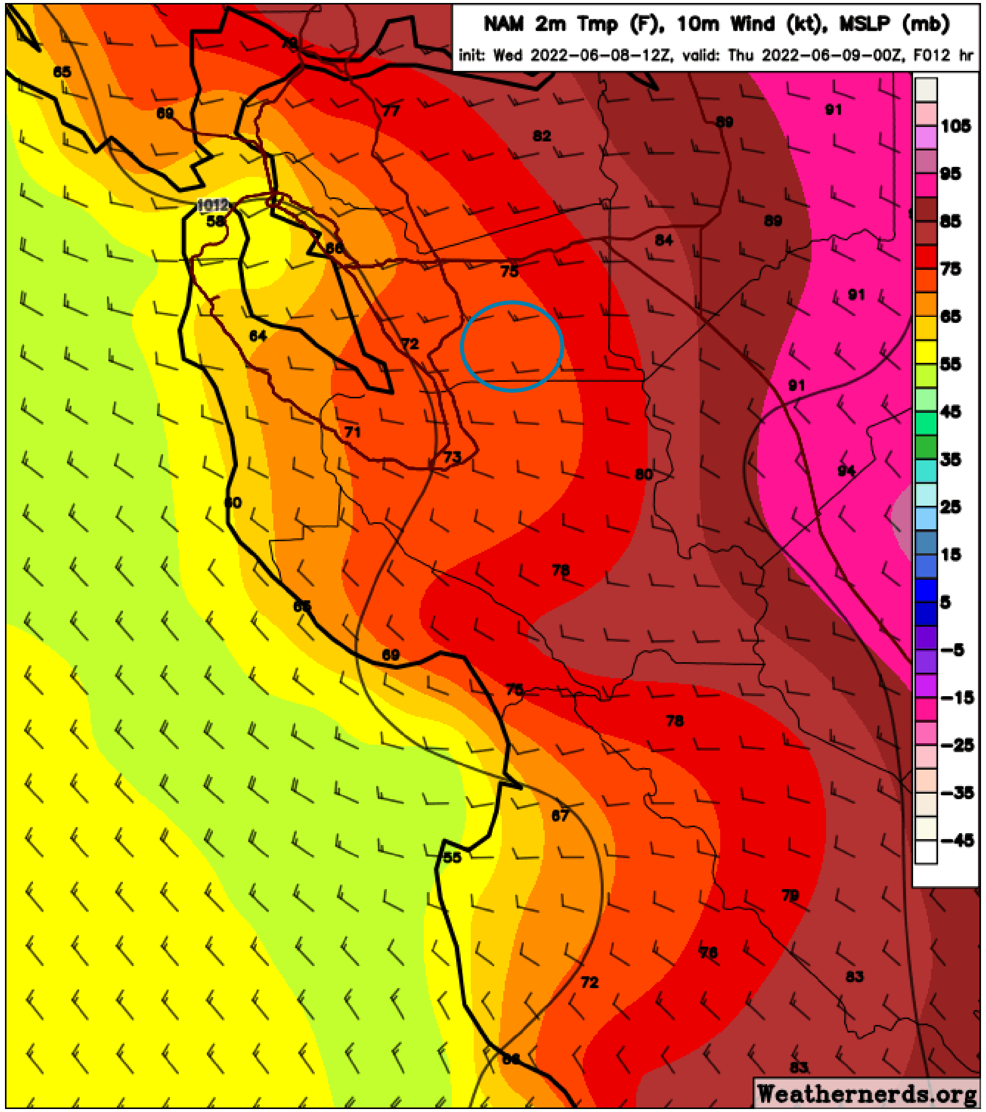
  - Do the same for drivers of system load/other weather risks
- …be concurrent and physically consistency
  - All variables represent the same time chronology and are from dynamically consistent sources
  - Mixing and matching should be avoided if possible and if done the consequences should be analyzed
    - Mixing examples: NSRDB and WINDTK; different NWP models on right; statistical models and observations
- …



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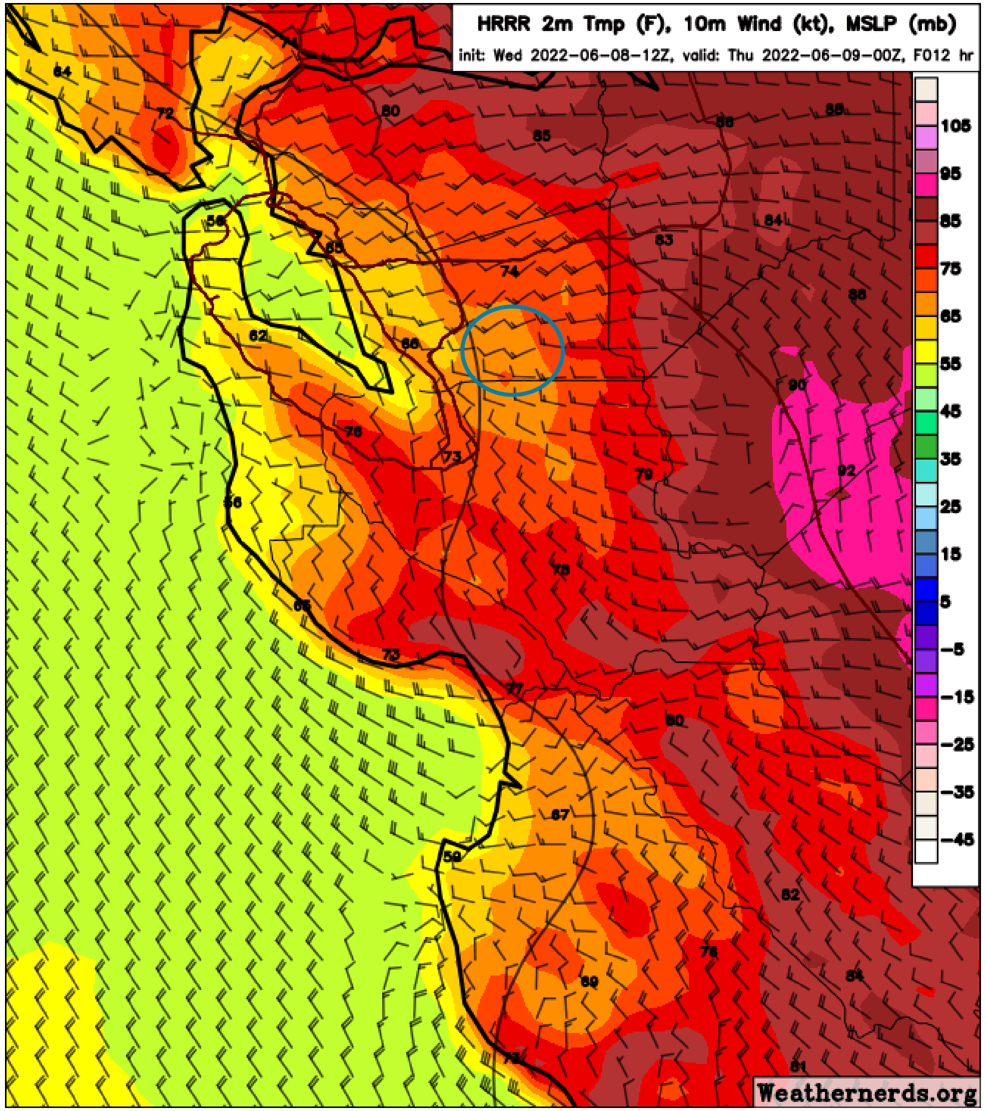
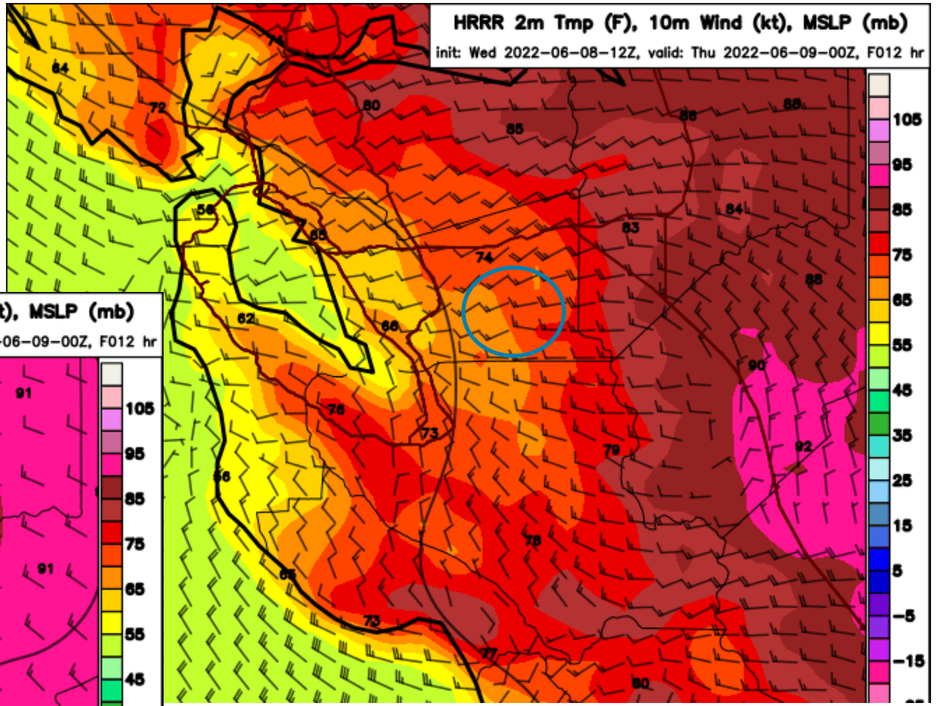
    - Mixing examples: NSRDB and WINDTK; different NWP models on right; statistical models and observations
- …provide a 30+yr, updated time history with a consistent methodology that minimize biases, trends, and “artifacts”

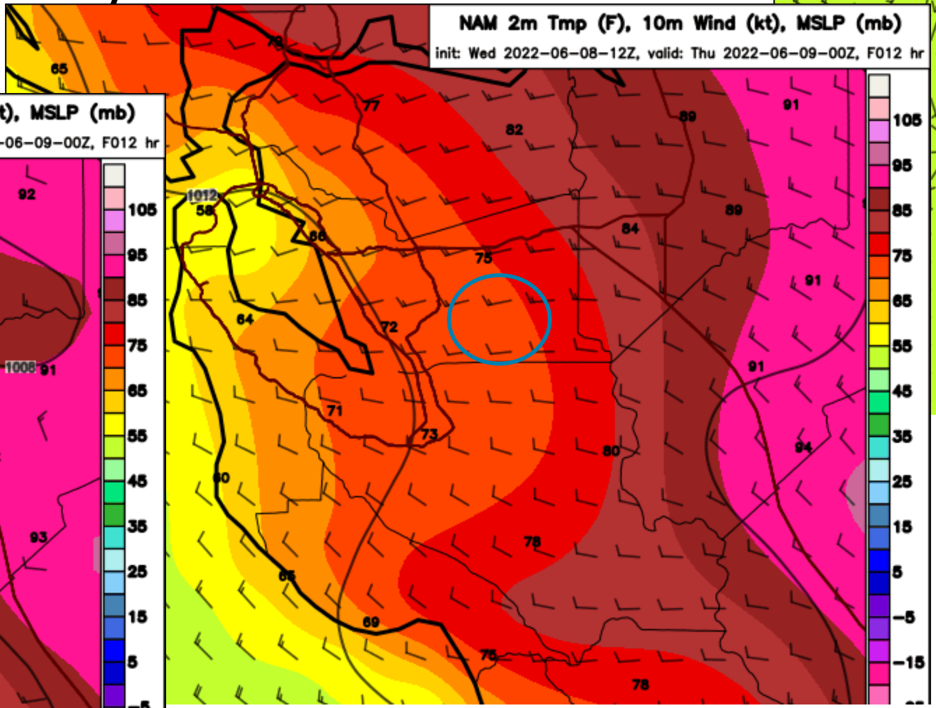


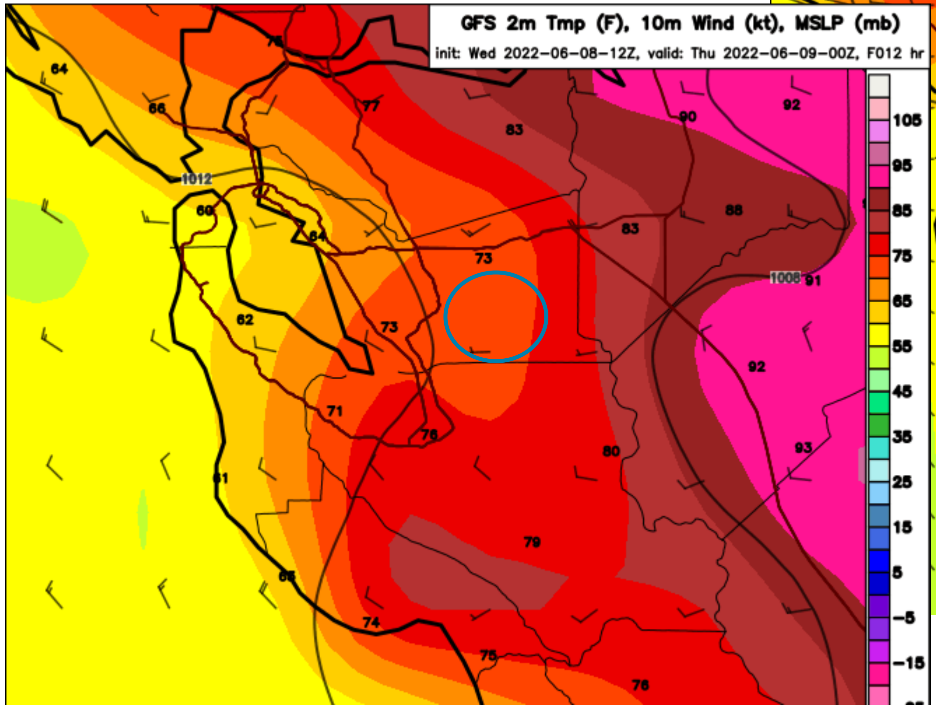
Not All Data Is Created Equal. Model Data ≠ Observations

Weather datasets For Power Systems Should…

- …be validated and have uncertainty quantified.
- Which of these representations is right? Most useful?
  - They can't all be right!
- Have you validated the data you use?







- 50's, 60's, 70's or 80's?
- Light, moderate, strong wind?
- Cloudy or sunny?

Not All Data Is Created Equal. Model Data ≠ Observations

More Nuance: Offshore Validation Example

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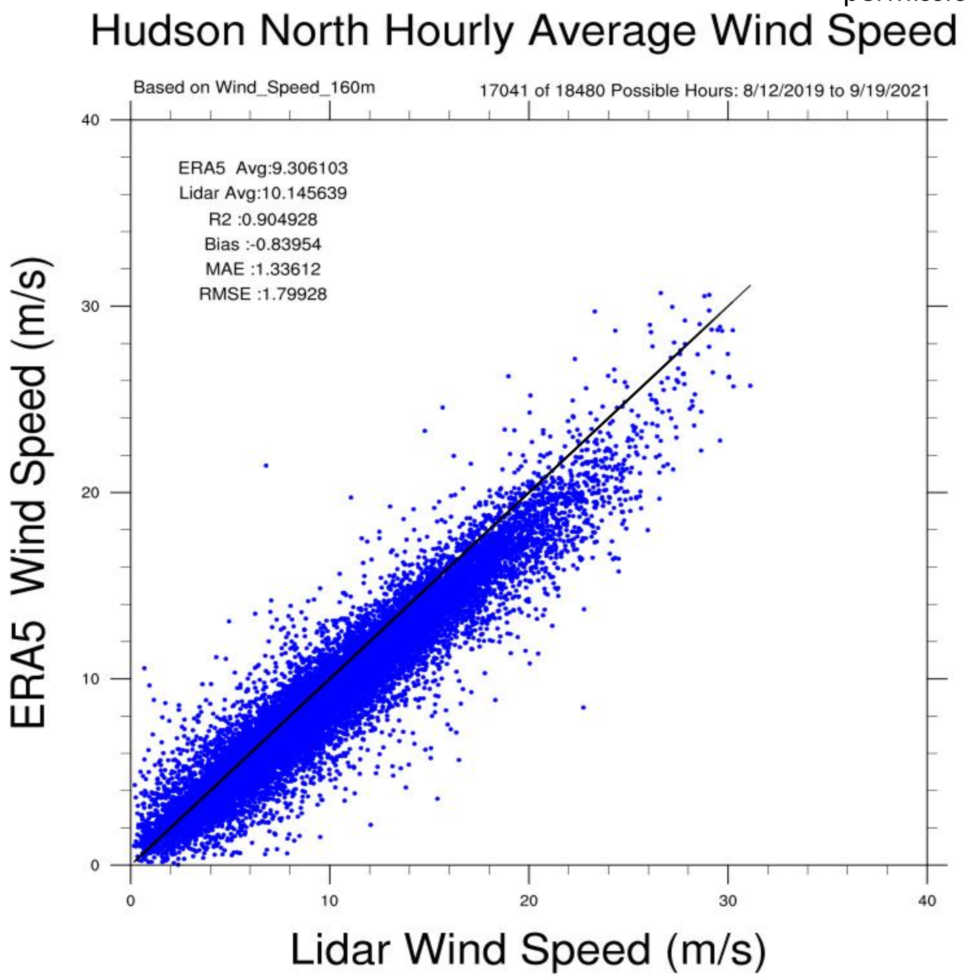
- Typical analyses look at standard metrics such as bias, MAE, RMSE, and correlation between measured and simulated data
- Here ERA5 160 m wind speed data evaluated with hourly average (+/- 30 mins) "Hudson North" Lidar measurements over a ~ 2-yr period
- Analysis indicates fairly good performance
  - R^2 of about 0.90
  - Bias (ERA5 a bit low): -0.83 m/s
  - MAE: 1.34 m/s
  - Similar performance results at other nearby measurement sites



So ERA5 should be fine for offshore wind integration studies?

The Impact of Data Assimilation Cycles

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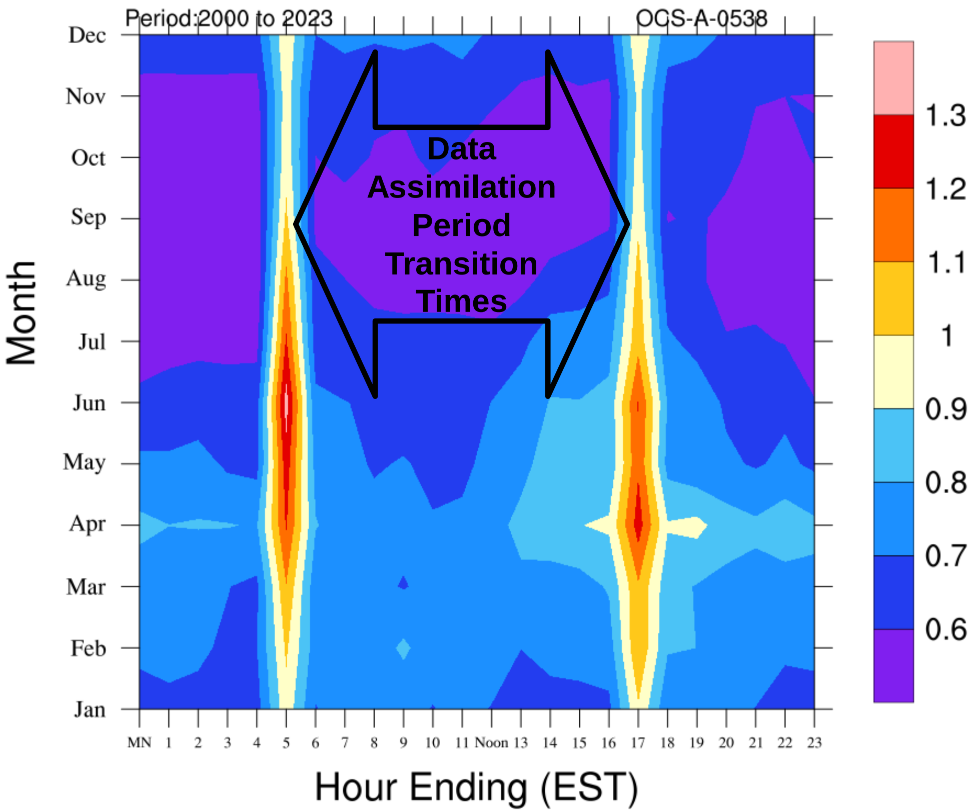
- The ERA5 data is created with a DA scheme where there are two major data assimilation cycles per day
- If we examine the average absolute value of the 1-hr wind speed change by month and time of day we see larger average changes occur at the transition time between data assimilation periods (0500 EST and 1700 EST)
- The Impact varies substantially by time of year
- Therefore, ramp event analysis using the ERA5 data is suspect for this location…and likely others

2000-2023 ERA5 Average 1-h Absolute Wind Speed Change (m/s) by Month & Hour of Day



This is among the list of known problems listed on the ERA5 web page…but who has time to read the manual or footnotes?

8. ERA5 diurnal cycle for near surface winds: the hourly data reveals a mismatch in the analysed near surface wind speed between the end of one assimilation cycle and the beginning of the next (which occurs at 9:00 - 10:00 and 21:00 - 22:00 UTC). This problem mostly occurs in low latitude oceanic regions, though it can also be seen over Europe and the USA. We cannot rectify this problem in the analyses. The forecast near surface winds show much better agreement between the assimilation cycles, at

Low Hanging Fruit for Validation and Uncertainty Quantification

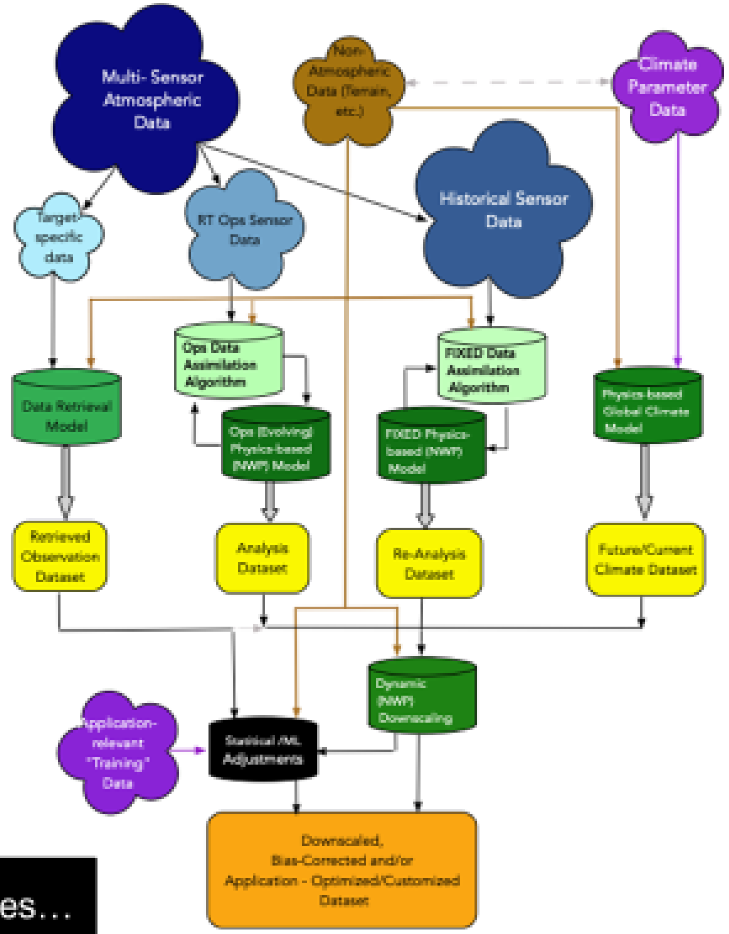
- Comprehensive industry wide data transparency and sharing is required: Met., generation, and availability data
  - Little proprietary value per site but a tremendous untapped asset if made public across all generators
- This will enable validation and UQ of synthetic datasets which is imperative for valid application. Ground truth data is also key to the model improvement process
- ERCOT is leading the way. Others should follow ASAP
  - This might require legislation/regulation.

User Knowledge/Education

Overview of the Current World of Datasets for Power System Planning

- ❑ **Wide Range of Methods to Construct Datasets**
  - **A few fundamental types of approaches**
  - Enormous number of significant variations within types
- ❑ **Therefore: Wide Range of Datasets Exist**
  - **Typically have very different attributes depending on how they were constructed**
  - Consistency of data attributes (e.g. spatial/temporal correlations) between datasets should not be assumed
  - **Critical need to evaluate comparative performance on parameters/scales important to specific applications**

Let's examine the key attributes of the fundamental types of approaches…



Slide courtesy of:

Dr. John W. Zack
Principal
MESO, Inc.
Troy, NY

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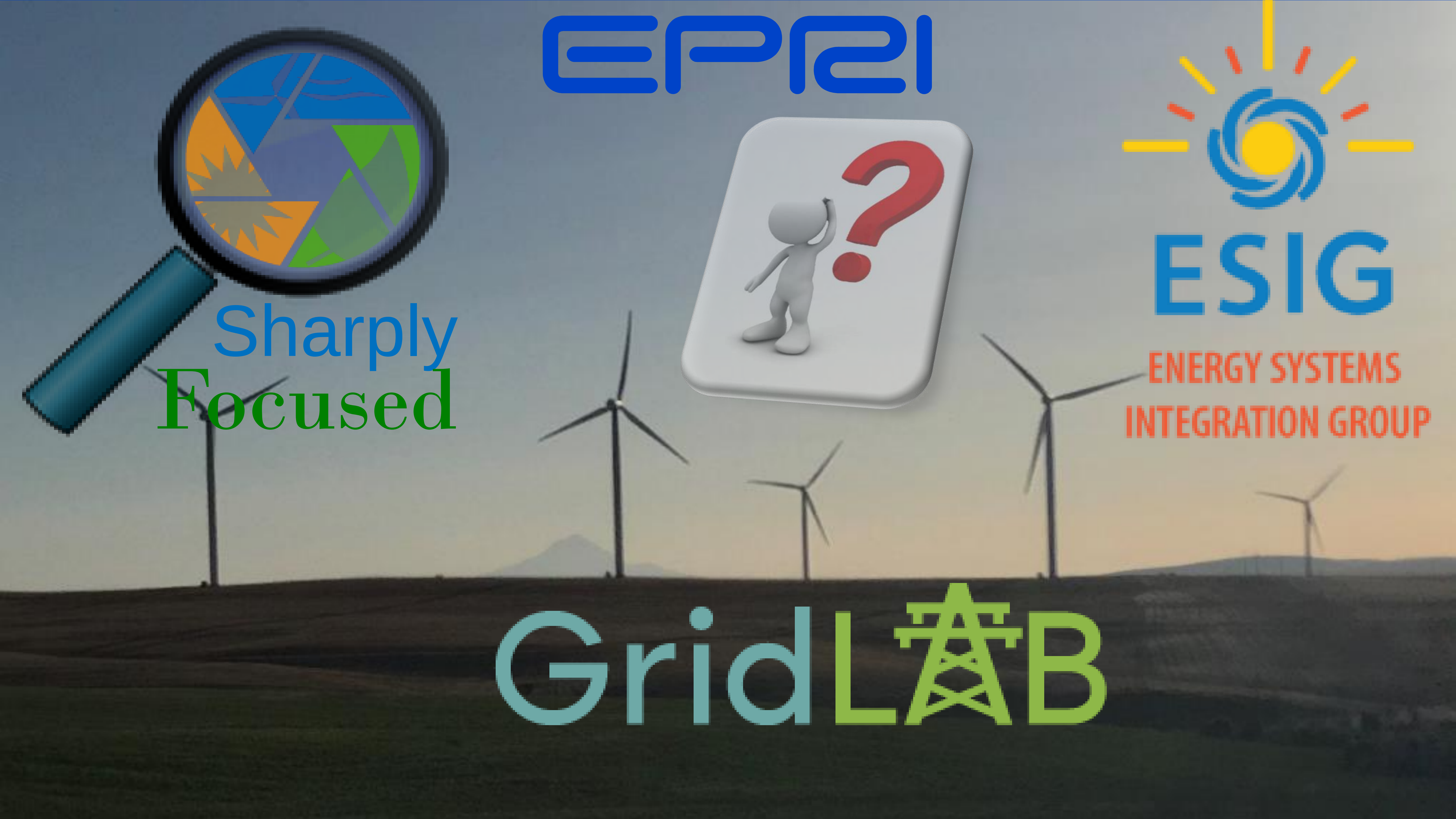
It's Complicated!!!

Summary

- Weather impact on the electric system is increasing significantly in complex, interdependent ways that need to be considered in planning and operations
- Current weather datasets and practices for their use are inadequate and urgently need updating. Key issues:
  - Lack of attention to validation and uncertainty quantification
  - Lack of understand of the inaccuracies, biases, and limitations of available synthetic weather data. They should not be treated like observations.
  - Lack of holistic vision, sector coordination, and funding to fix the problem
  - Lack of sector weather and power data sharing to improve modeling and validation
- Producing quality fit-for-purpose weather datasets is achievable, and an imperative ongoing need for the sector. Not a once and done research project.
- Industry momentum to move forward is building
- EPRI's has the trans-disciplinary skills to coordinate this with multiple partners
  - A strong match for Public-Private Partnership
  - Looking for utility partners to team with to push forward the process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