# Weather and Climate Intelligence for an Increasingly Weather Dependent Grid

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


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Technical Leader


Avista DPAG
December 3, 2024

Support and content provided by:

ESIG
ENERGY SYSTEMS INTEGRATION GROUP

GridLAB

Sharply Focused
Understanding Renewable Resources

www.epri.com

# 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

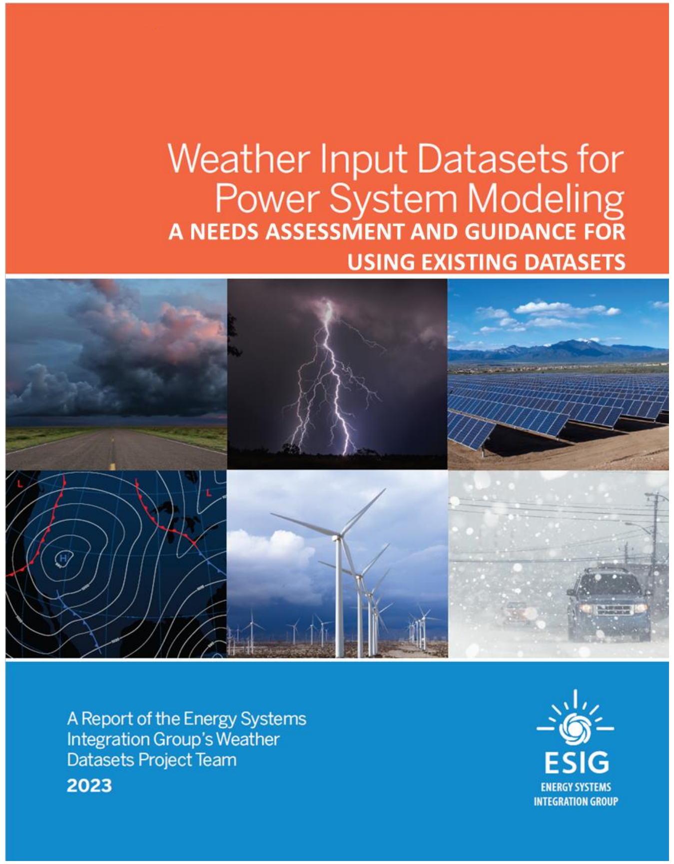
Website: msites.epri.com/LFI

*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.




[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.

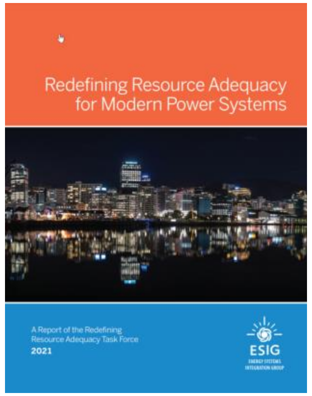
# Motivation: The Energy Transition

THE ELECTRIC SYSTEM IS CHANGING

…RADICALLY…

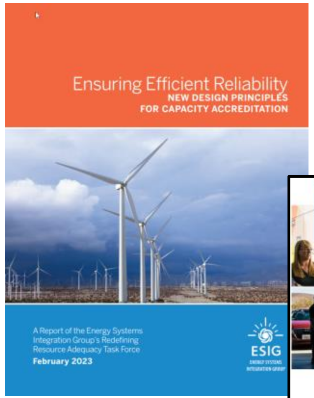
AND IS FULL OF UNCERTAINTY

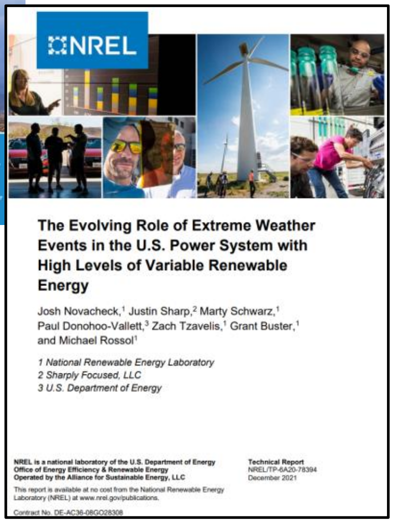
THE SECTOR HAS TO EVOLVE ITS METHODS ACCORDINGLY




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




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)



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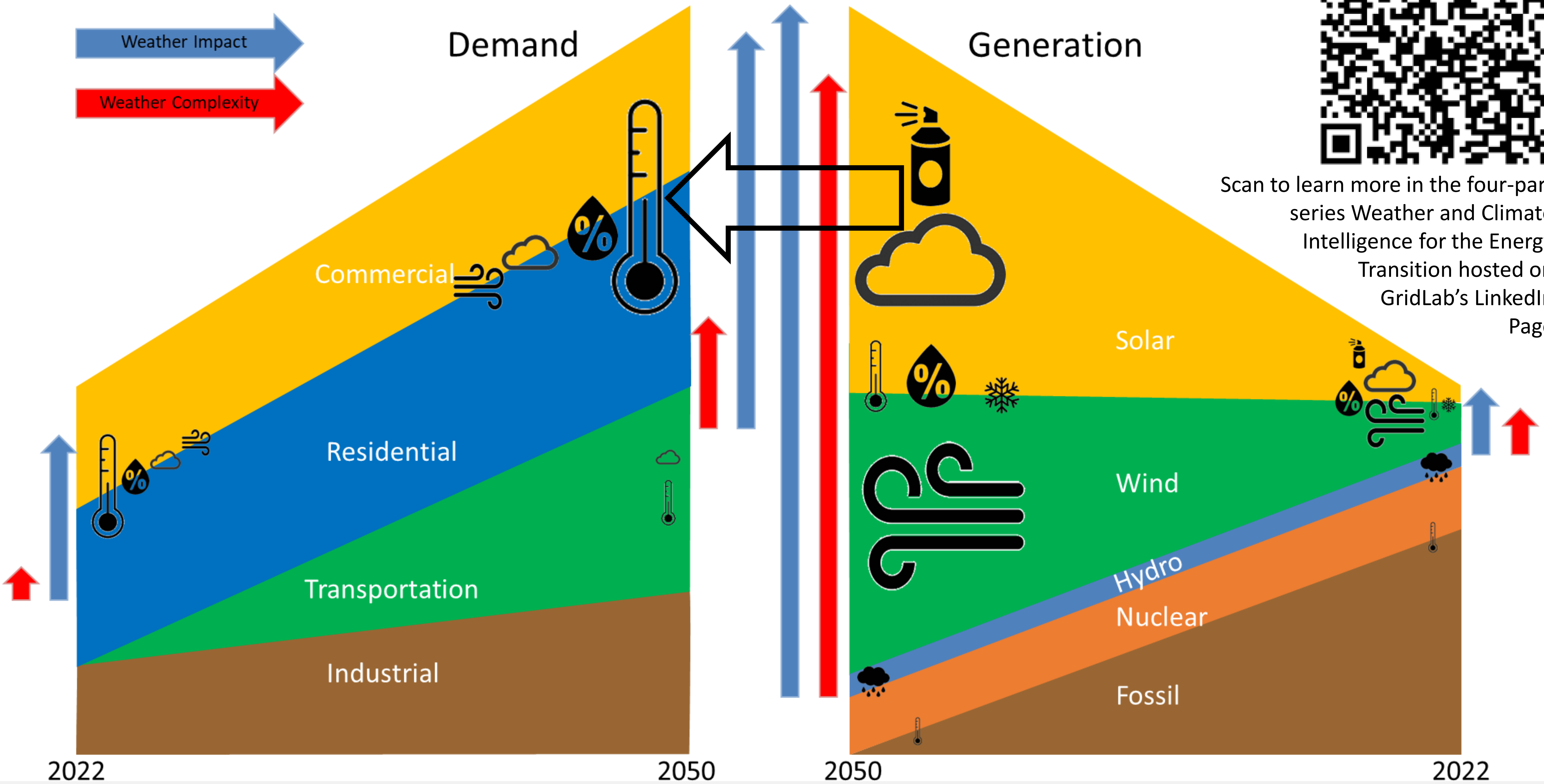
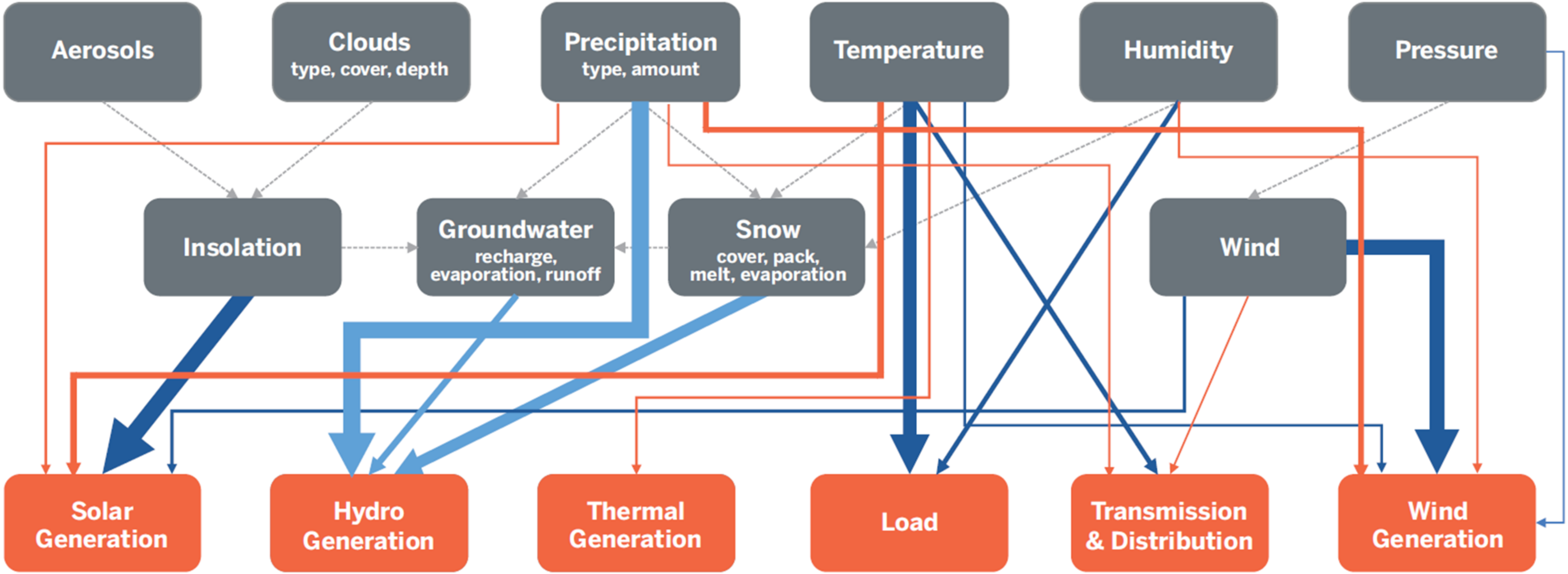
# The Evolving Energy – Weather Nexus

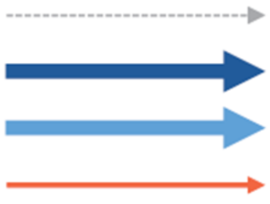



Scan to learn more in the four-part series Weather and Climate Intelligence for the Energy Transition hosted on GridLab's LinkedIn Page

# 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.

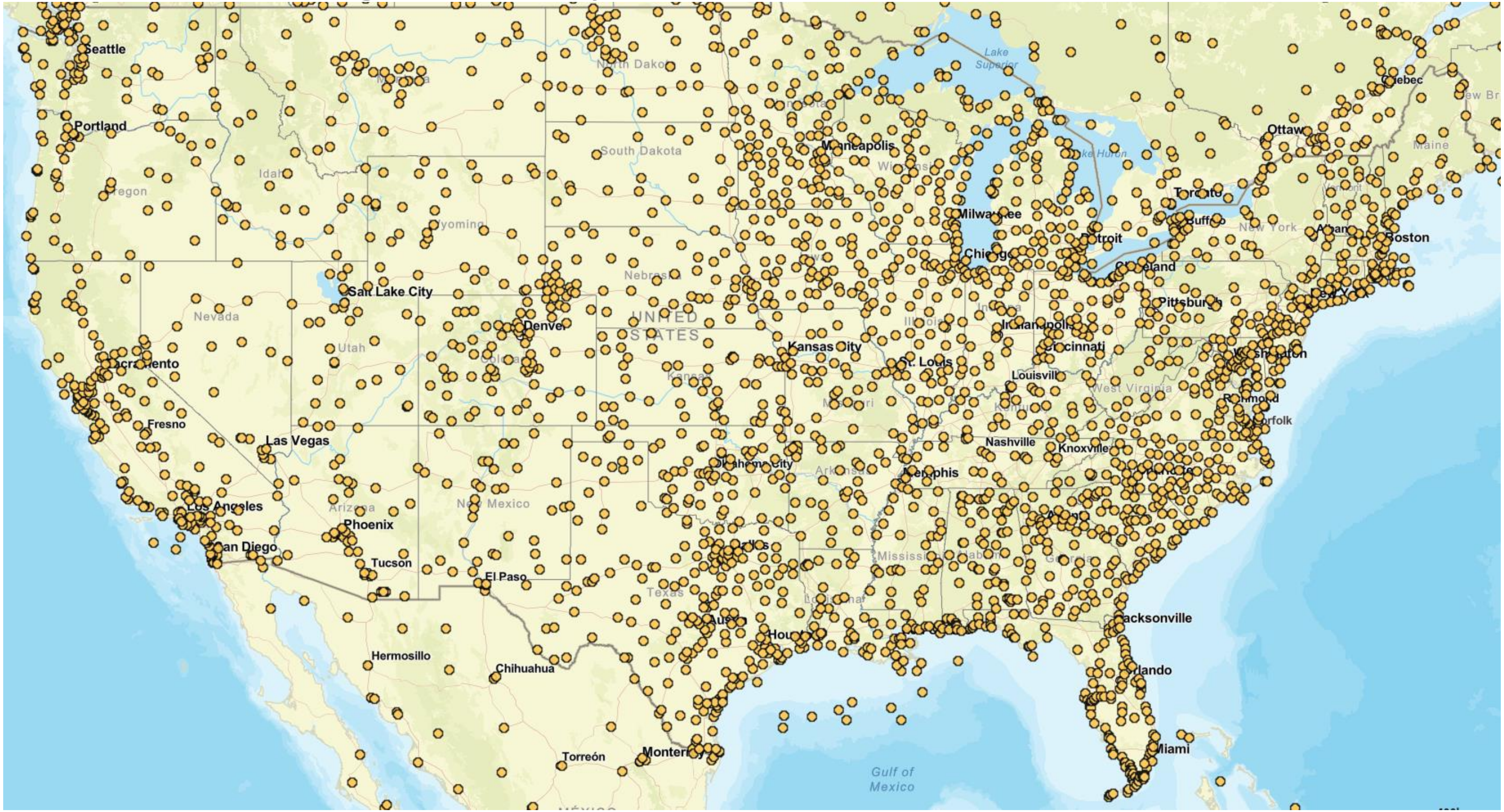
Dependence of the electricity system on the climate system.

Strength of dependence is highly variable and depends on asset type and location.

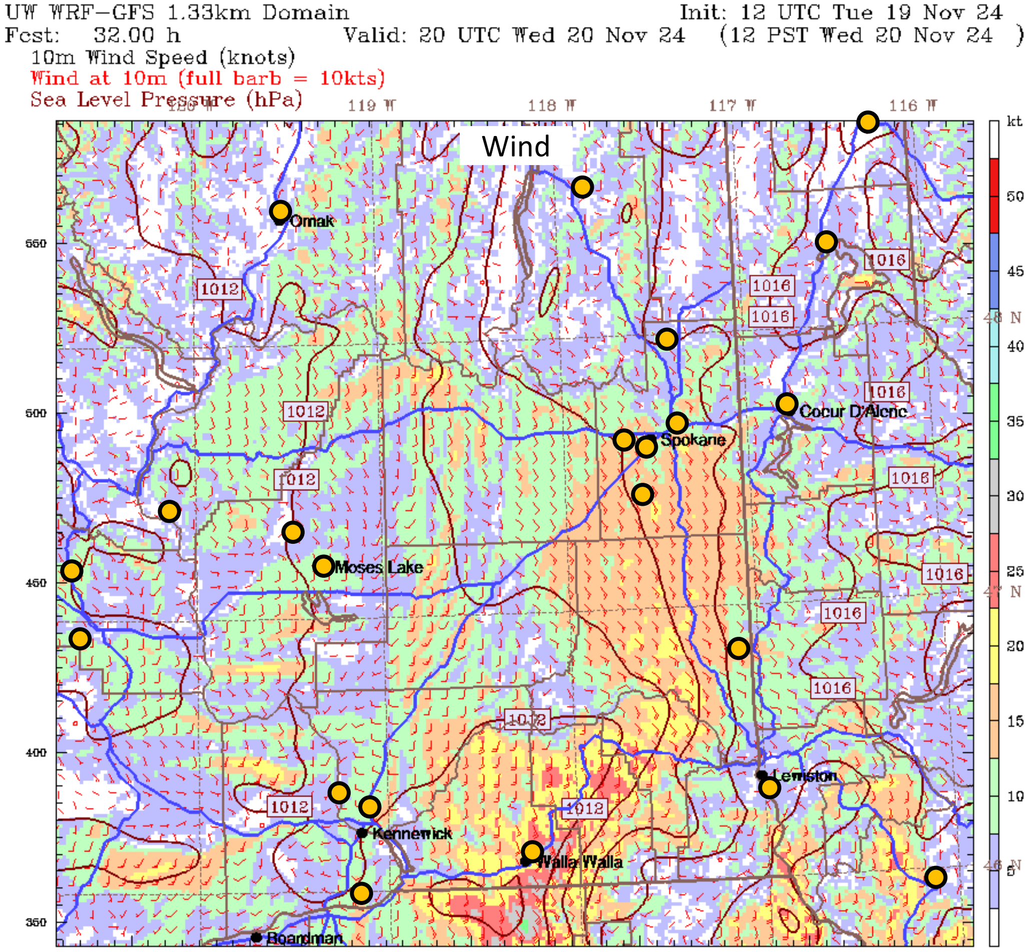
Degree of dependence can be greatly amplified by specific weather and climate conditions.

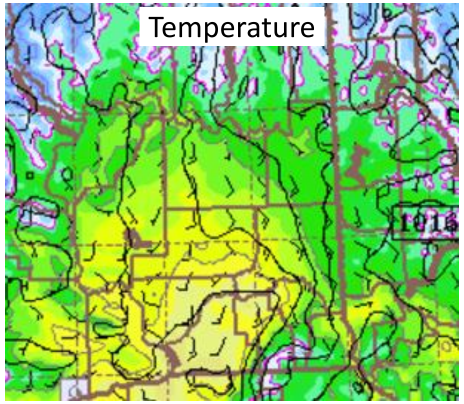
Source: ESIG Weather Data for Power System Planning https://www.esig.energy/weather-data-for-power-system-planning/

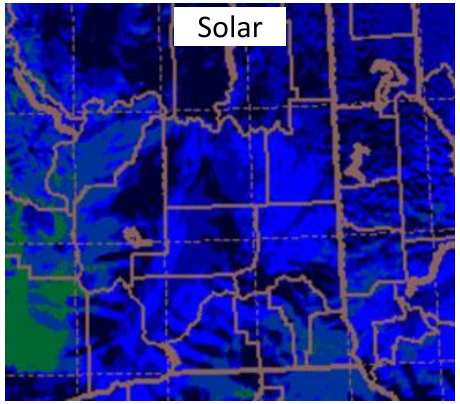
# Active High-Quality Public Weather Observations



- 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/

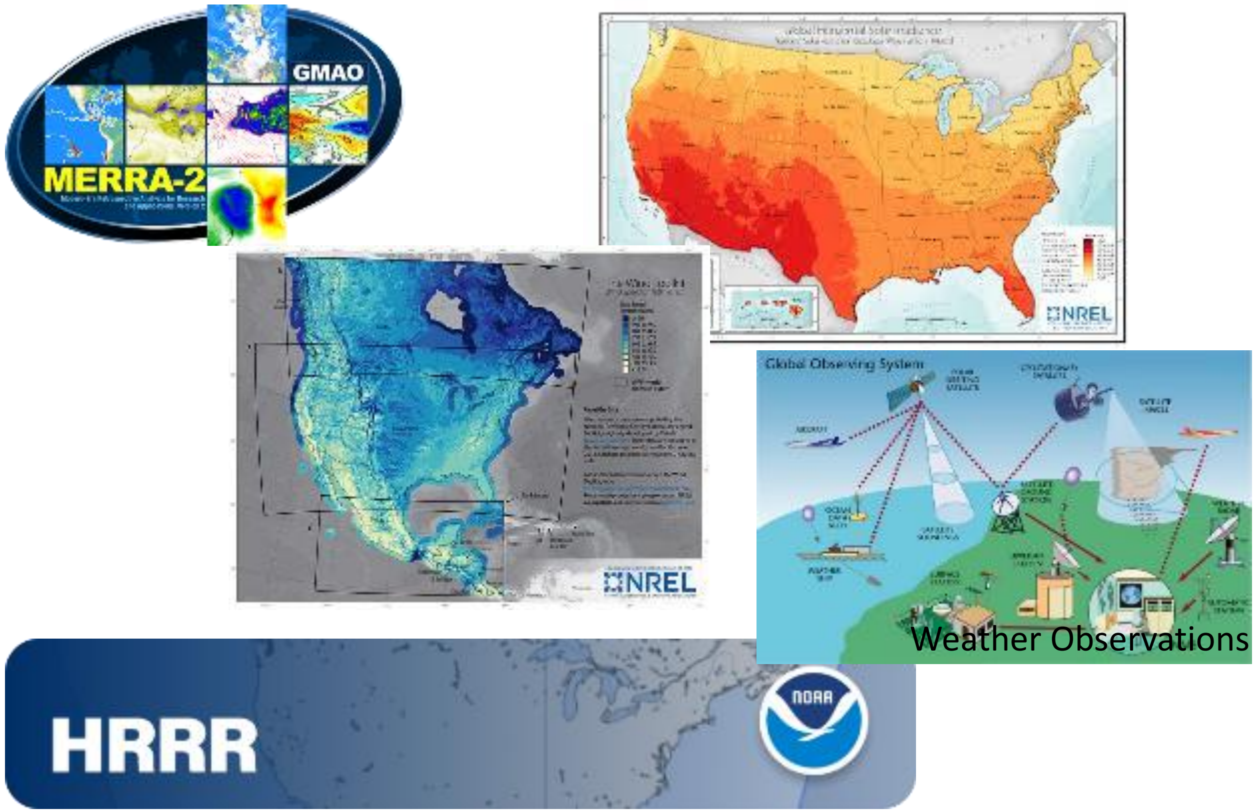
| | |
|---|---|
| **Including the necessary variables** | Include the necessary variables at sufficient spatio-temporal resolution and accuracy to reflect actual conditions that define the generation potential at current and future wind/solar sites and temperature at load centers |
| **Covering multiple 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

Copernicus

Europe's eyes on Earth




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.



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| | 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 |
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| **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

# 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

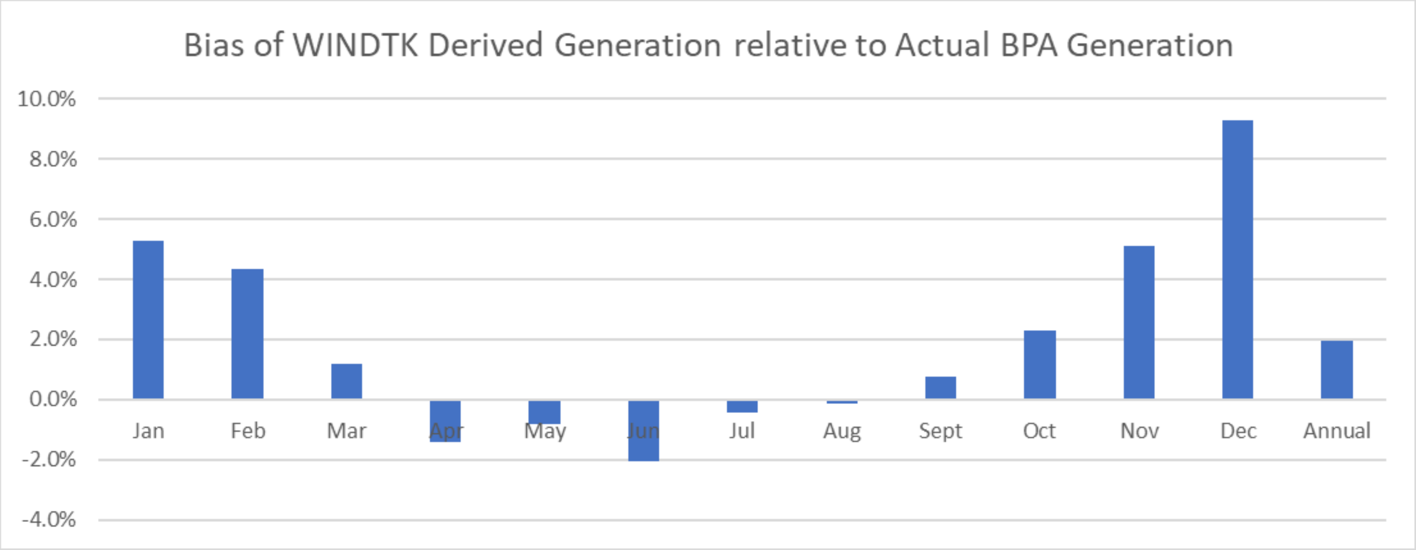
Summary of the most applicable datasets globally that are (or can be) used to provide weather inputs for power system analysis tasks, especially for providing estimate of site-level generation, and concurrent weather-driven load and generation outage risks. The degree to which the needs of each column 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.



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# Our Weather “Intelligence” is Inadequate

<u>Producer(s)</u>

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**

<u>Users</u>

End-use application of data

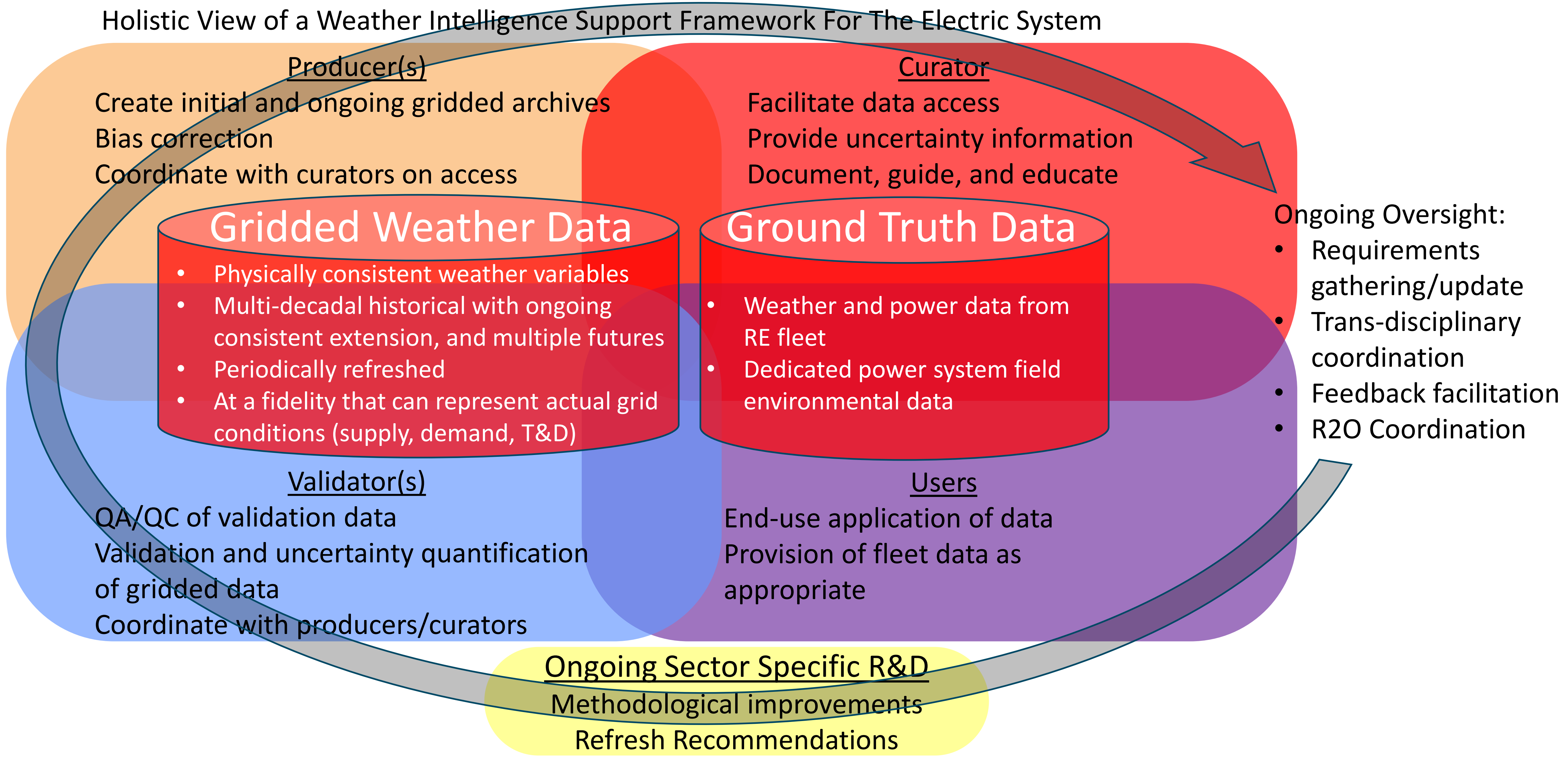
We are transitioning to a much more weather dependent electric system:

- 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

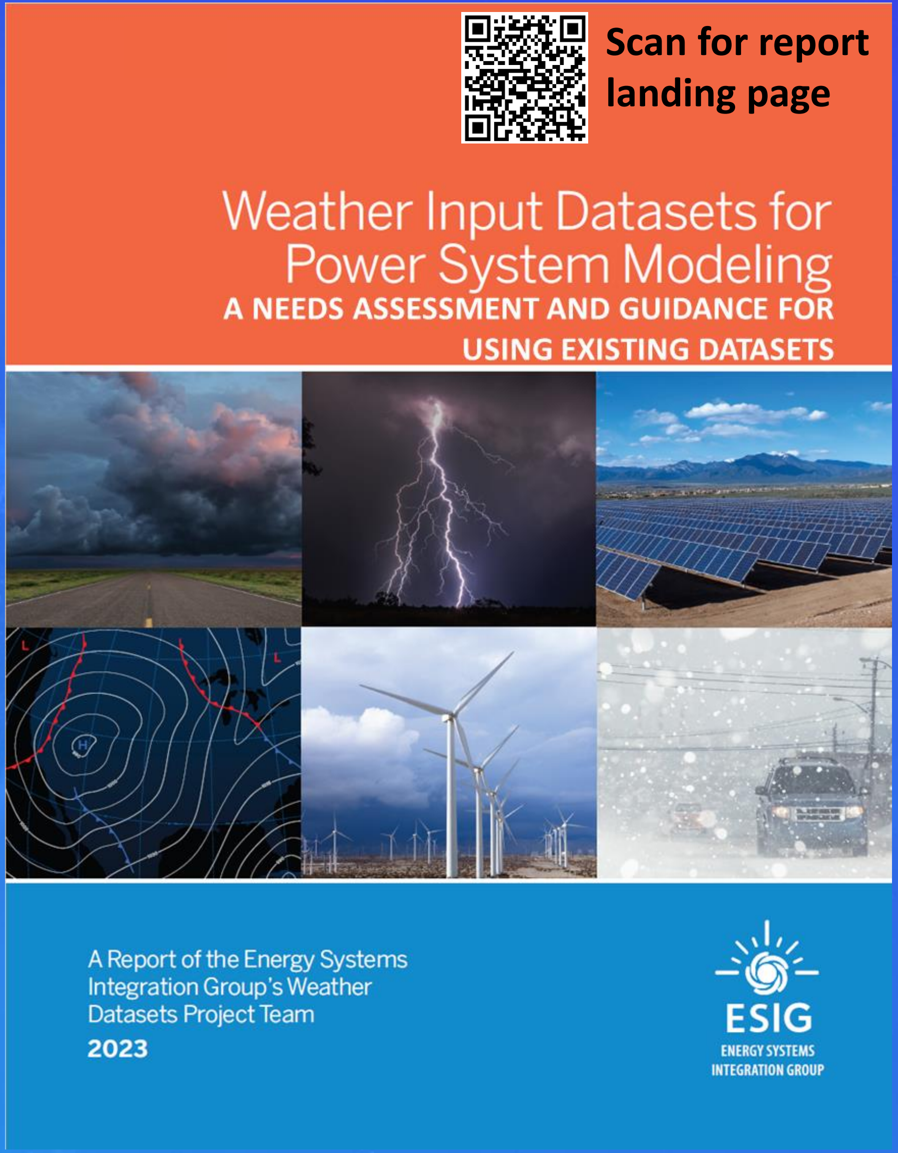
## <u>Yet We Are Largely Flying Blind</u>

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?

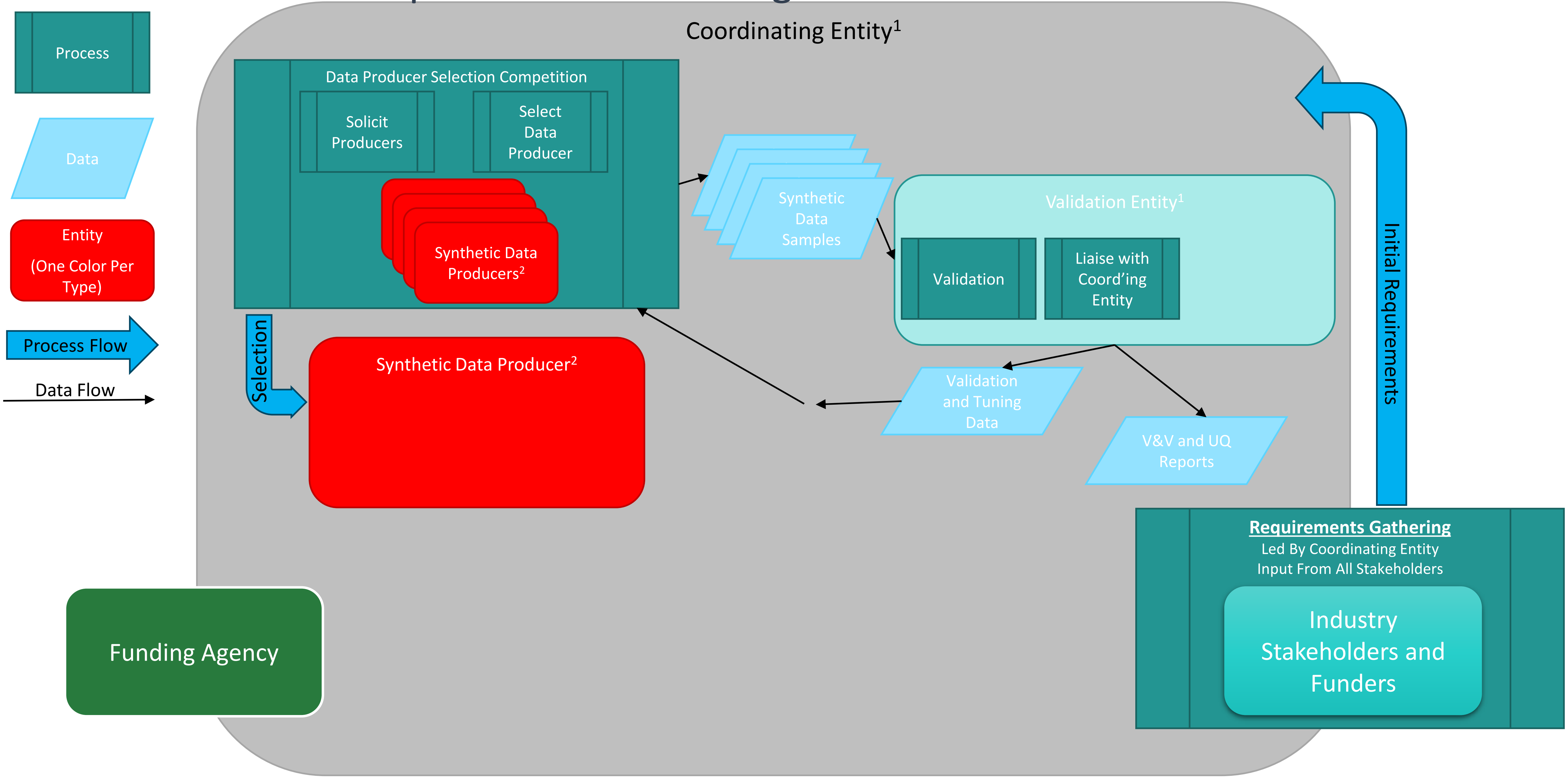
## One solution is to fly blind and largely ignore the problems and hope they wash out in the analysis. This is often the current practice.

# 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

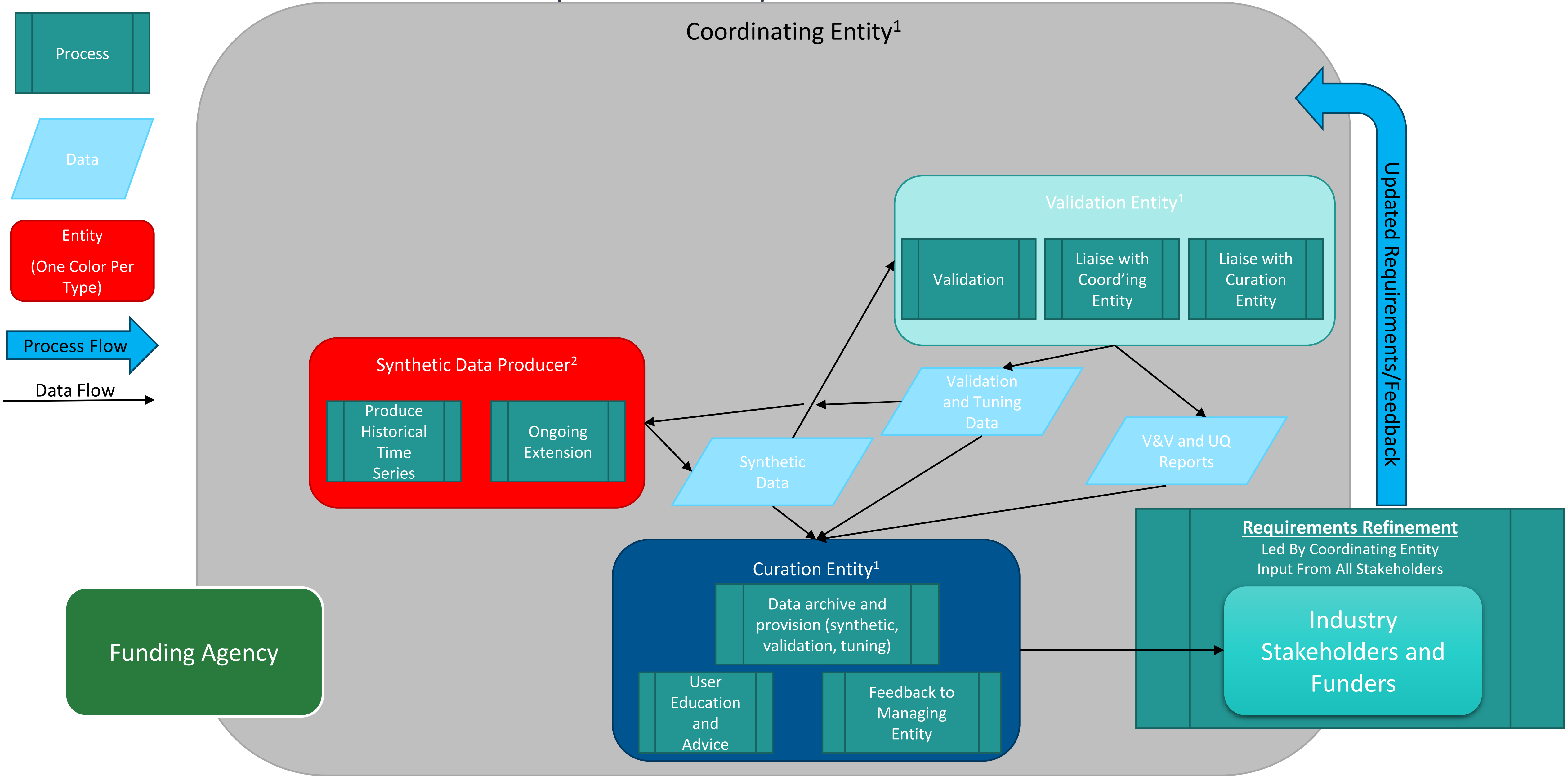
## There are achievable, better options. I'll take you through a (methodologically agnostic) proposed approach.

# 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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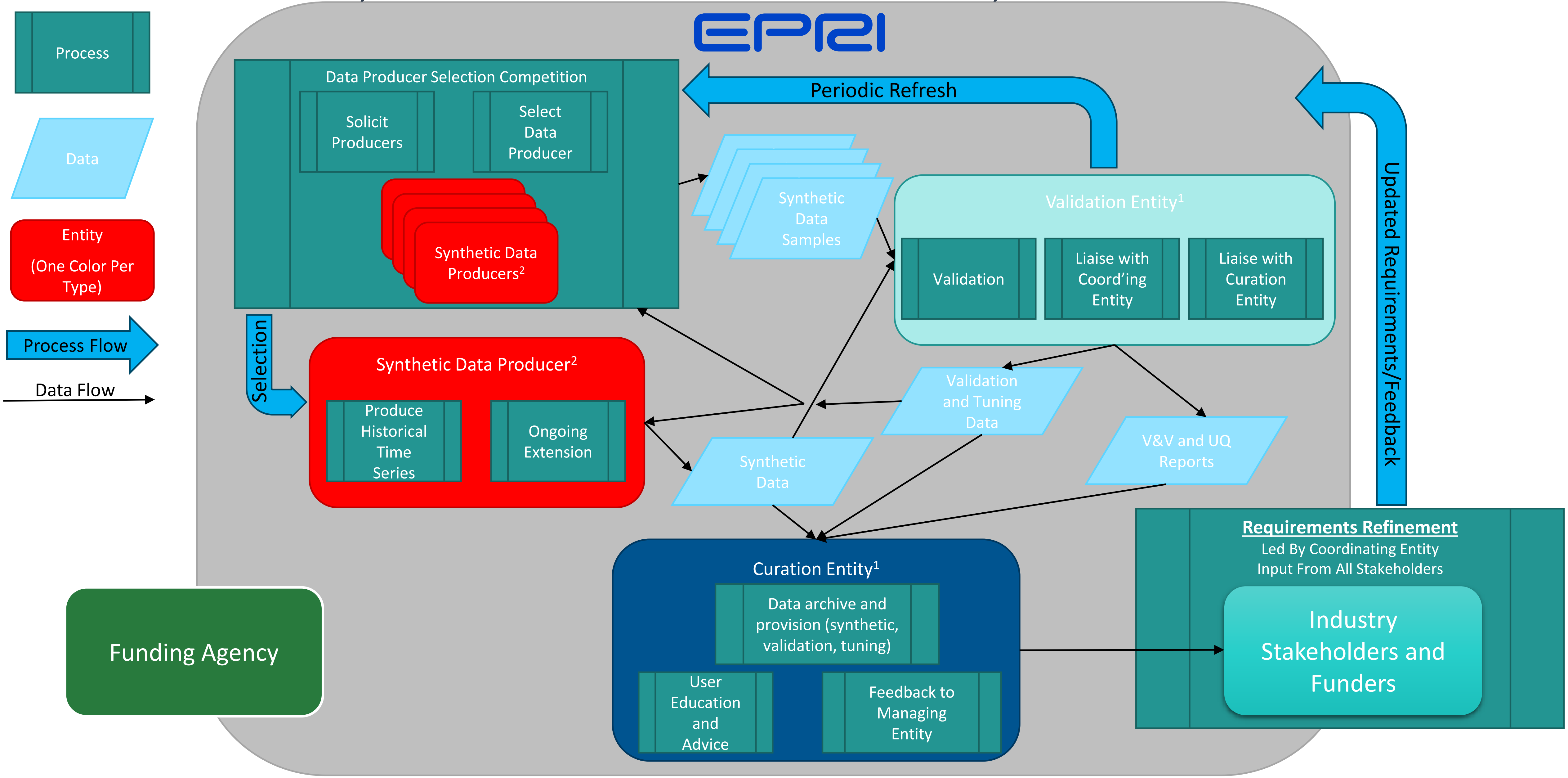
# Production, Validation and Curation Processes, with Periodic Refresh

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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**

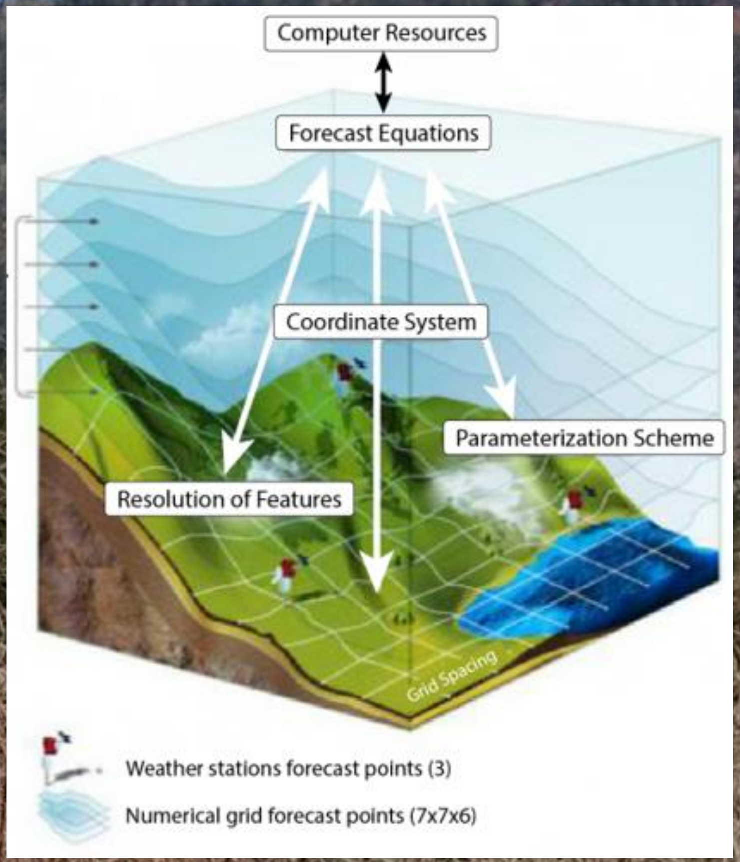
**Expected grid decarbonization investment by 2035: $330-740B[1]**

**<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

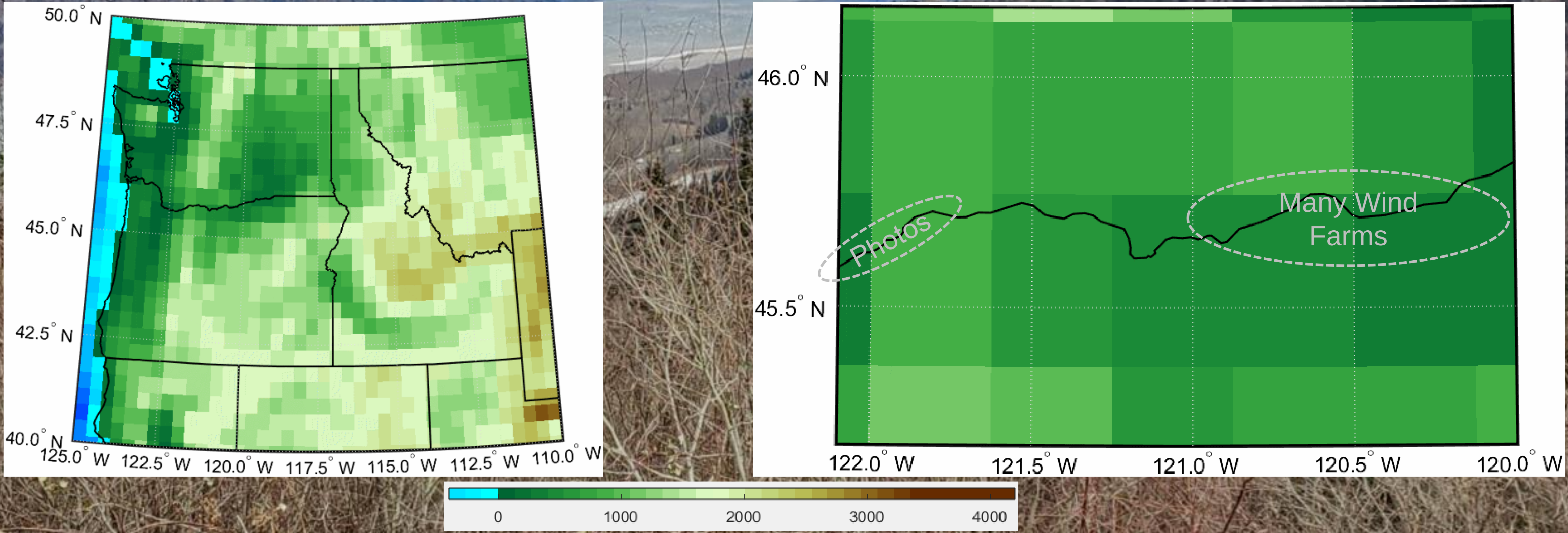
# Getting into the Weeds

## All Data Is Not Created Equal
## The Impact of Grid Spacing

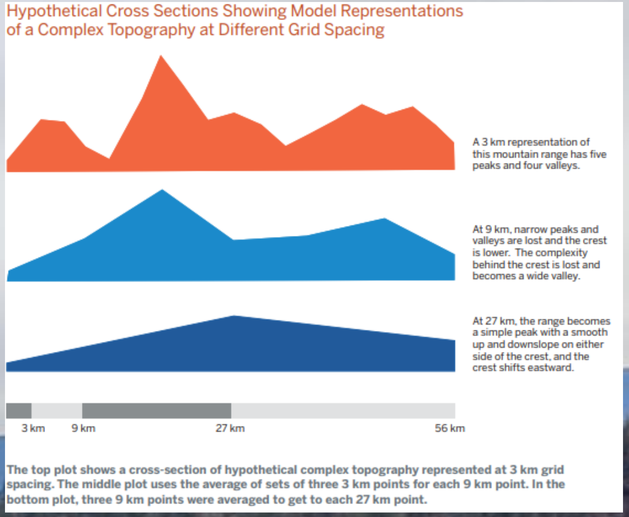



# Representation at 30 km Grid Spacing (About the same as ERA5)

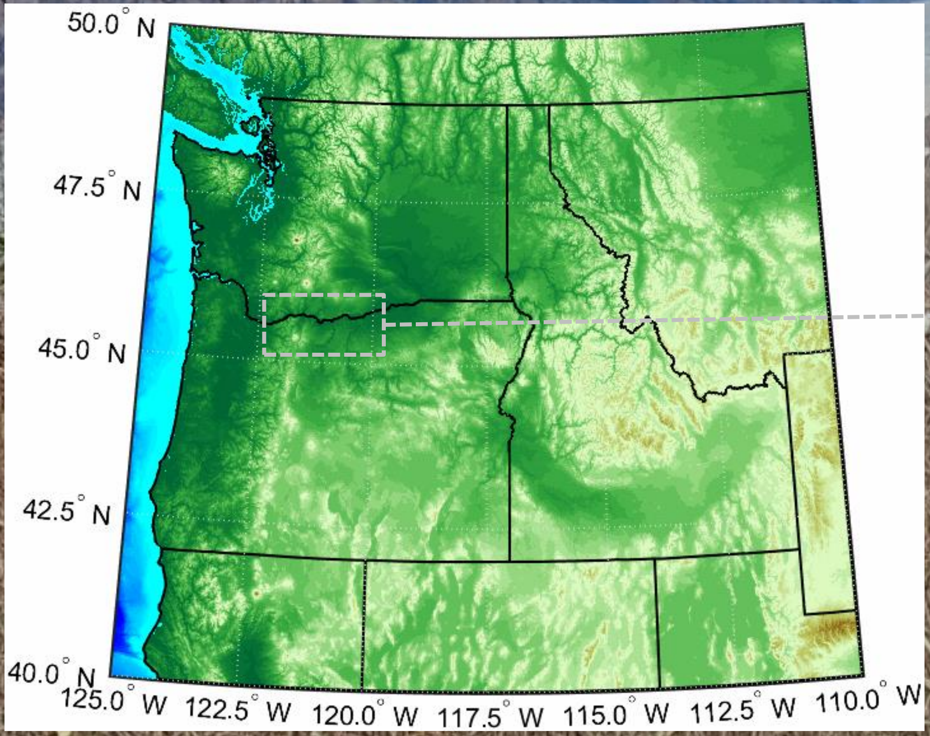
30 km Grid Spacing (~ERA5)

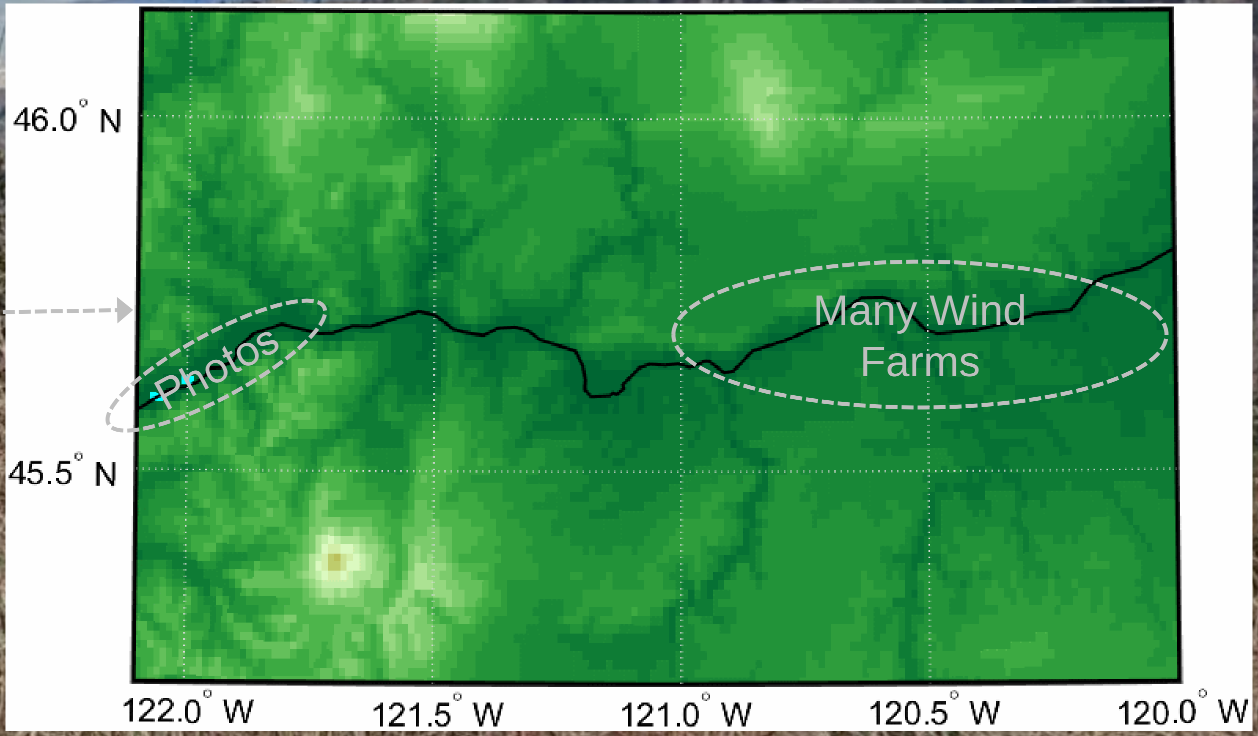


# Representation at 1 km Grid Spacing (The WIND Toolkit has 2 km Resolution)

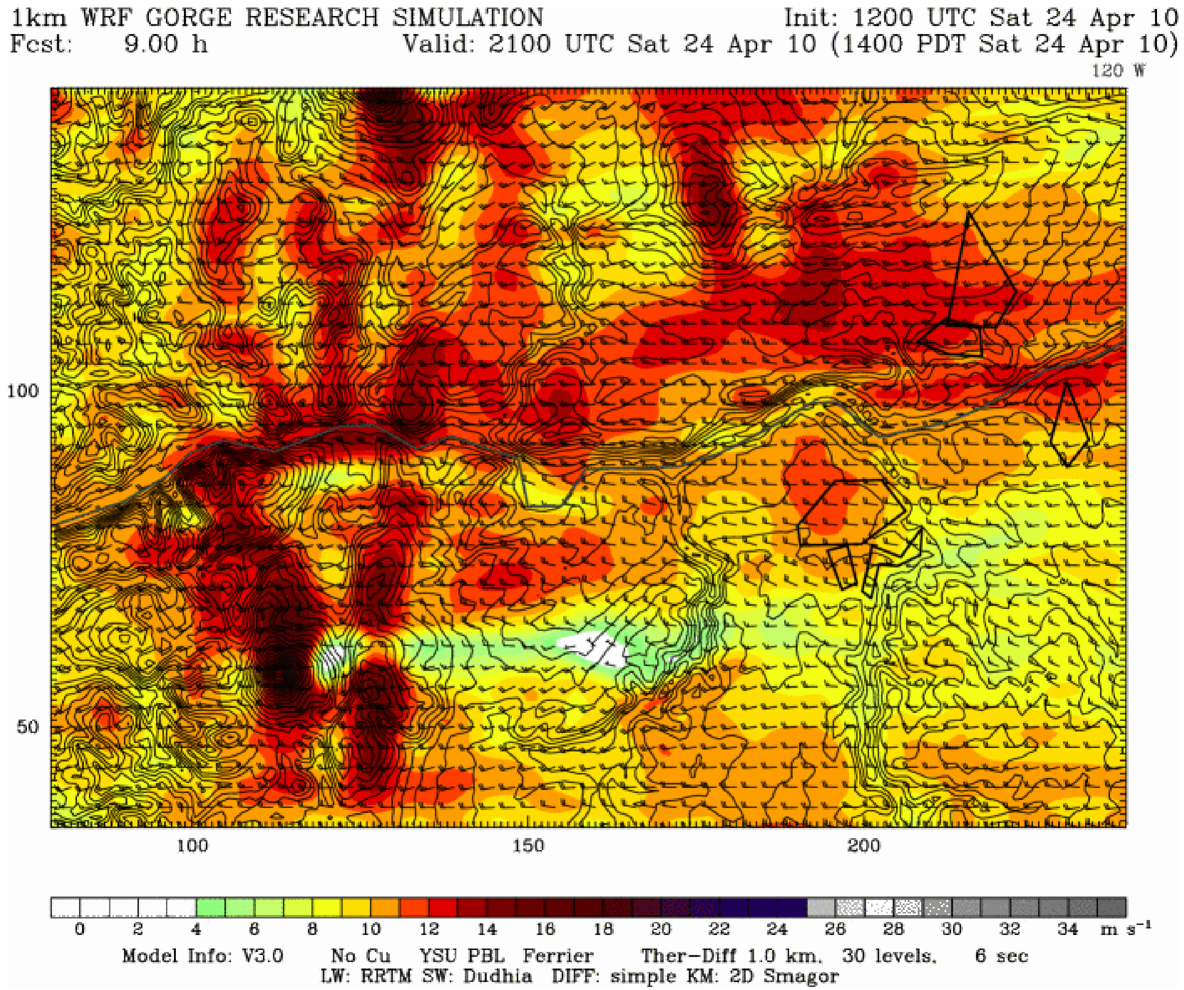


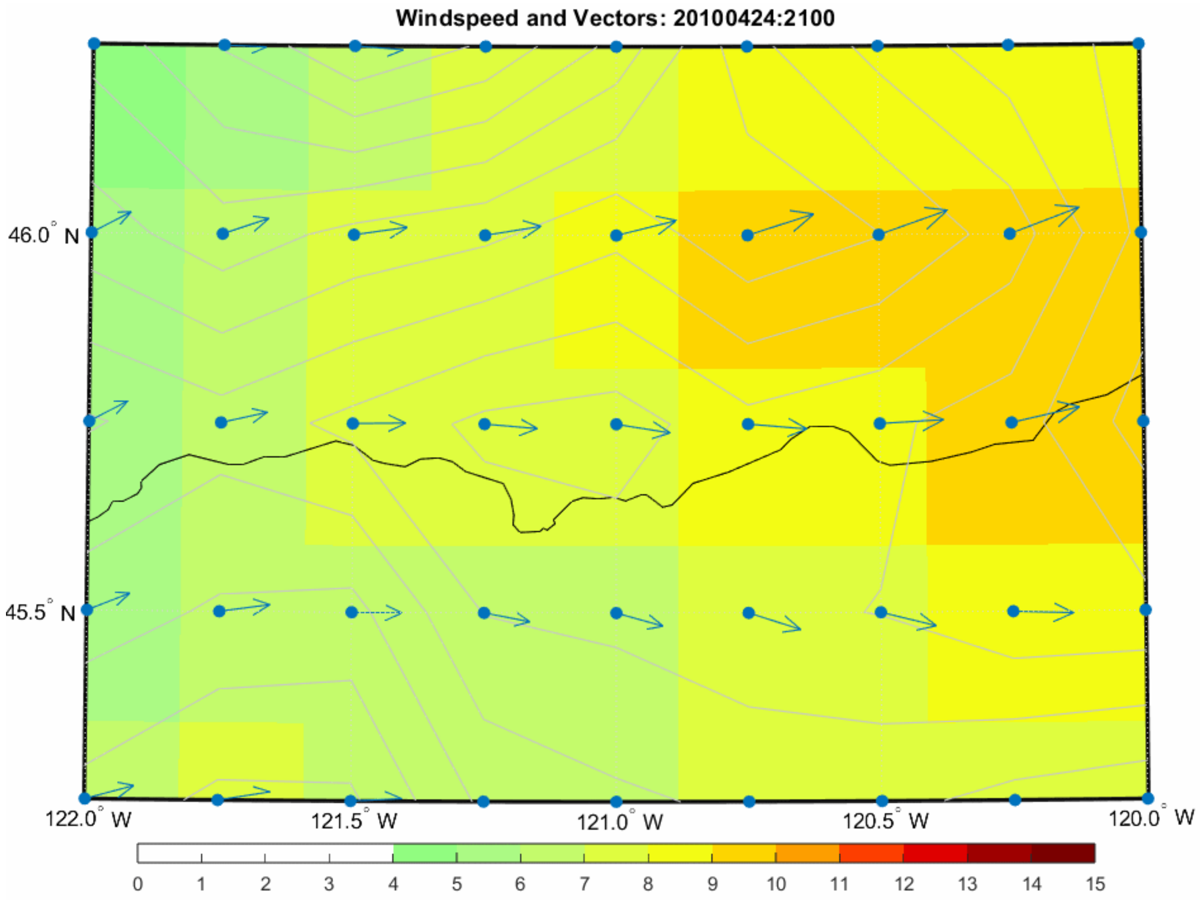
The top plot shows a cross-section of hypothetical complex topography represented at 3 km grid spacing. The middle plot uses the average of sets of three 3 km points for each 9 km point. In the bottom plot, three 9 km points were averaged to get to each 27 km point.



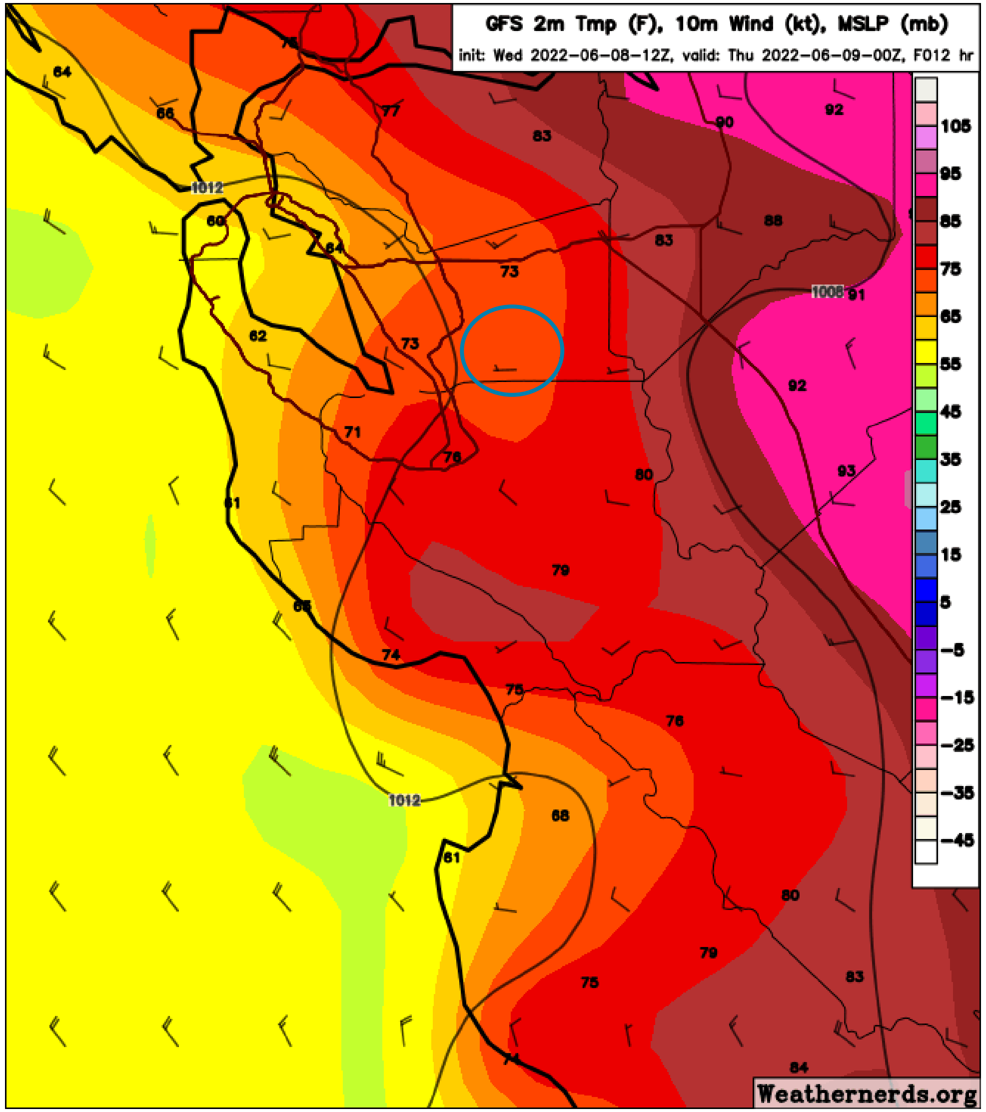

# An Example of Resolution Impacts



# 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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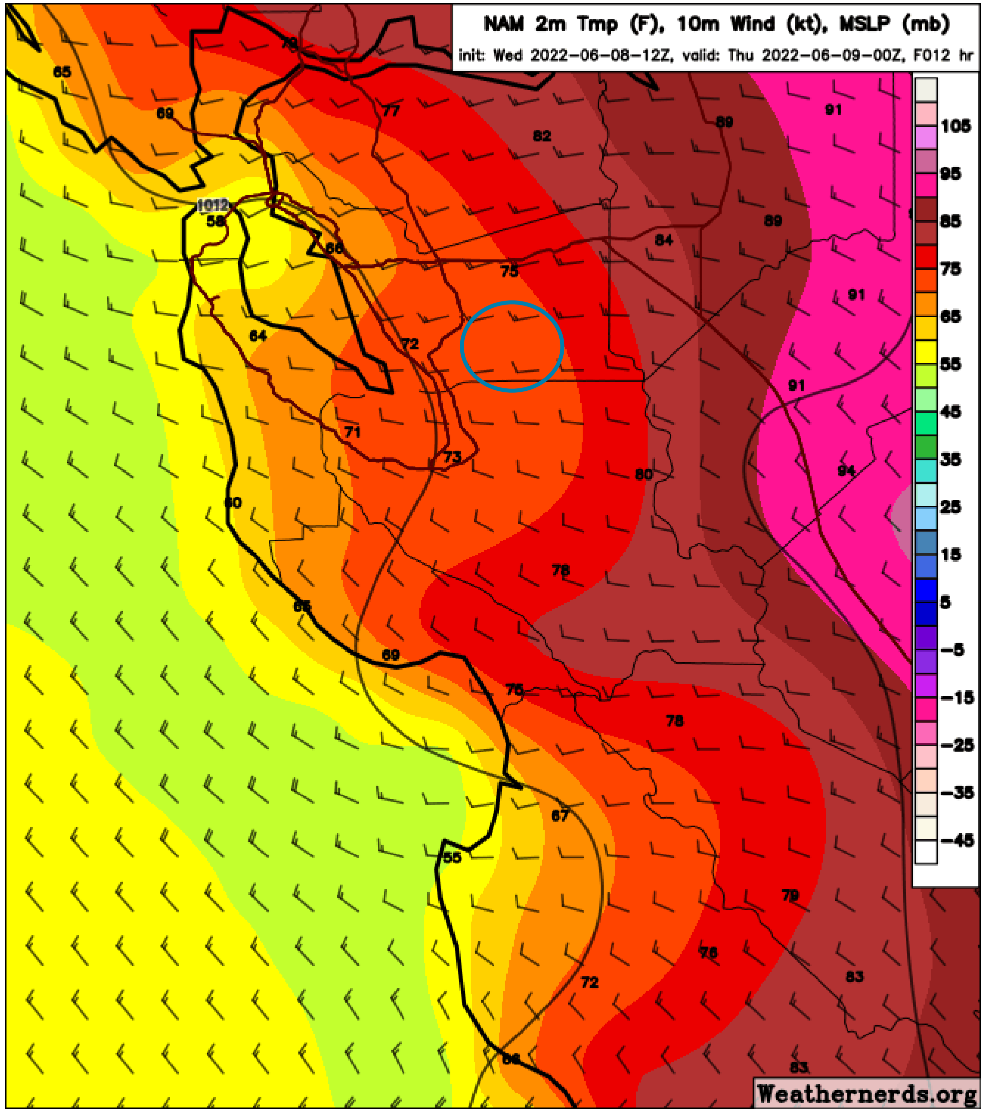
# Weather datasets For Power Systems Should…

- …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 forecasts of the resource drivers
  - 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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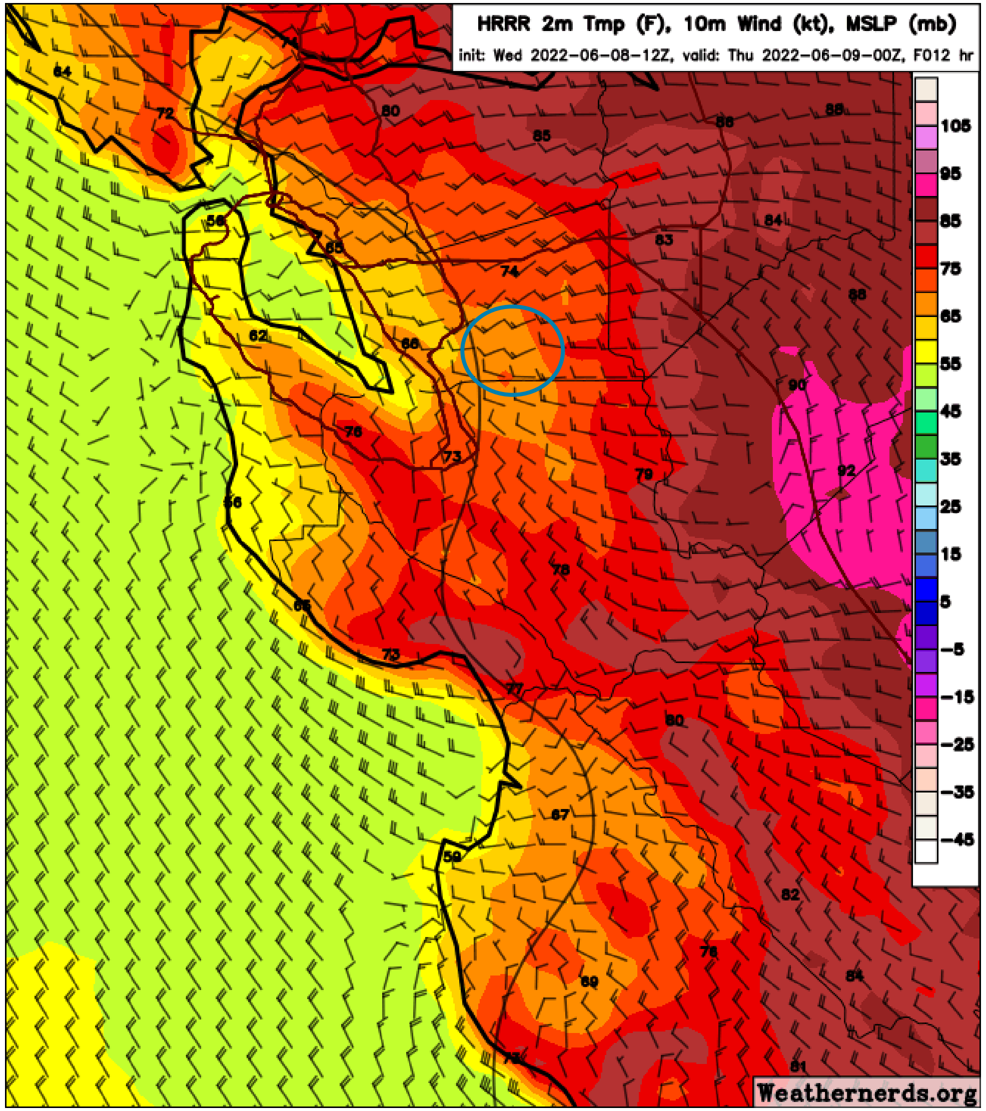
- …provide a 30+yr, updated time history with a consistent methodology that minimize biases, trends, and “artifacts”

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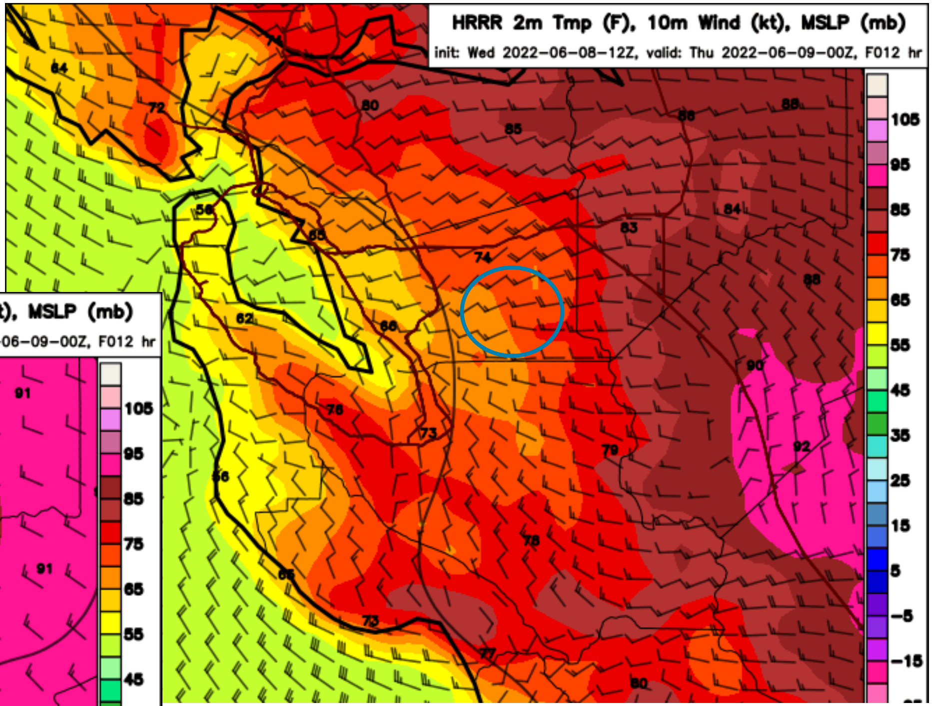
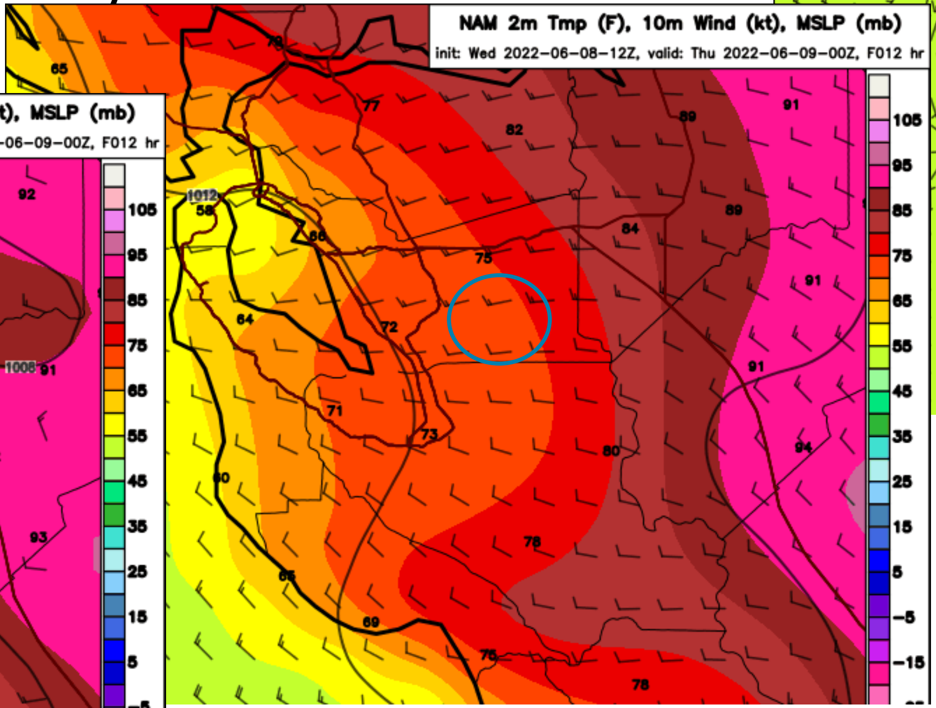
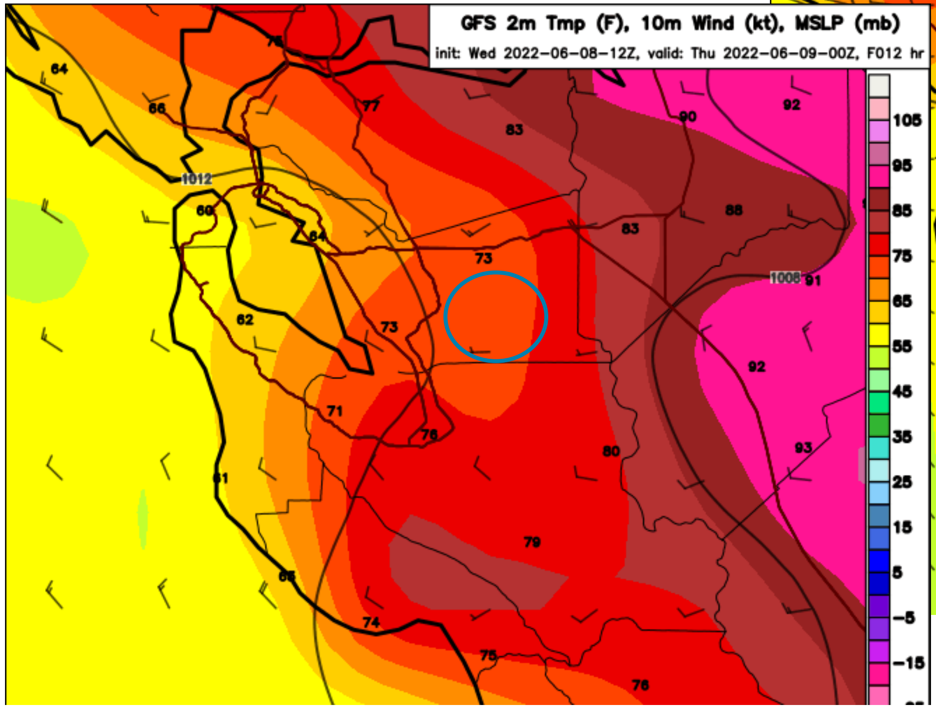
# Weather datasets For Power Systems Should…

- …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**

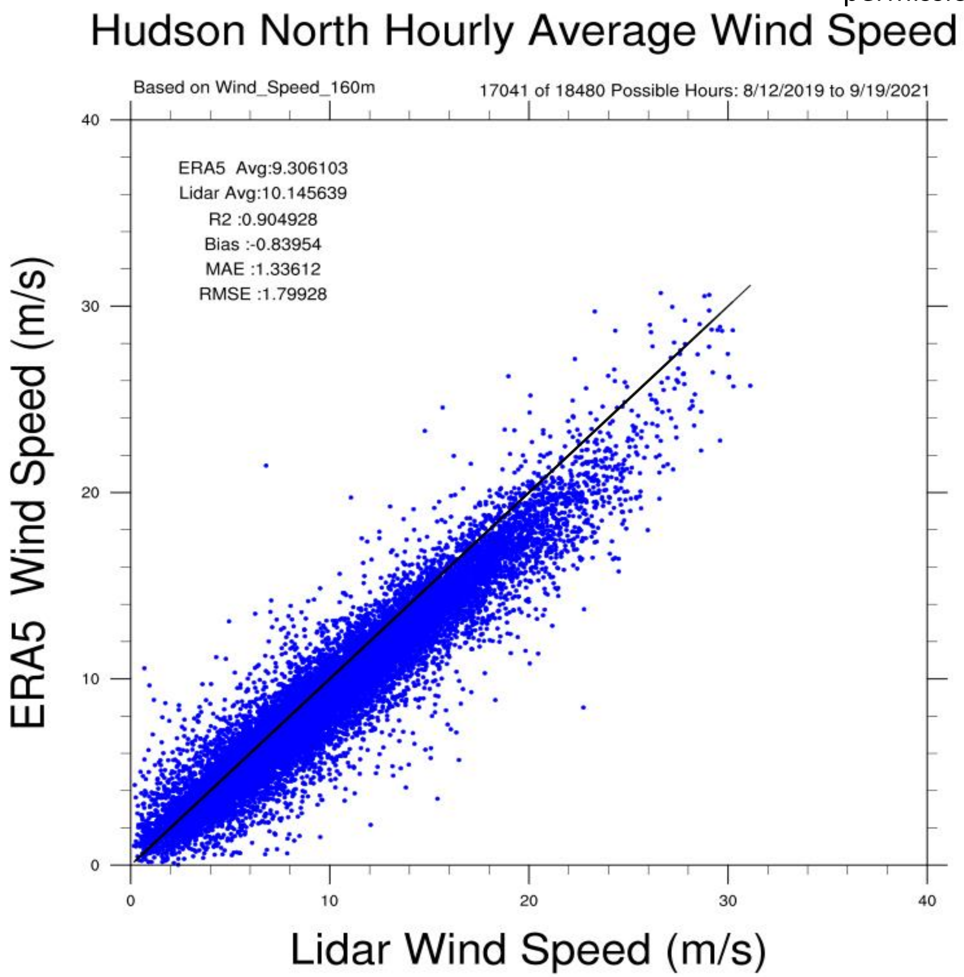


EPRI

# More Nuance: Offshore Validation Example

Slide adapted from content from Dr. John Zack, MESO Inc. and used with permission

- 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



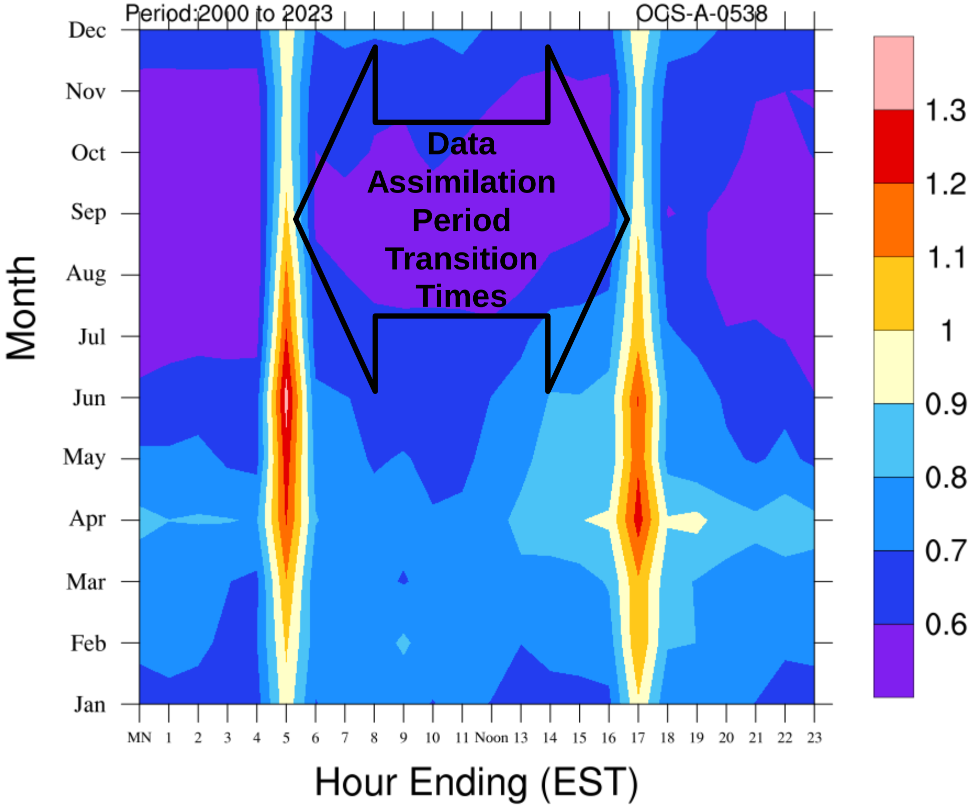

**So ERA5 should be fine for offshore wind integration studies?**

# The Impact of Data Assimilation Cycles

Slide adapted from content from Dr. John Zack, MESO Inc. and used with permission

- 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

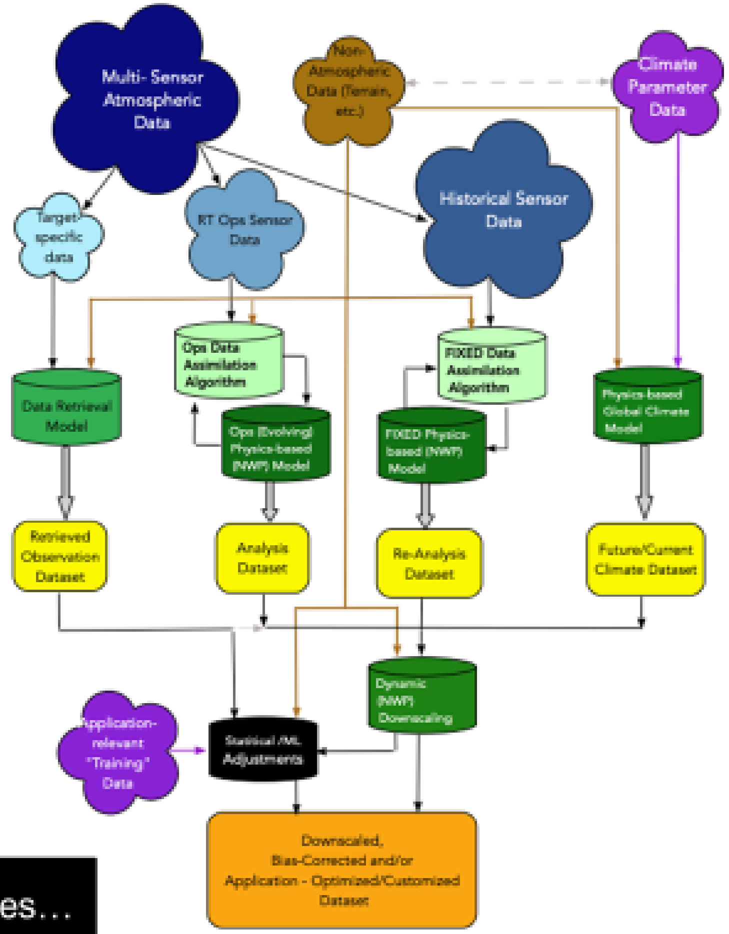
- Comprehensive industry wide data transparency and sharing is required: Met., generation, and availability data
  - Little proprietary value per site but a tremendous untapped asset if made public across all generators
- This will enable validation and UQ of synthetic datasets which is imperative for 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

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Troy, NY

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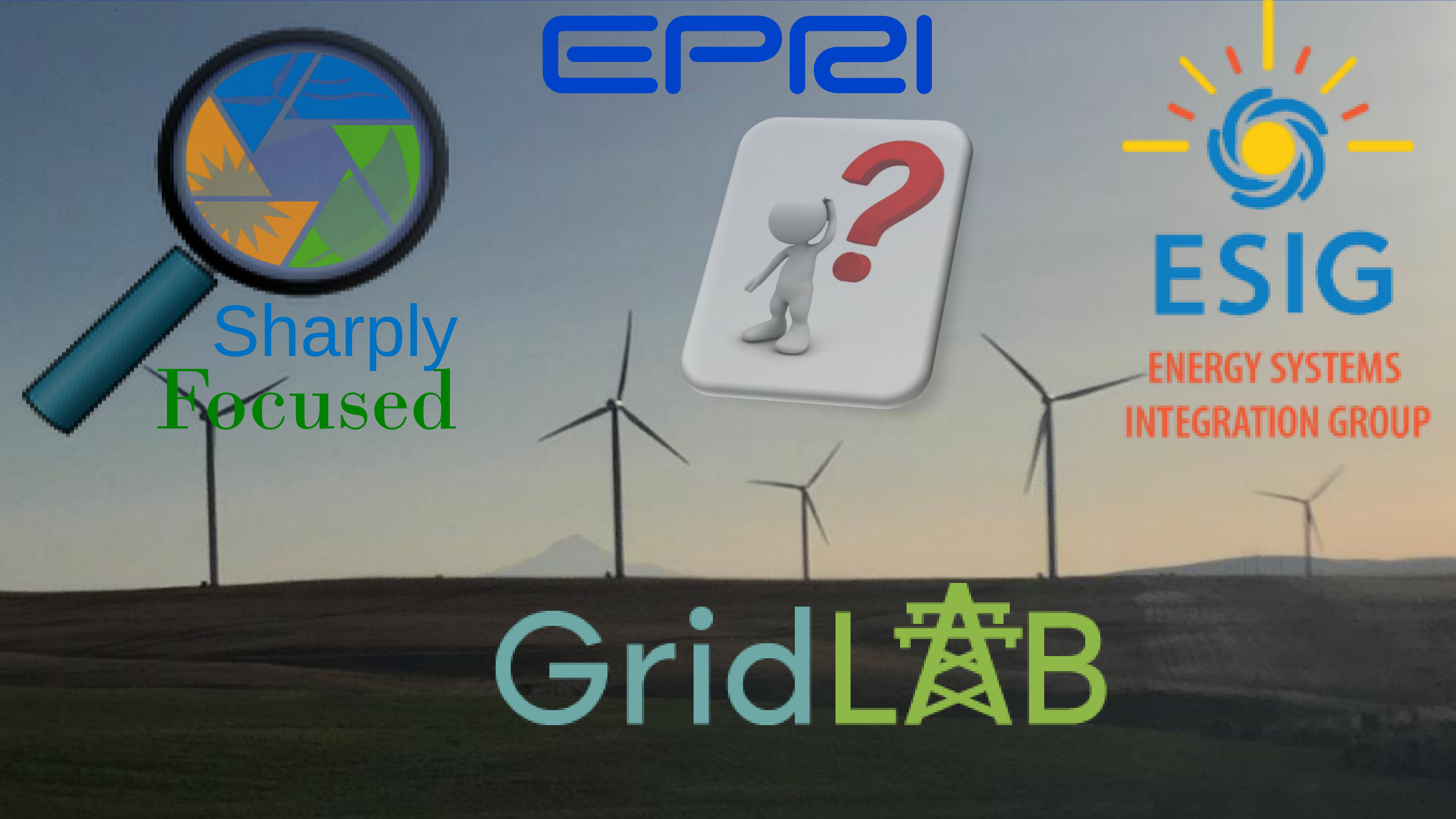
## It's Complicated!!!

# 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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