Weather and Climate Intelligence for the Energy Transition

What is Needed and Why, Current Status, Gaps, and a Call to Action

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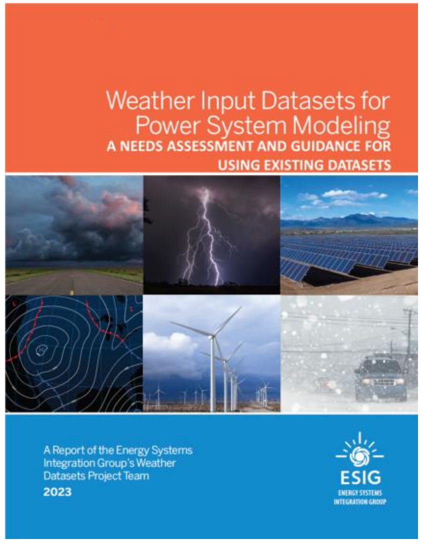
Technical Leader

Task 51 Meeting on Datasets and Forecast Challenges
October 29, 2024. New Brunswick, New Jersey



GridLAB

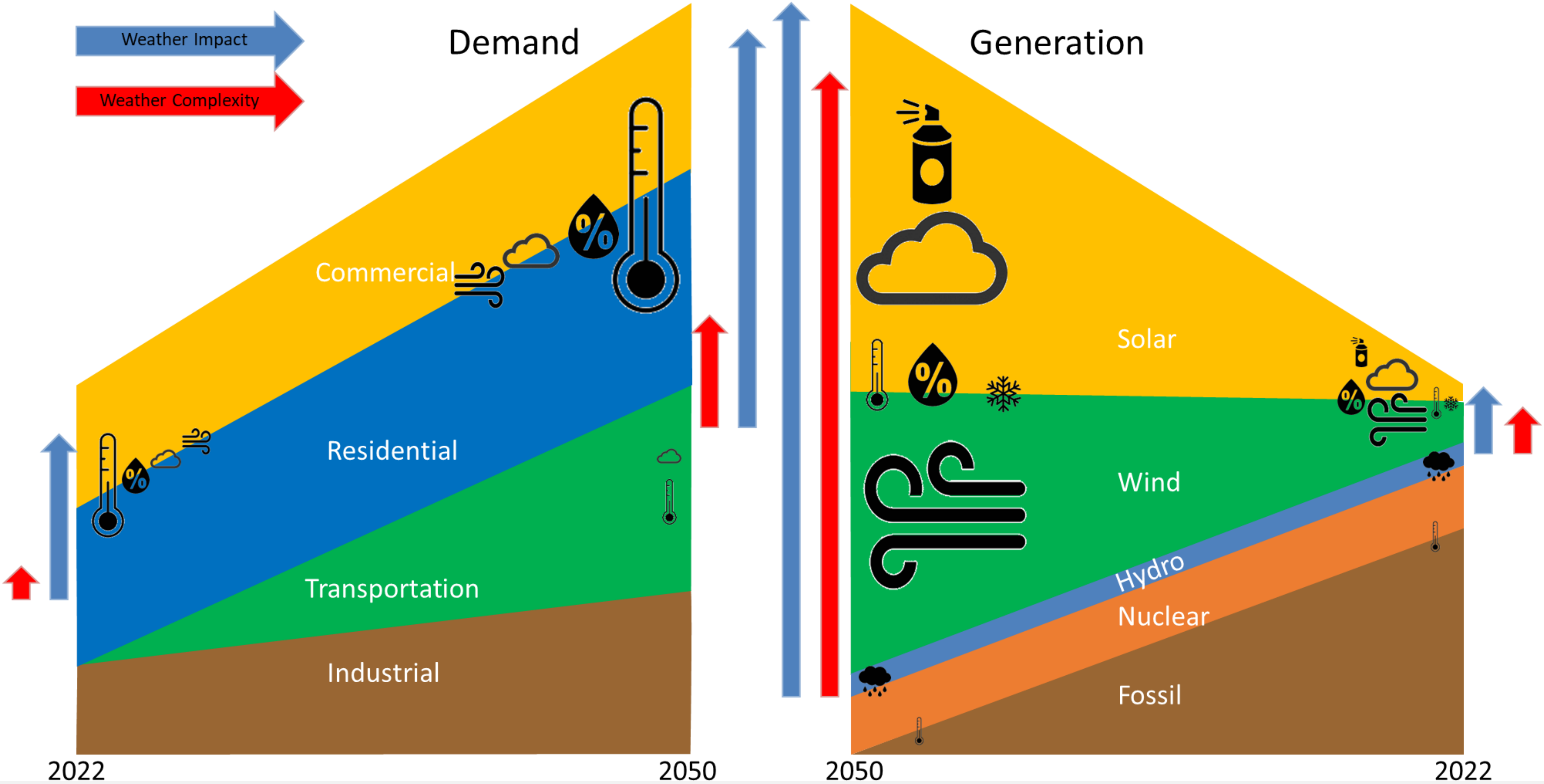
ESIG ENERGY SYSTEMS INTEGRATION GROUP

Sharply Focused Understanding Renewable Resources

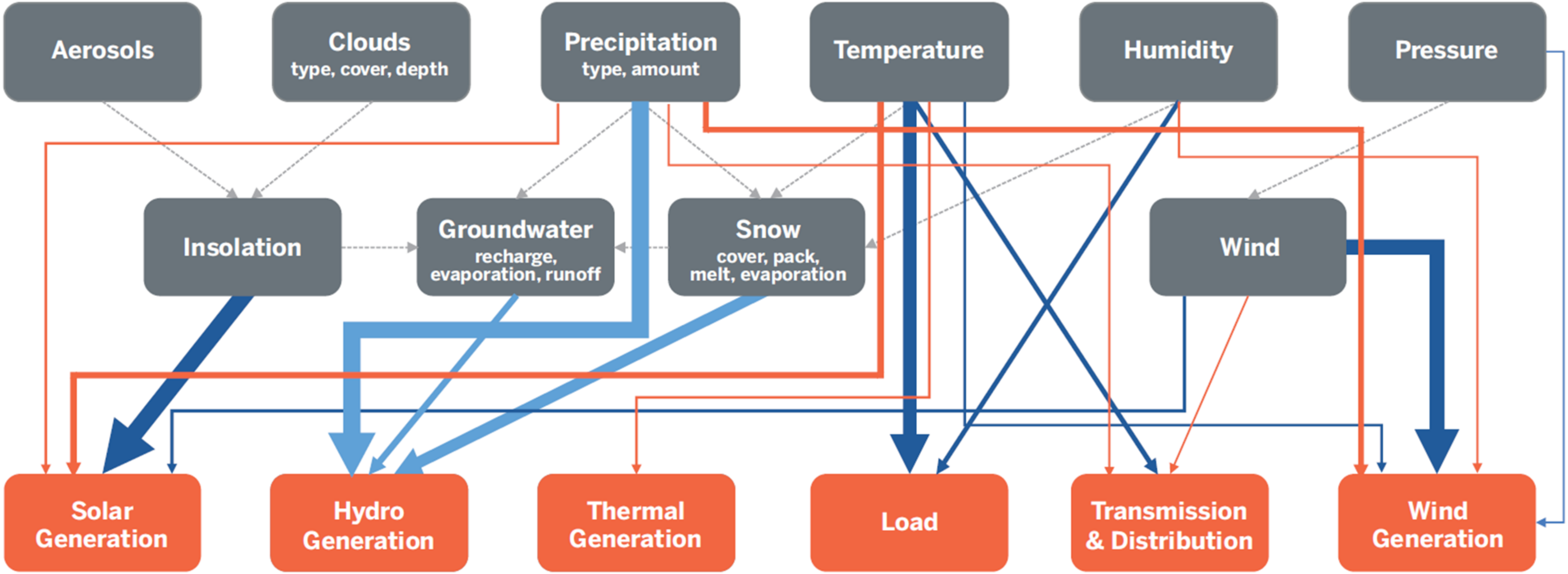
Scan for [report landing page]

www.epri.com

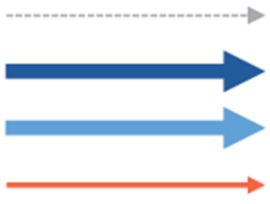
The Evolving Energy – Weather Nexus



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/

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

	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

The Data We Have Today

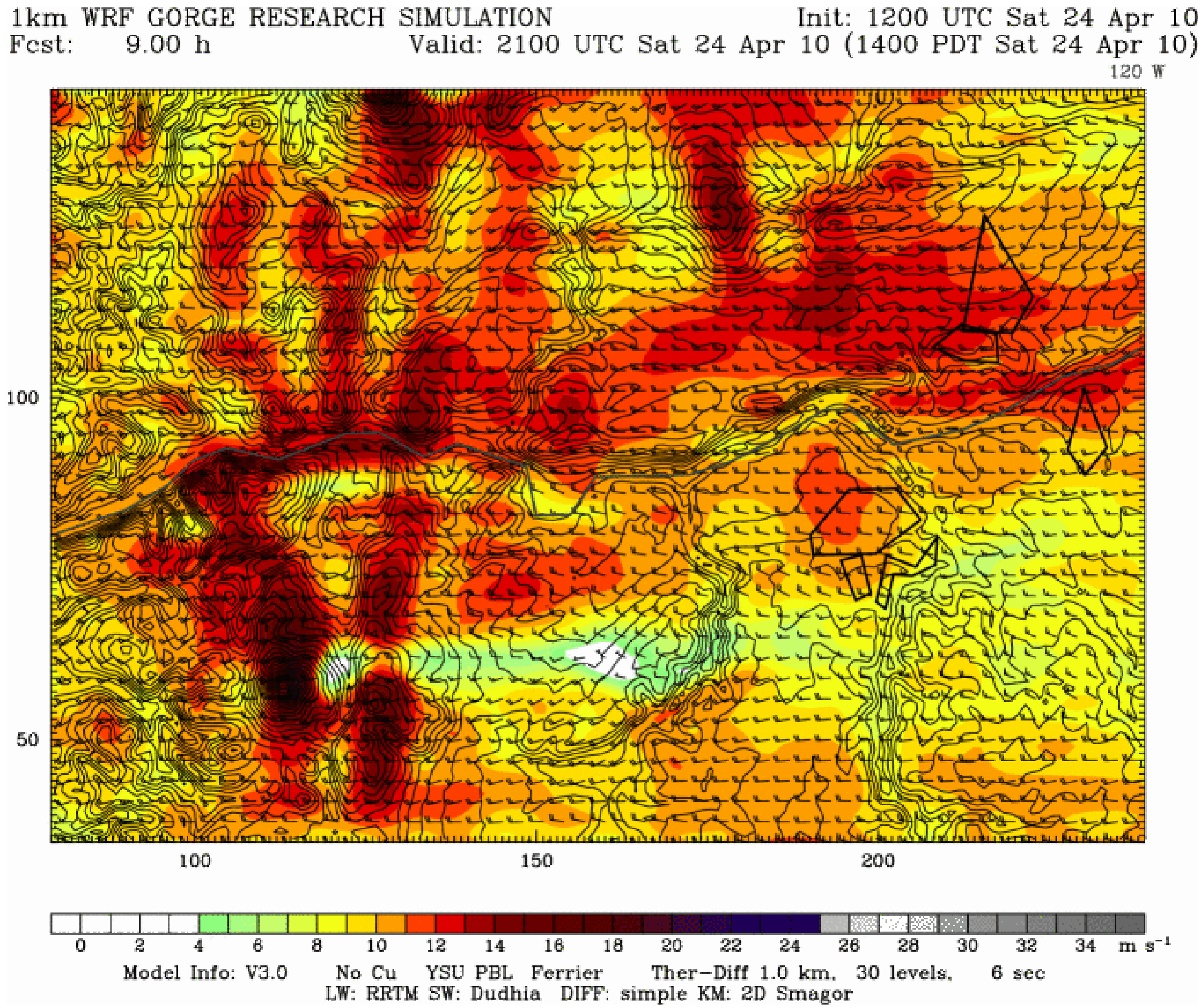
The data currently available to the sector (on left) is not adequate for the tasks at hand. No single dataset meets all the needs. Mixing and matching causes physical consistency issues.

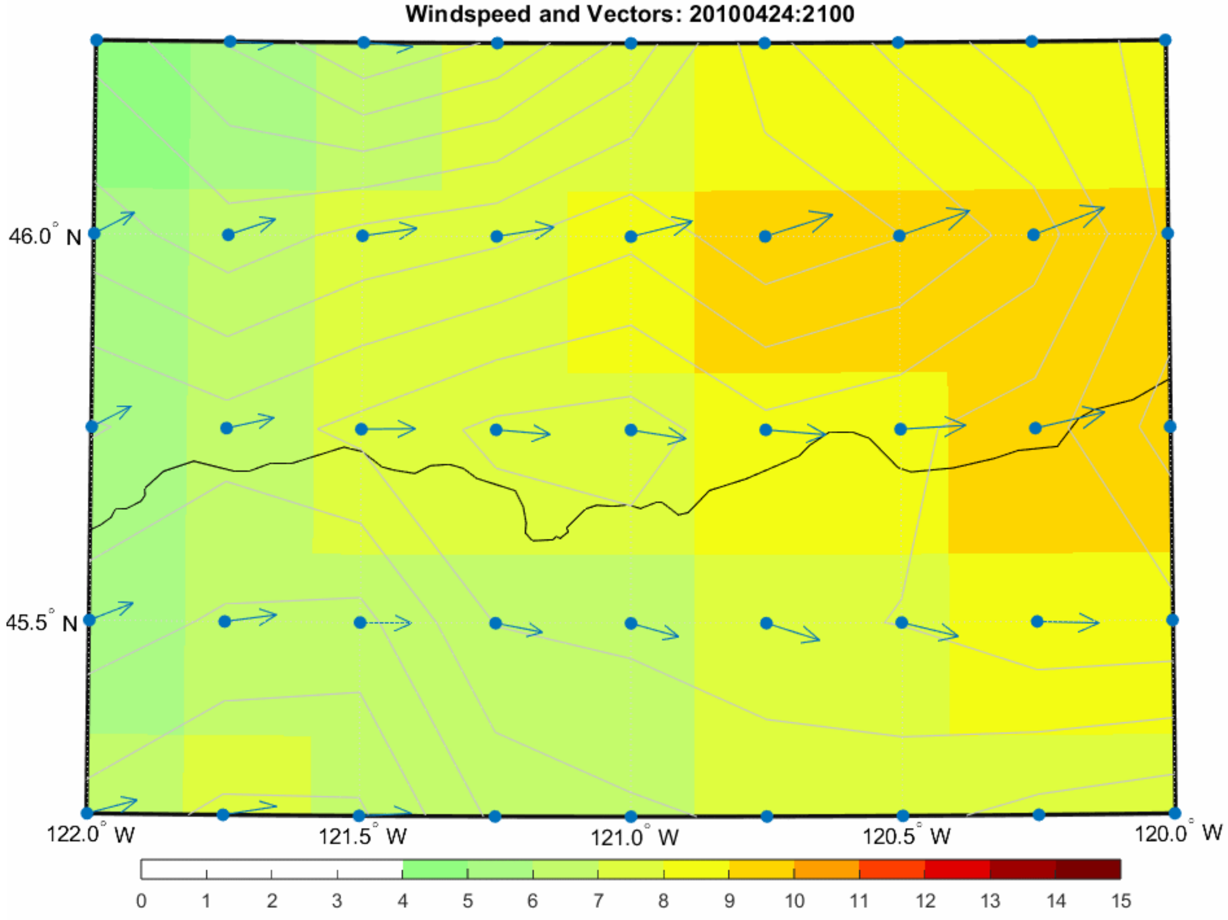
TABLE 2
Summary of Current Power System Modeling Weather Input Data Sources

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

An Example of Resolution Impacts

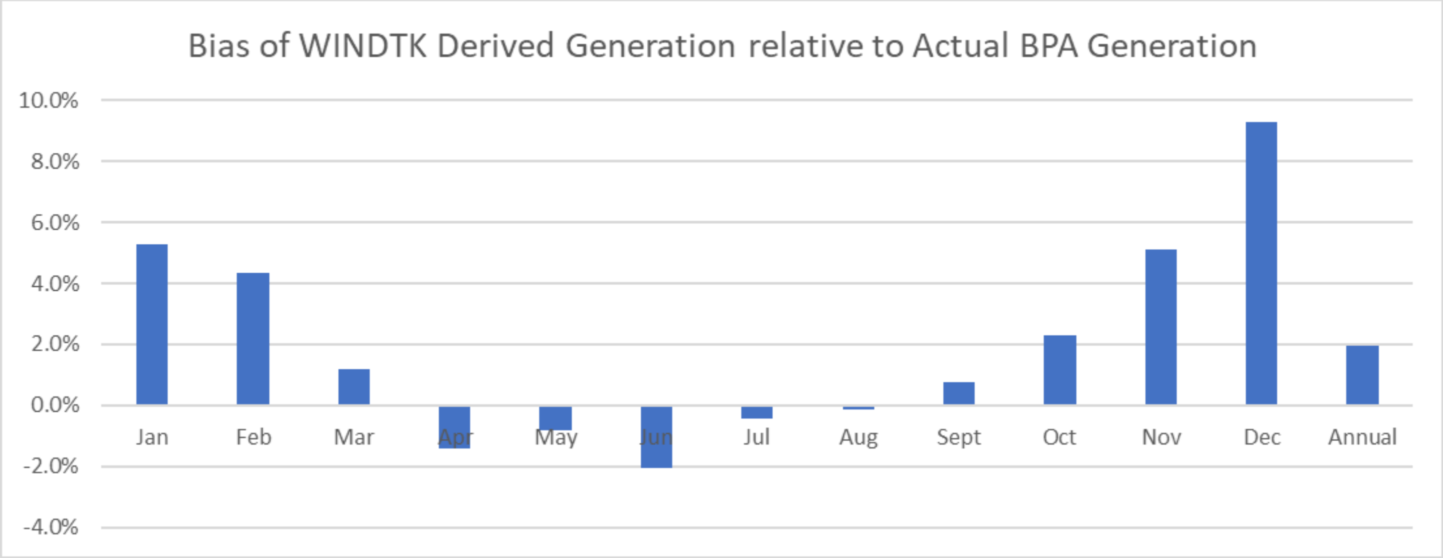




Which is Best? Validation and Uncertainty Quantification are Essential

Use Case Specific Validation and Uncertainty Quantification

- 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
  - E.g. For integration studies, wind ramp artifacts must be removed



Bias correlated with high risk events ⮥:

High bias in WIND Toolkit simulated winds is correlated with high load events due to regional mesoscale meteorology

Tail event deviations can lead to >7x bias in model vs actual.

e.g. BA wide wind gen. estimates of 23% vs 3% in reality.

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

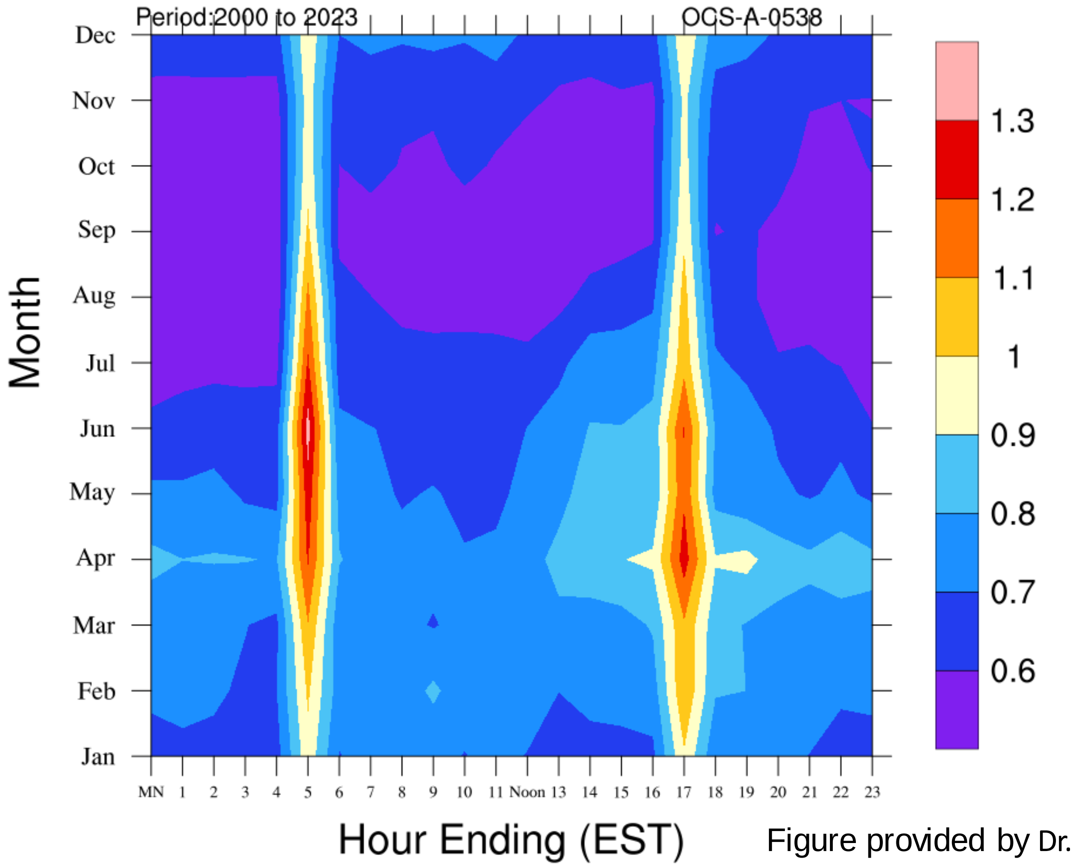


Figure provided by Dr. John Zack, MESO Inc. and used with permission

Assimilation Artifacts ⮥ :

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

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
  - Voluntary adoption preferred to legislation/regulation.

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

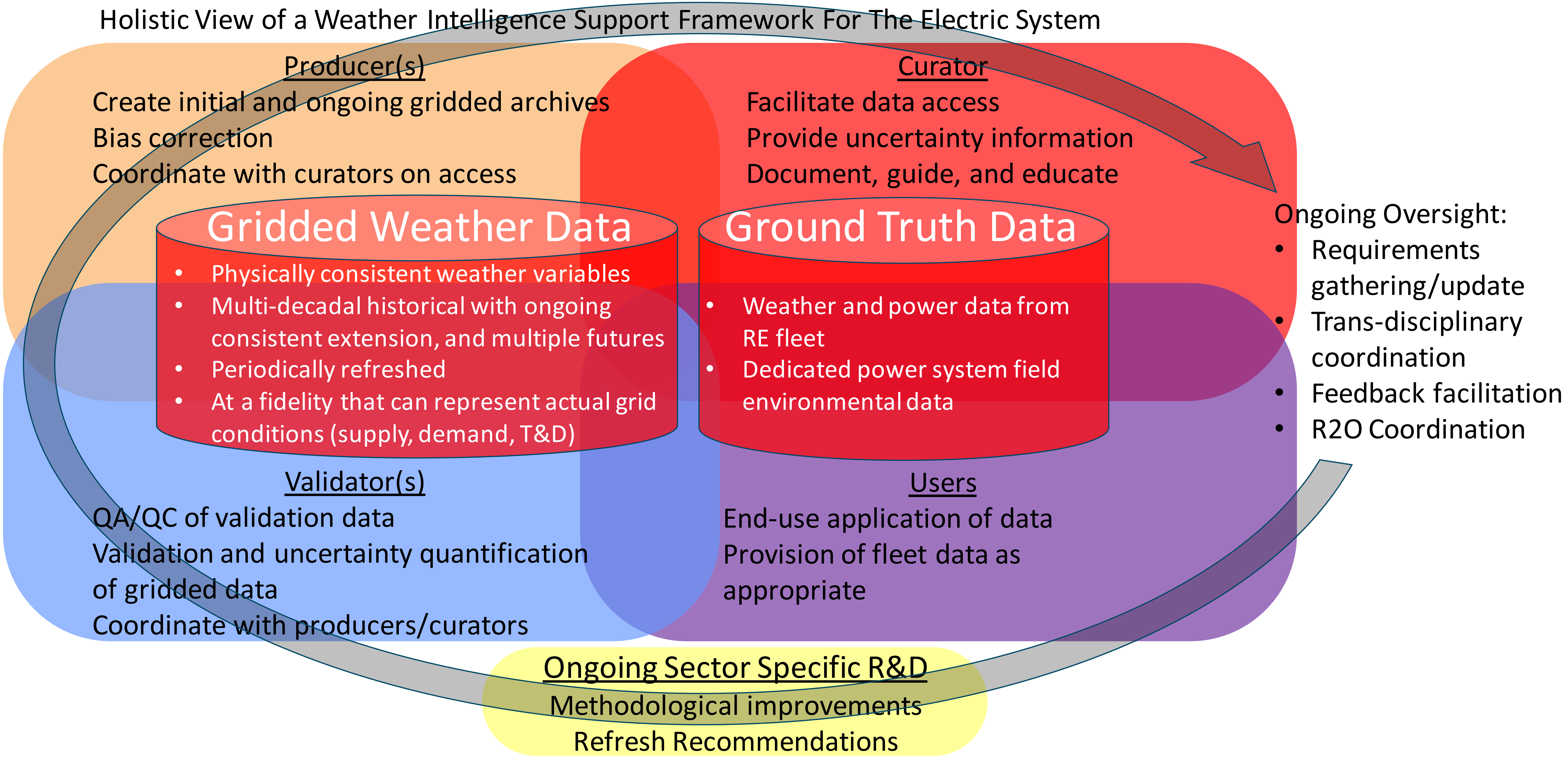
We are transitioning to a much more weather dependent electric system:

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



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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.

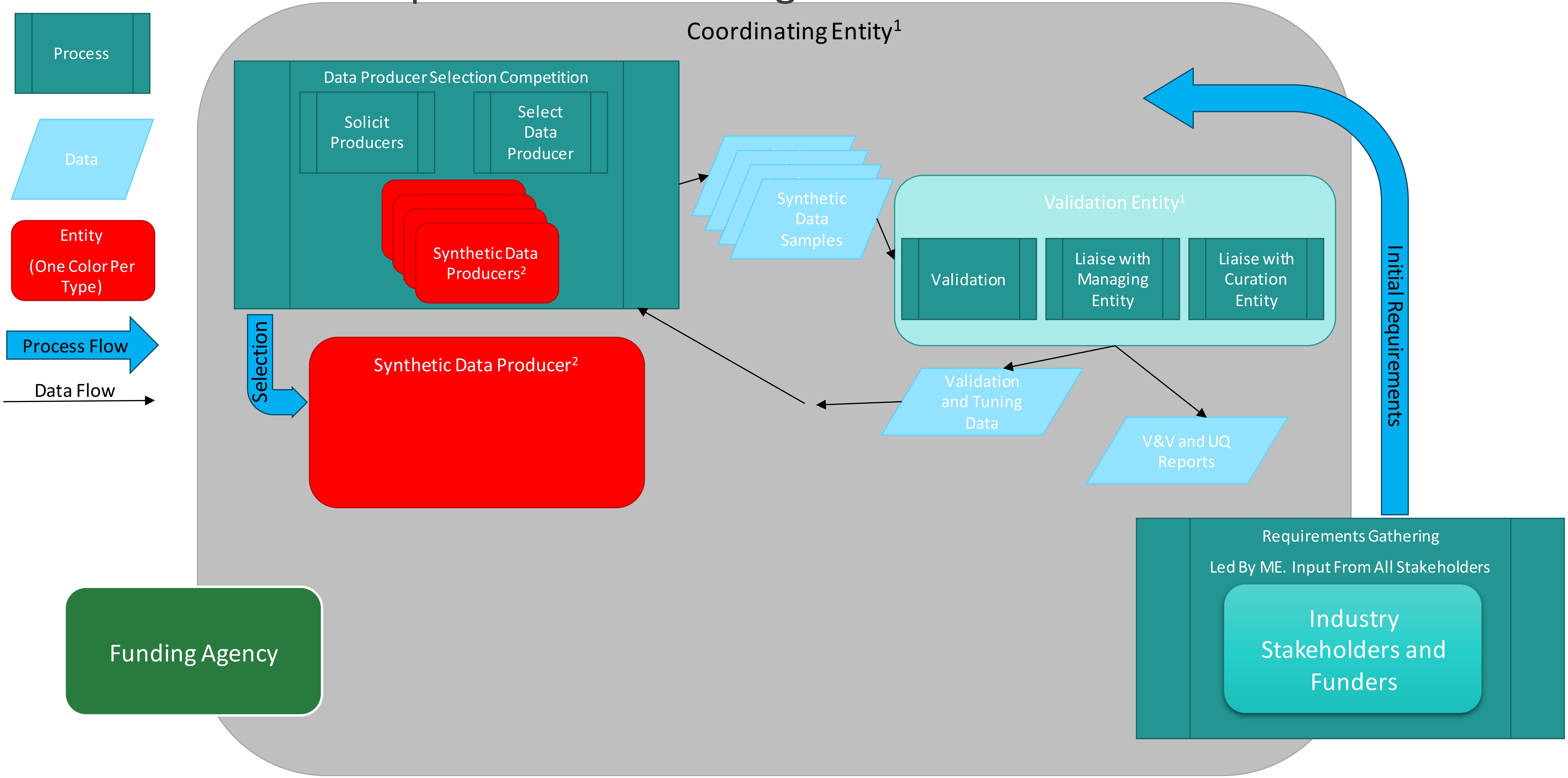
Garbage In = Garbage Out

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.

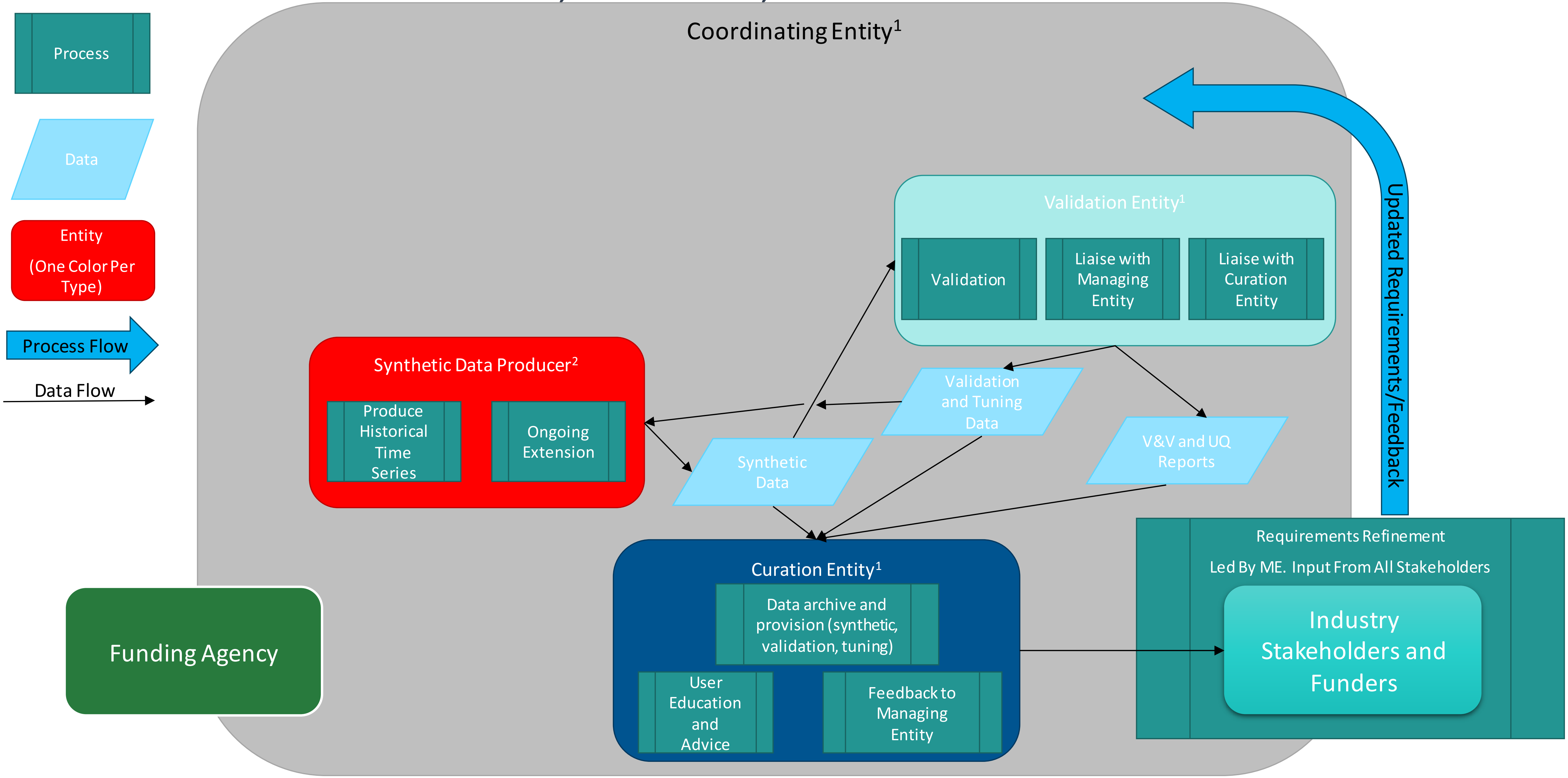
EPRI

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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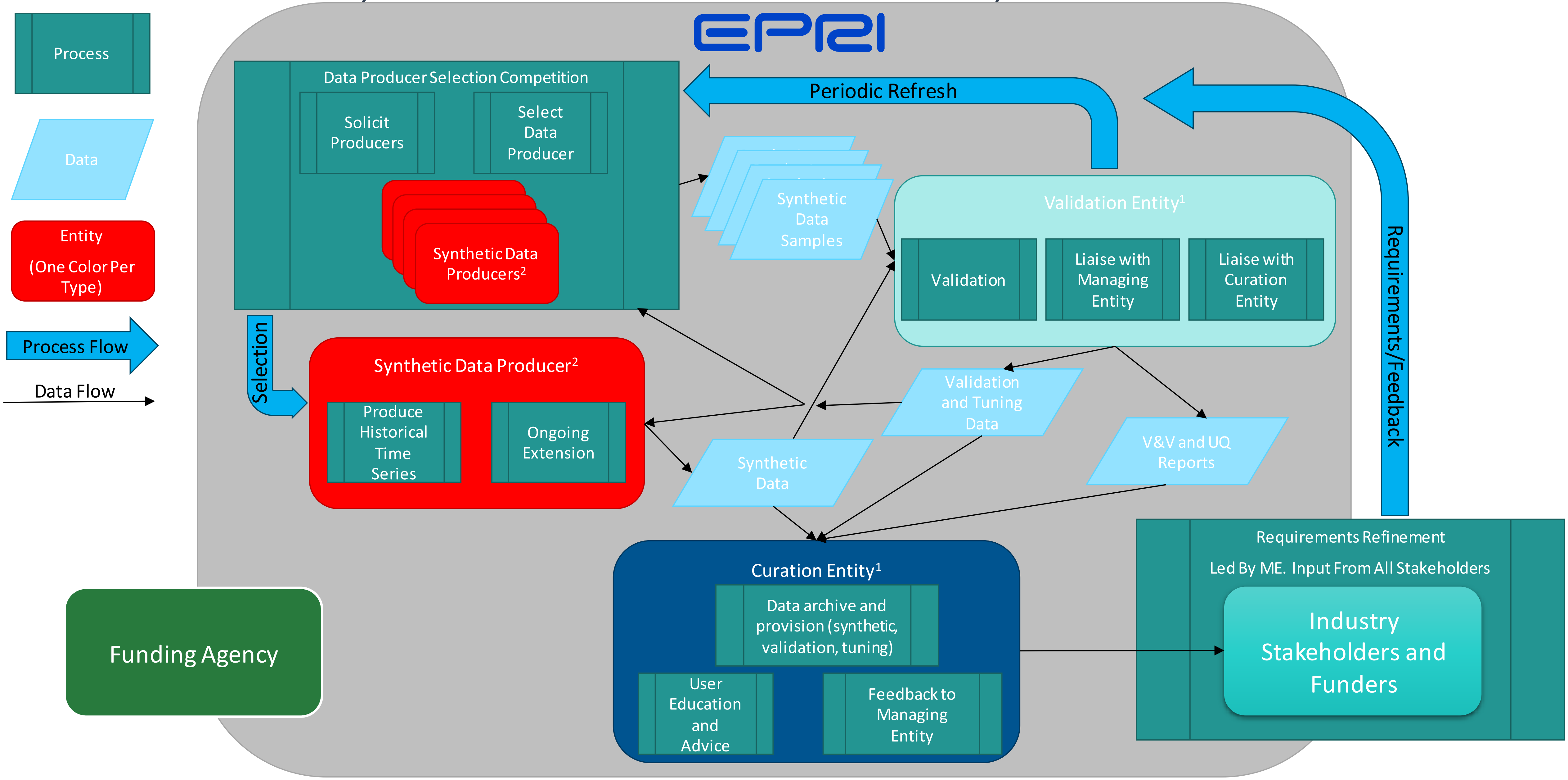
Production, Validation and Curation Processes, with Periodic Refresh



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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.

OR

- 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>.

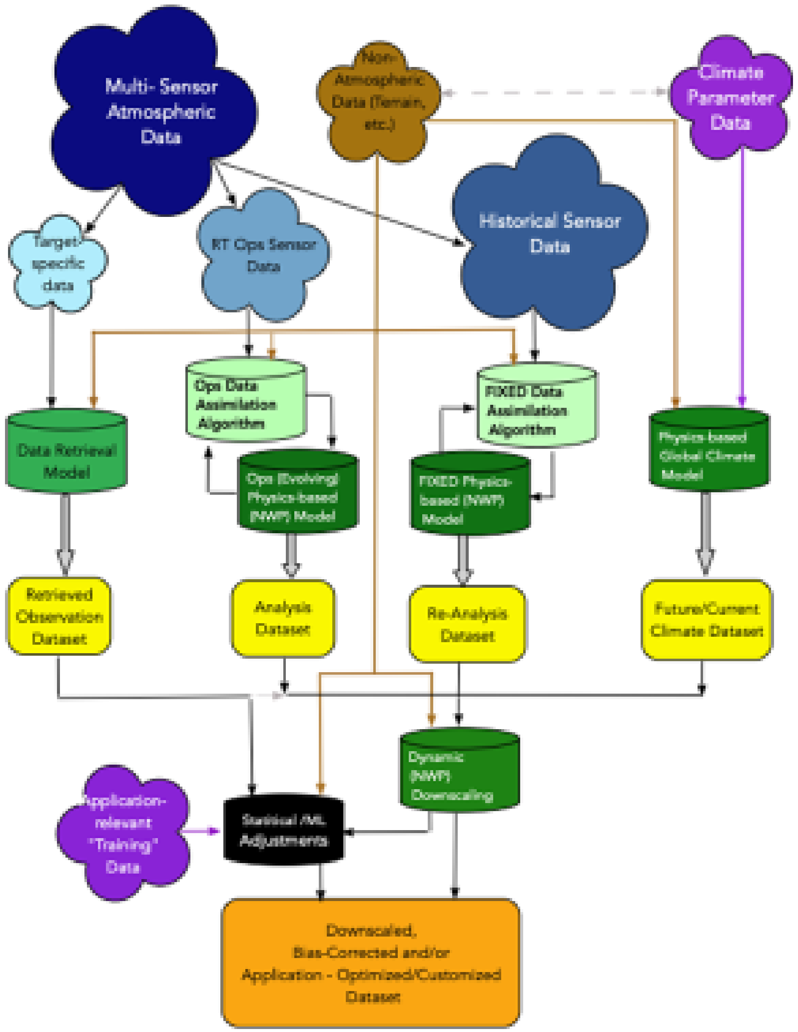
Custom 1990-2035 Climate Dataset for Electrification: $35-70M + validation hardware costs
Expected grid decarbonization investment by 2035: $330-740B[1]
<u>**The "map" costs < 0.01% of expected investment. The potential cost of flying blind is…???**</u>

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

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**



Slide courtesy of:

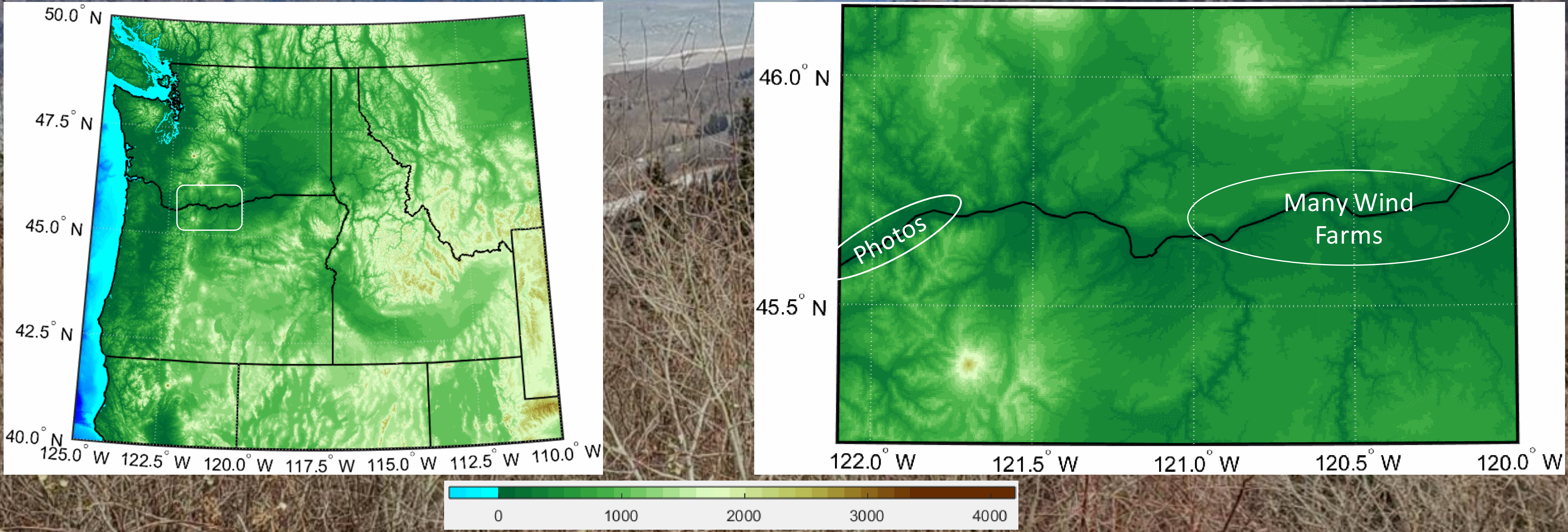
Dr. John W. Zack
Principal
MESO, Inc.
Troy, NY

Used with permission.

It's Complicated!!!

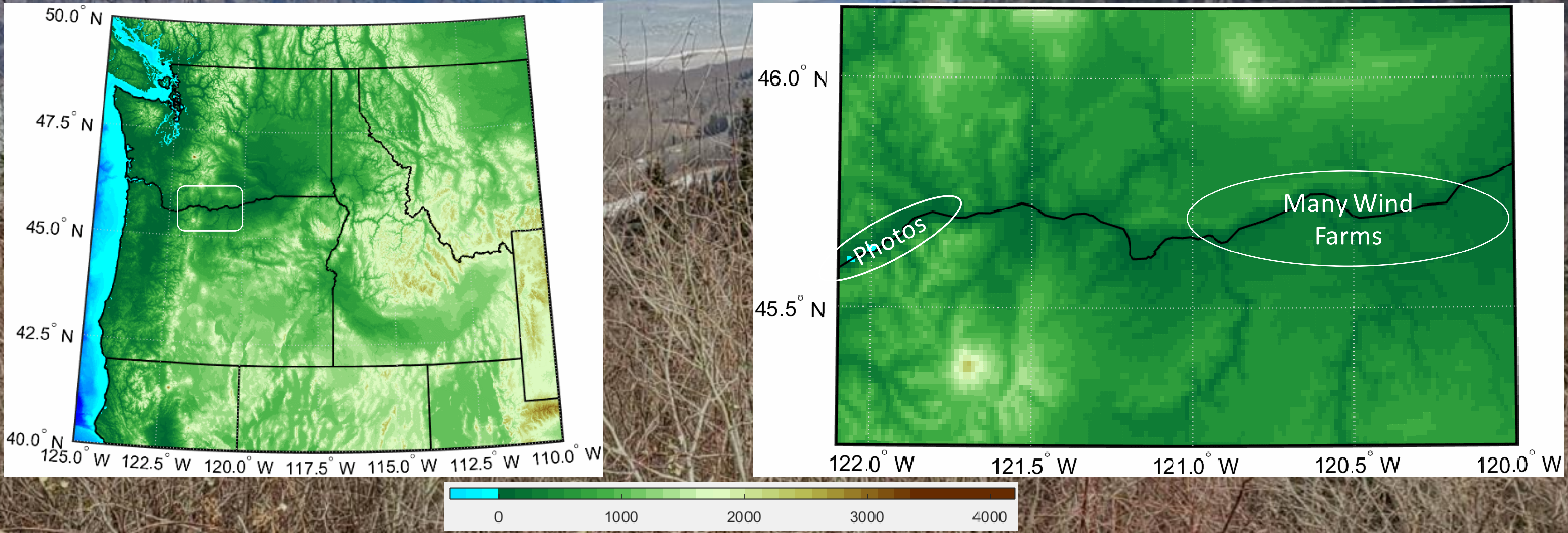
Understanding Grid Spacing (Resolution)

USGS 15 arcsecond topography



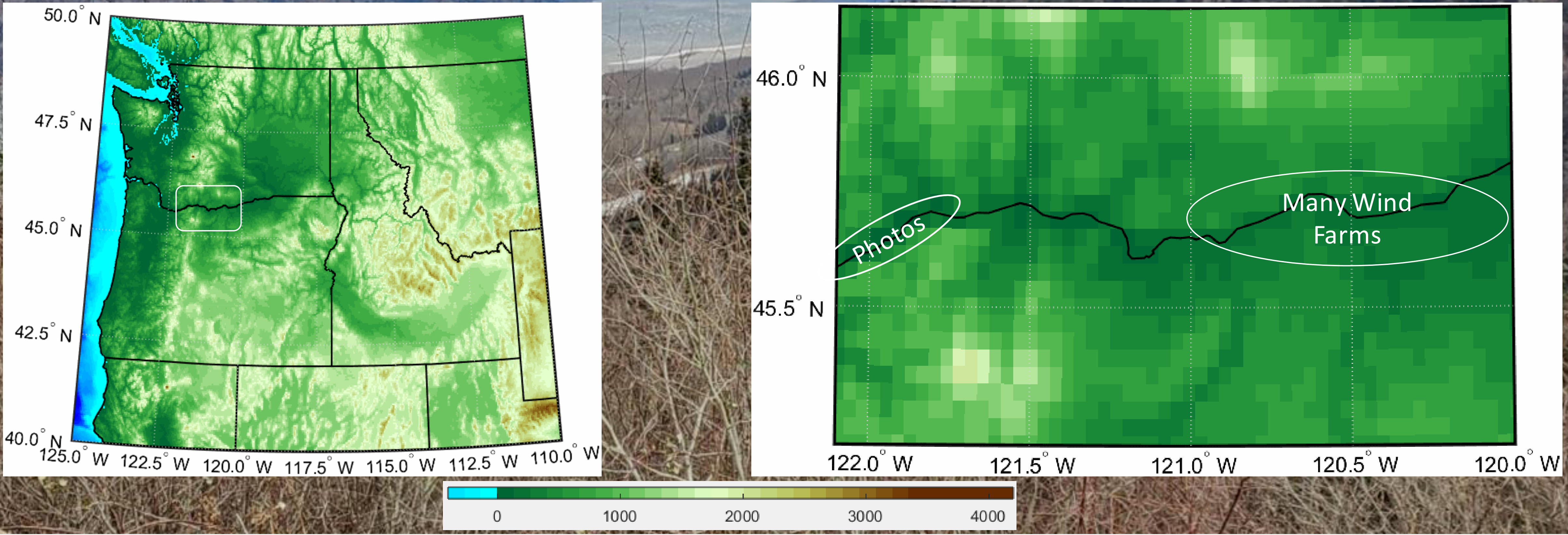
Understanding Grid Spacing (Resolution)

1 km Grid Spacing (WINDTK is 2 km)



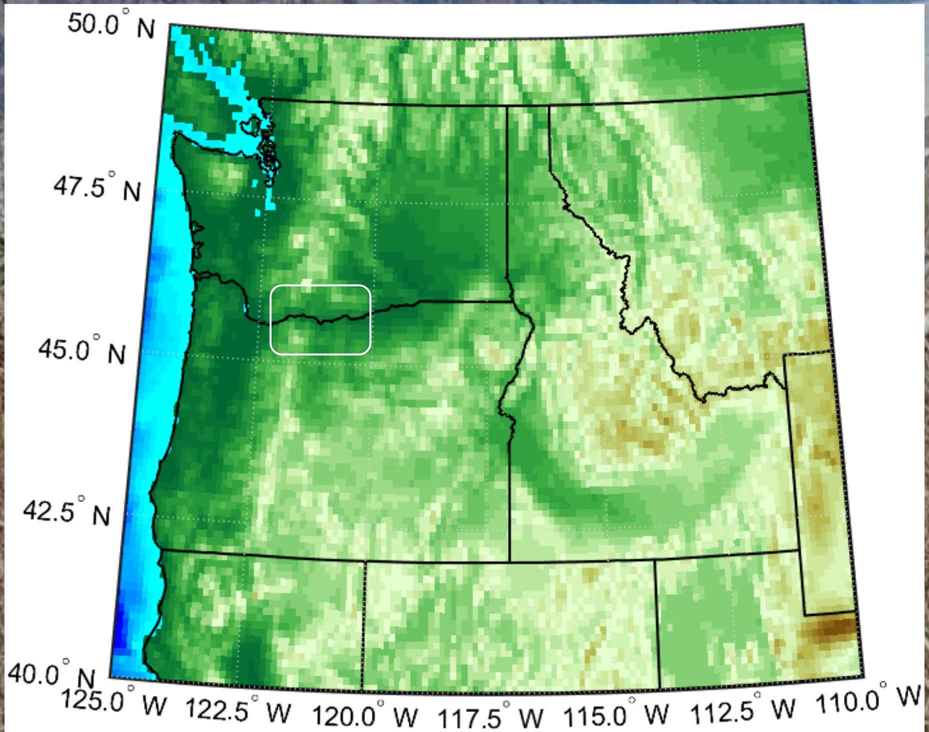
Understanding Grid Spacing (Resolution)

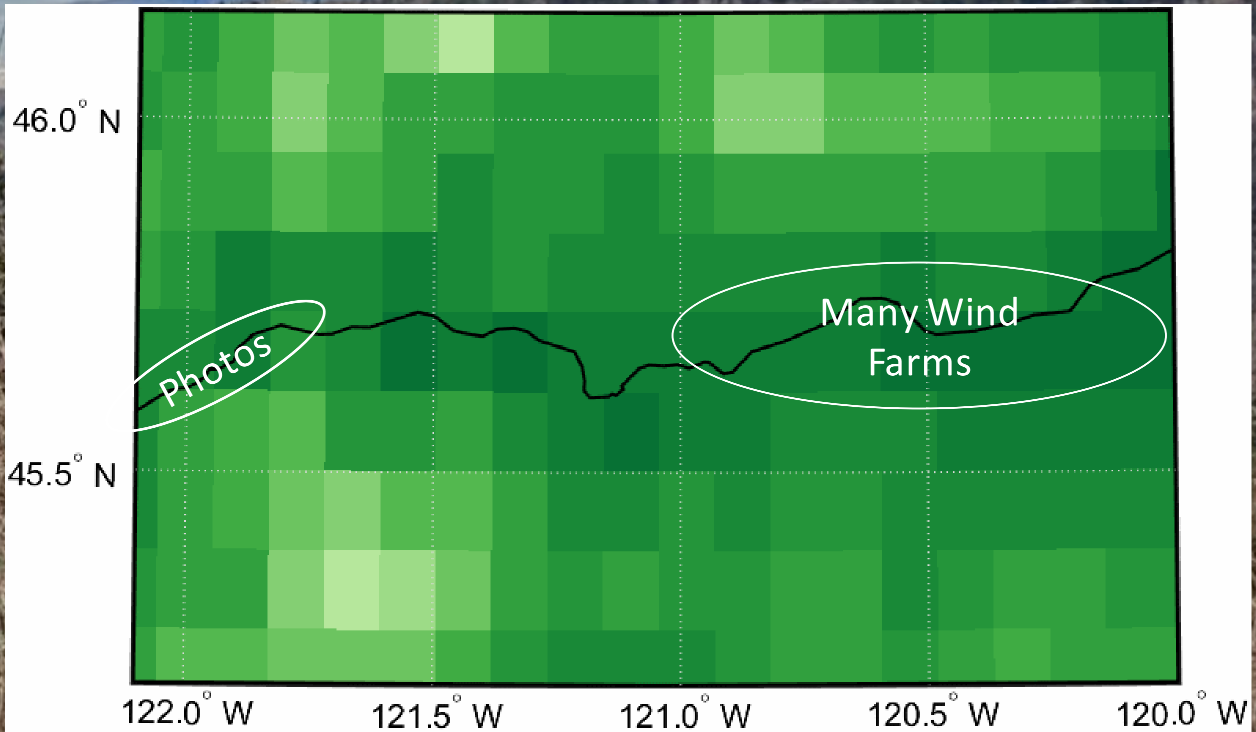
3 km Grid Spacing (~HRRR)

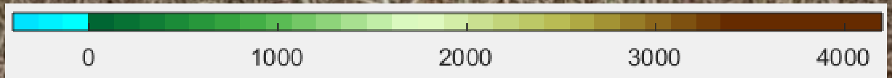


Understanding Grid Spacing (Resolution)

9 km Grid Spacing (~ECMWF)







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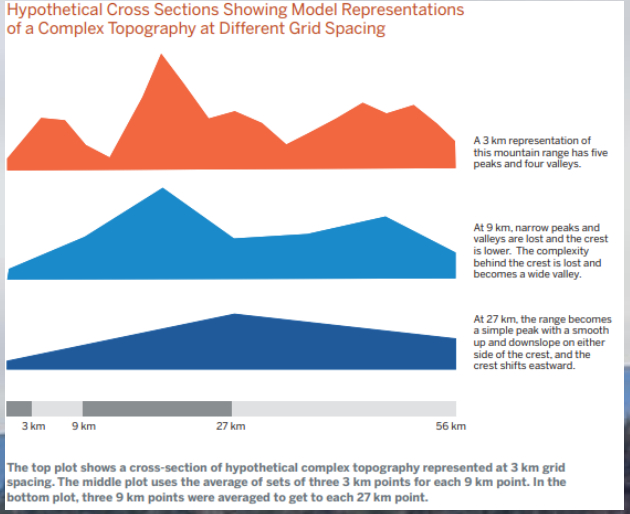

30 km Grid Spacing (~ERA5)