Accounting for Extreme Weather Events in Weather Inputs for Power Systems Analysis

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Hay Canyon Wind Farm. Photo © Justin Sharp

Sharply Focused
Understanding Renewable Resources

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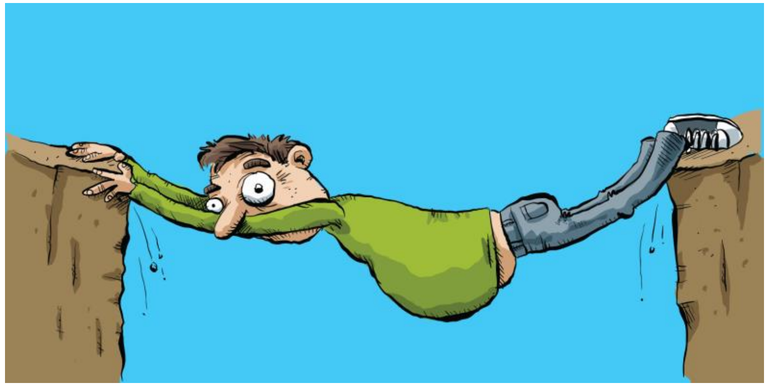
The Energy Transition

Today, fossil fuels are the primary fuels.

Tomorrow, the weather will be the main fuel and the trend will be to electrify everything



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

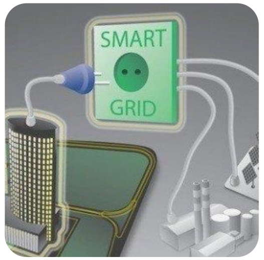
The Renewable Energy Transition






Weather modulated load and generation
Largely thermal
Dispatchable
Centralized
N-1 contingency
Lots of inertia but little storage
Slow to moderate ramping rates







Mostly weather driven generation
Strong correlation between weather and generation
Weather modulated load and Wx driven response
More storage but less inertia
Fast ramping rates
More distributed
Gas use ultimately depends on effective planning of weather driven resources and storage

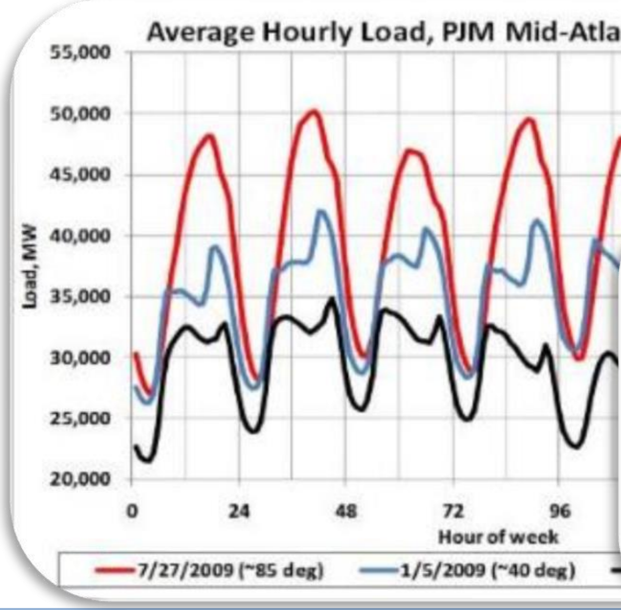
Motivation: An Increasingly Weather Dependent System

Before:

- Load: <u>Moderated</u> by T, RH, solar etc
- Distribution: wind, snow and ice
- Transmission: T, fire, ice, wind
- Generation: T and extreme T events
- Wx dependent hydro

Now:

- All that...Plus...
- Wind and solar generation
  - <u>DEFINED</u> weather conditions
- Increasing complexity from energy limited resources



- Electrification
- Climate change

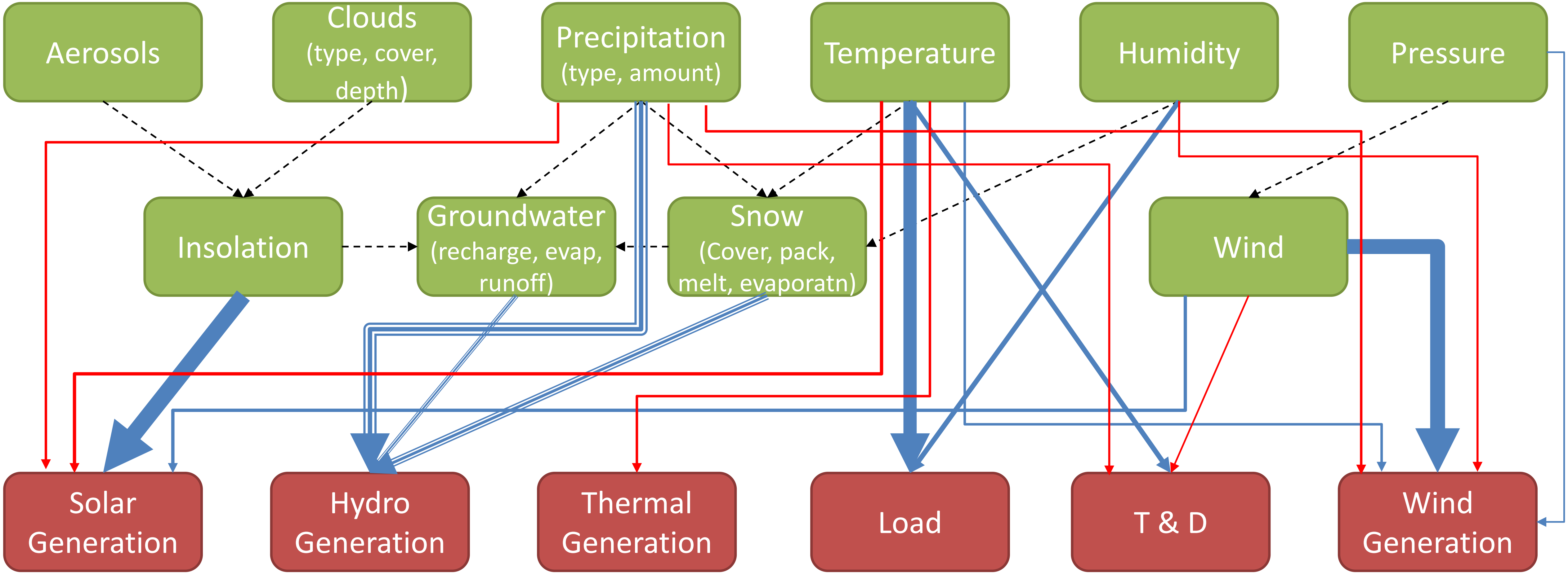
The Electric System is Changing…RADICALLY…and it is full of uncertainty

- Loads are going to evolve dramatically with deep decarbonization
- Economics and policy are driving an every larger RE share
  – Phew! There's hope for humanity…<u>but</u> we've got to keep the lights on
- 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)

- 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?
  – Will people shift their consumption behavior?
- But WE DO KNOW A LOT ABOUT WEATHER AND CLIMATE
- We <u>MUST</u> 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
  – <u>Procure/create the right data</u>

- Use this knowledge to ADAPT AND EXPAND THE TRANSMISSION GRID AND STRATEGICALLY PLACE GENERATION to minimize risk

Summary of Primary Weather and Climate System Interactions with Electric System Components



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

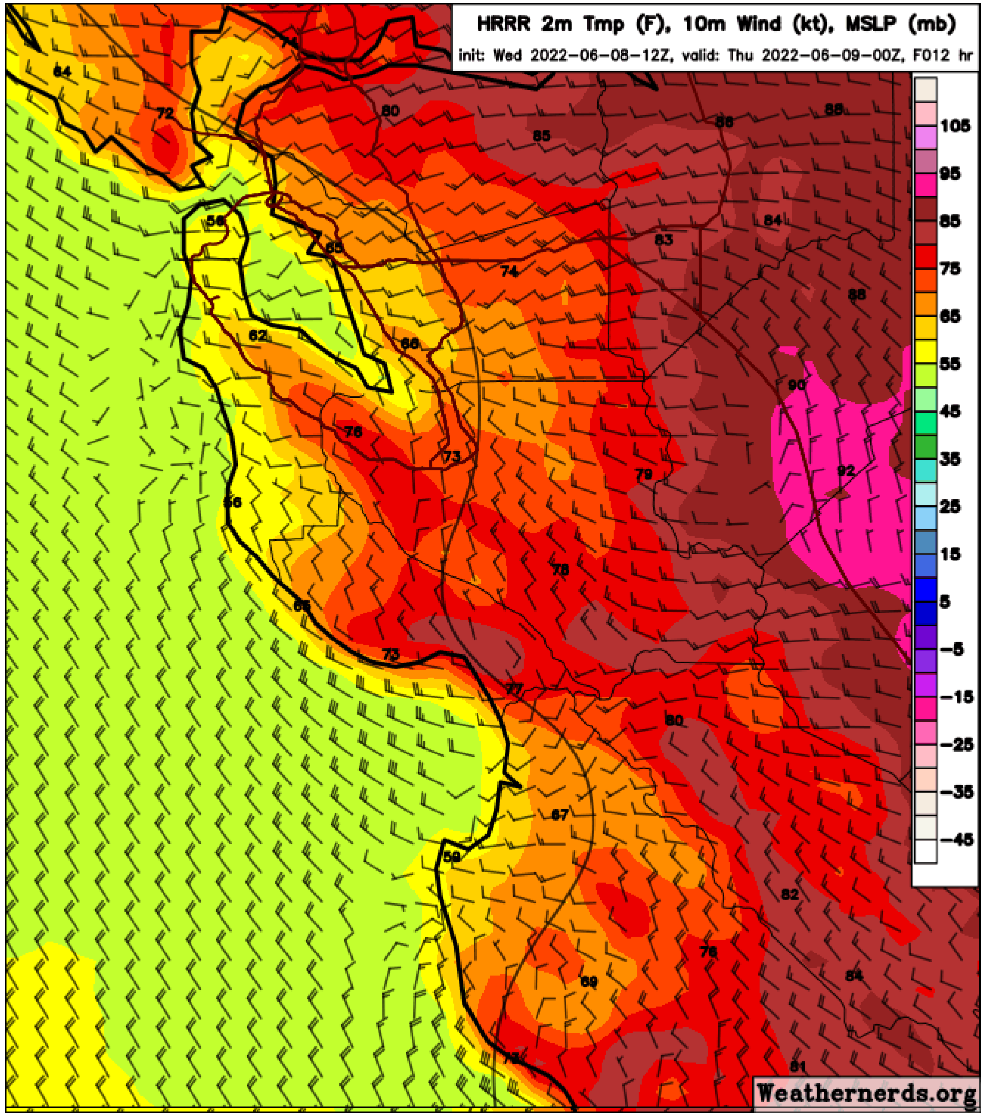
Climate system -> electric system dependency with typical magnitude approximated by line width

Dependency strength is highly variable depending on asset type and location

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

Requirements For Weather Inputs to Power Systems Models

- At 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
- Physical consistency and concurrency
  - All variables represent the same time and are dynamically consistent
  - Is it important? It depends on application
    - E.g. NSRDB and WINDTK, or the example on the right
- Provide a representative time interval <u>and</u> temporal consistency of biases throughout that time period
  - Model and IC/BC consistency
- [Able to represent a non-stationary climate system?]



HRRR

The Main <u>Concurrent</u> Components

- The Renewable Resource (Wind, Solar) Dataset ("Truth")
  - Accurately characterize the resource
  - Spatial covariance and temporal autocorrelation must represent those present at scales being examined
  - Seamless or as close to seamless as possible
- The Renewable Resource Forecast Dataset
  - At time horizons that accommodate study's gate closures
  - Representative of the state-of-the-art for each time horizon
  - Portrays the distribution of errors between truth and forecast
- The Load and Load Forecast Dataset
  - Load is synthesized a combination of temperature data and actual historic load
    - Much lower error that wind/solar synthesis but care still needed here to maintain consistency
  - Load forecast attributes should be the same as for the resource forecasts to capture correlations between resource forecast errors and load forecast errors
- A means to access common mode outages across generation and transmission
- Hydrological data – Not an after thought, but not the focus today.

Data Currently Being Utilized In US Power Systems Modeling

- National Solar Radiation Database (NSRDB) and Wind Integration National Database Toolkit (WINDTK)
  - NSRDB: 4 km, 30 min (no forecast). Native resolution for observational based solar data, but other variables are from MERRA-2 with simple downscaling to 4 km
    - Creates potential for major misuse of the data
  - WINDTK: 2 km, 5 min (6 km forecast). 2007-2013. Rapidly becoming archaic.
  - Both have been well validated against observations with bulk statistics but problems remain!
  - Concurrent and so **typically** used as if they are dynamically consistent. They're not!
- MERRA-2 and ERA-5
  - Not of sufficient resolution to resolve topographically driven winds or clouds in the west where there is a lot of wind and solar generation
- HRRR and NAM
  - Hi-res but non-stationary models…how much of a red flag is this. I'm not sure, but I find it concerning
- Observational Data
  - The most used data by professional consultancies providing data to utilities and RTO's
  - I have encountered shockingly bad methodologies for filling and applying such data

A Fun Example of Data (Mis-)Use

Here's our load, wind and solar data for the study!

Awesome. But it's not coincident or long enough. What to do?

Solar Project Shapes From NSRDB 1998-2021

Wind Project Shapes From Facility Data 2012-2018

Wind Project Shapes From WINDTK 2007-2013

Database of RTO Average Daily Temperature 1991-2020

Database of Utility Loads 2012-2018

A Fun Example of Data (Mis-)Use

I'll have one of my sharpest engineers work something out!

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Wind Project Shapes From Facility Data 2012-2018

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Database of RTO Average Daily Temperature 1991-2020

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A Fun Example of Data (Mis-)Use

Ted, can you clean up and fill this data. You know the PUC likes 30-year studies now

Let me think about it. But, ugg, I hate that WINDTK data. It seems to have a high bias

Since we've got actual wind data, I'll work with that instead and we'll synthesize load from temperature like we usually do.

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Wind Project Shapes From Facility Data 2012-2018

Wind Project Shapes From WINDTK 2007-2013

Database of RTO Average Daily Temperature 1991-2020

Database of Utility Loads 2012-2018

A Fun Example of Data (Mis-)Use

Will that work?

Find the nearest temperature match around the same time of year and that will be a similar day

Then we can just use the same wind and solar shape from the match

I've got it. We've got 30 years of temperature.

Solar Project Shapes From NSRDB 1998-2021

Wind Project Shapes From Facility Data 2012-2018

D-2	D-1	Today	D+1	D+2

Database of RTO Average Daily Temperature 1991-2020

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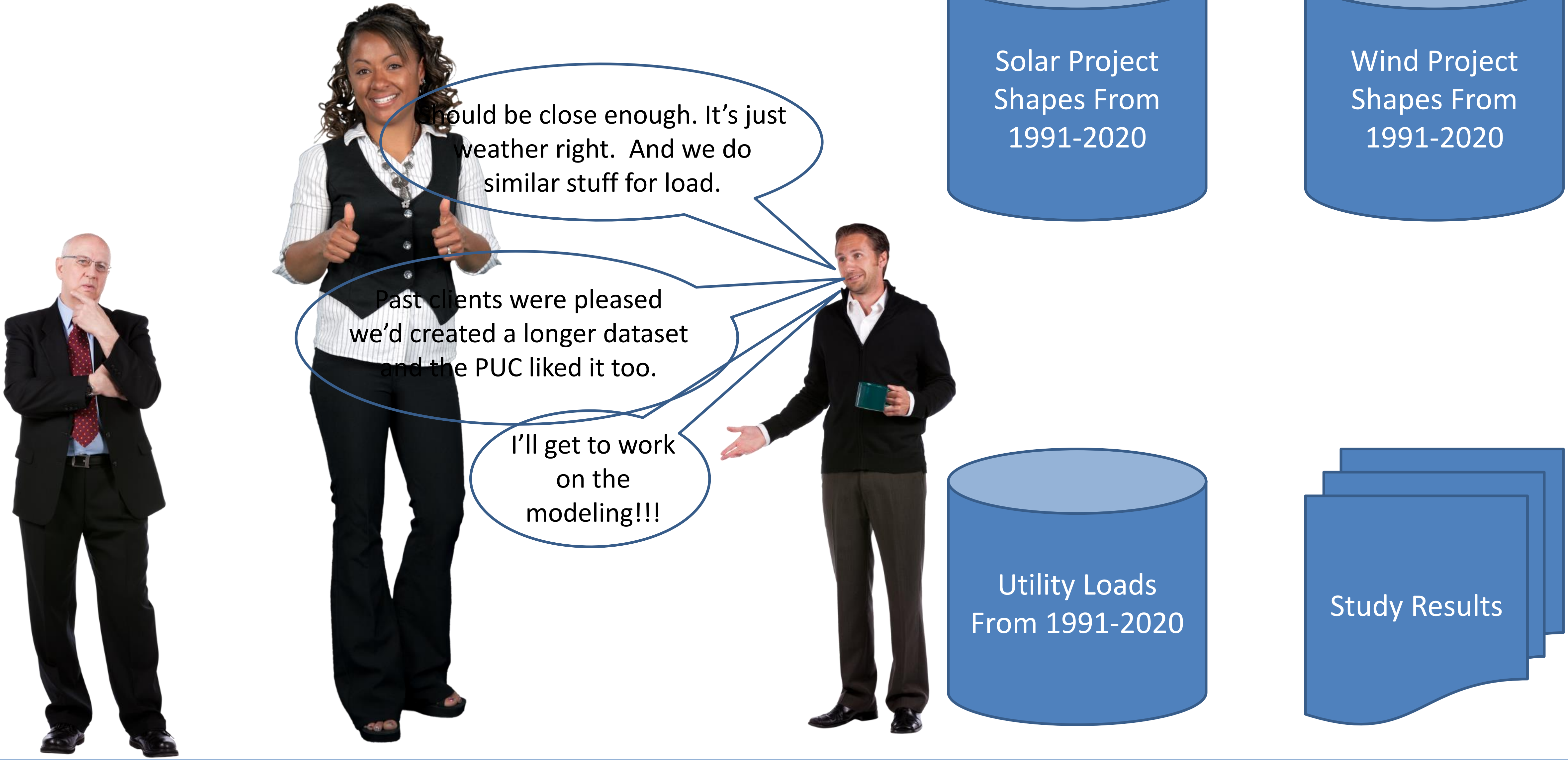


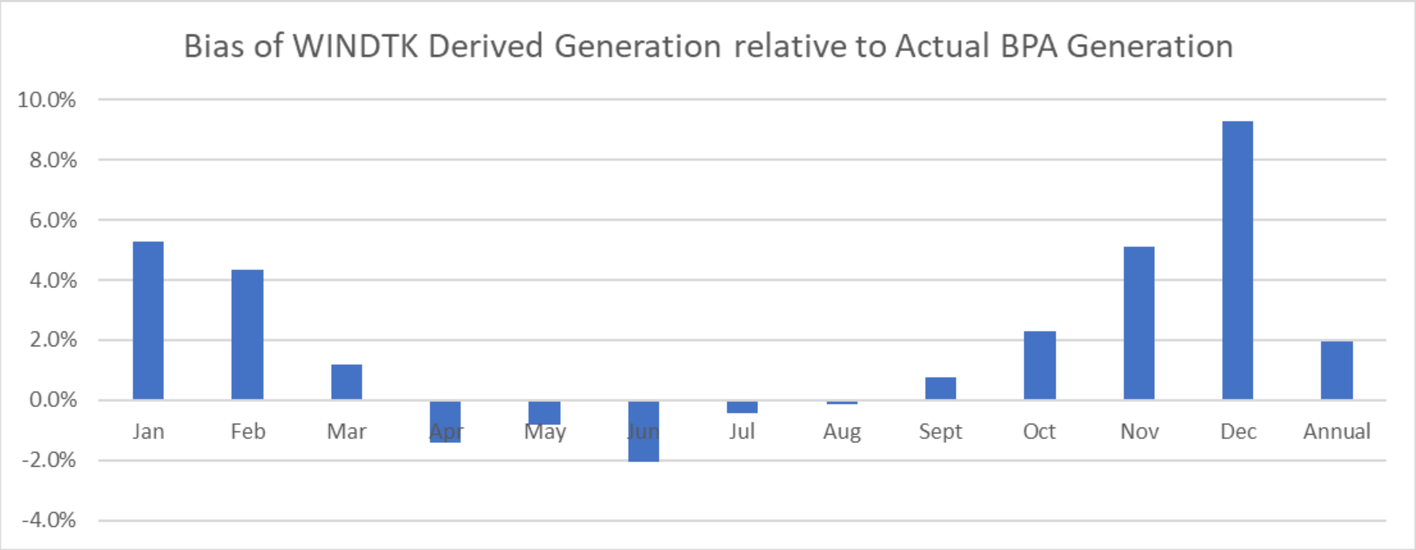
A Meteorologist's Reaction To This Methodology

But in fairness what are entities supposed to do if the data simply isn't available to do the job and nobody is providing what is needed or education on limitations?

Educate, Educate; Cross-Pollenate; Validate, Validate!!!

- We must all work together and understand the problem space
- We must validate everything. Not just the averages, and distributions, but the tails
- The distribution of coincident tail events MUST be close to reality otherwise the data value is dramatically diminished.
- Example:
  - WINDTK data in the BPA area
  - Wind resource in BPA BA is notoriously difficult to predict with NWP
    - Very 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%!

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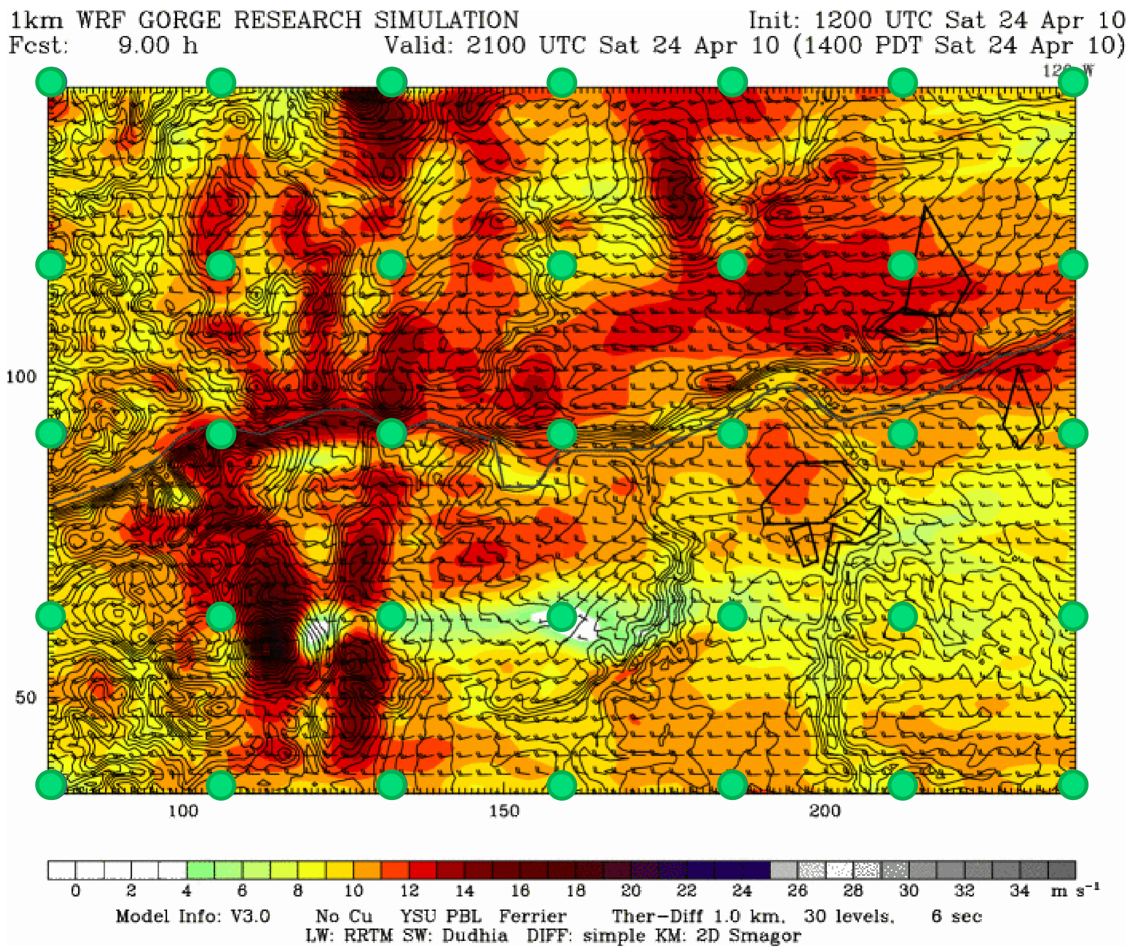
Current Practices and Data

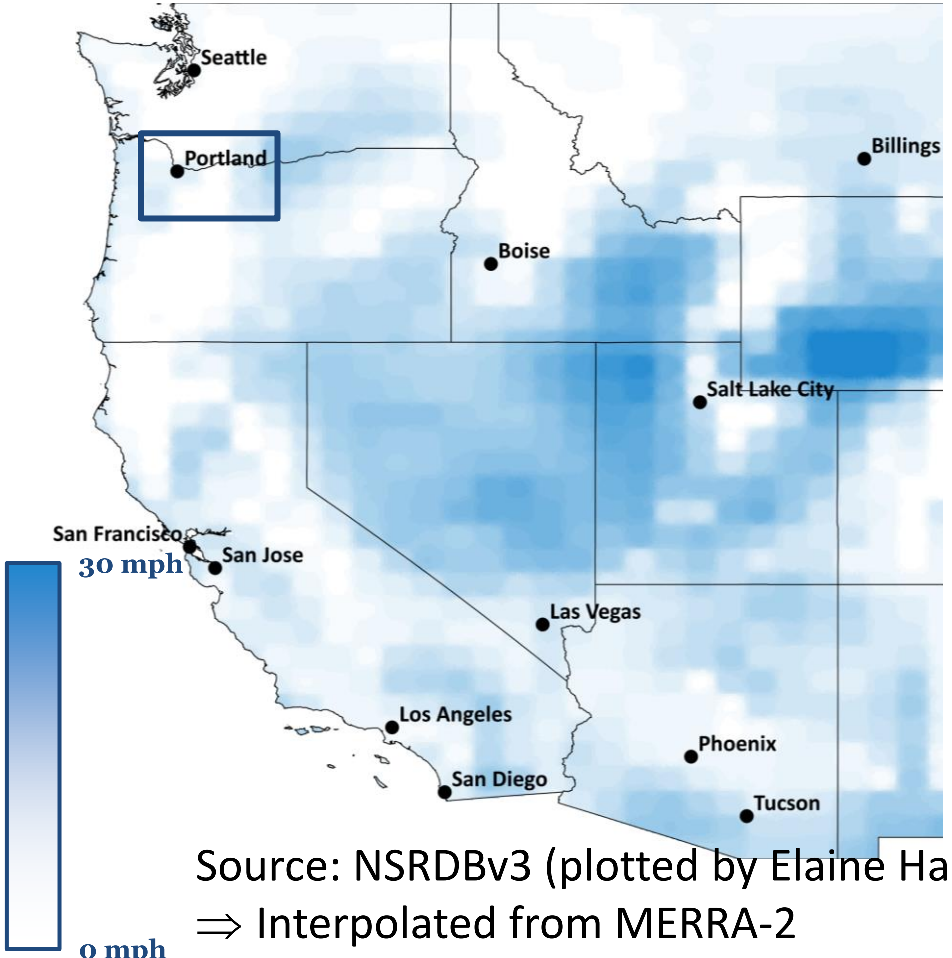
- Archaic, simplistic and often, frankly flat-out unscientific methodologies
- Poorly quality controlled observational data being used in a black box environment with little expert oversight
- Gridded data which in some cases is produced with power systems modeling in mind or some sector input but:
  - Becoming obsolete, and/or problems discovered: e.g. WINDTK
  - Incomplete and only covers one sector: e.g. WINDTK, NSRDB
  - Opaque and lacking peer review: e.g. private sector offerings
  - Produced for other purposes. e.g. generic research or operational forecasting and inconsistent in time, insufficient resolution, missing key variables/levels and/or insufficient validation of what matters.

More On Resolution Impacts on Gridded Operational and Reanalysis Datasets

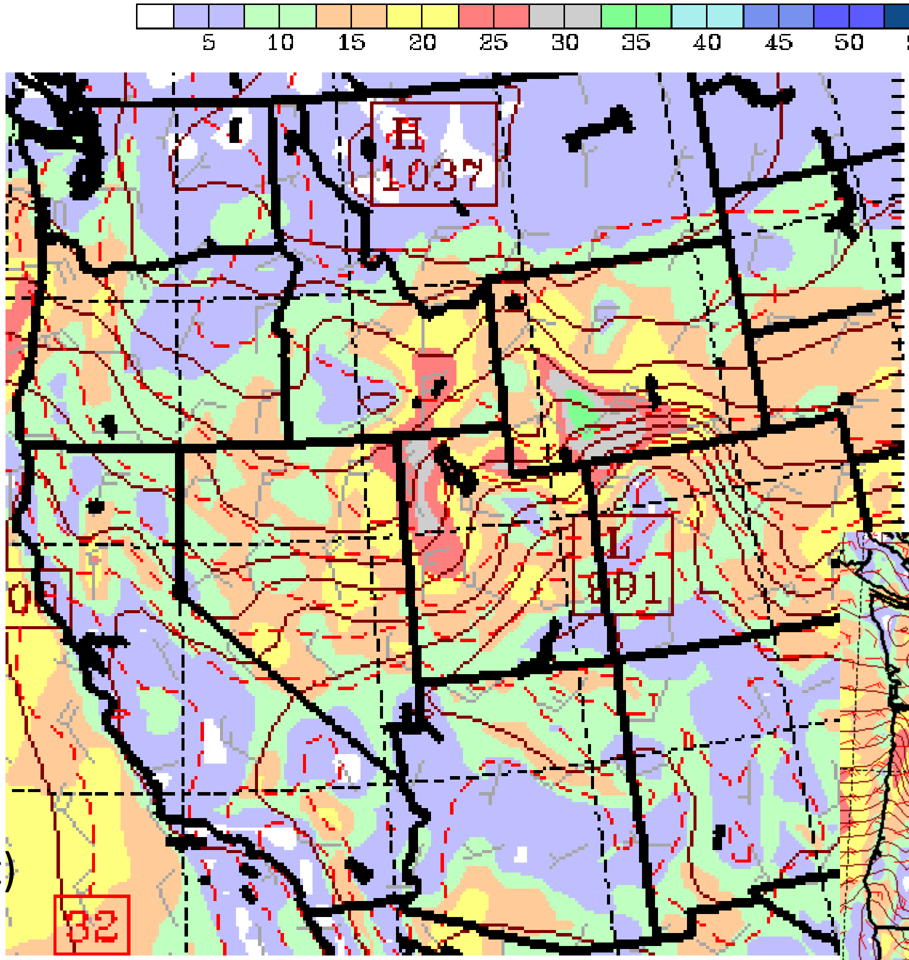
- MERRA and MERRA-2 was widely used for resource assessment especially for long term variability adjustments.
- Also used in some PS analysis where it has significant shortcomings
  - Low resolution, temporal seams and the lack of a forecast to accompany "truth"
- Fortunately, MERRA-2 is largely being replaced by ERA-5
  - Still not high close to high enough resolution to resolve complex topography
  - But on the plus side…somewhat future proofed
- Can ML techniques be used to downscale?



A Comparison of Windspeed Sources During an Extreme Event: September 8, 2020@9: UTC Windspeeed Comparison

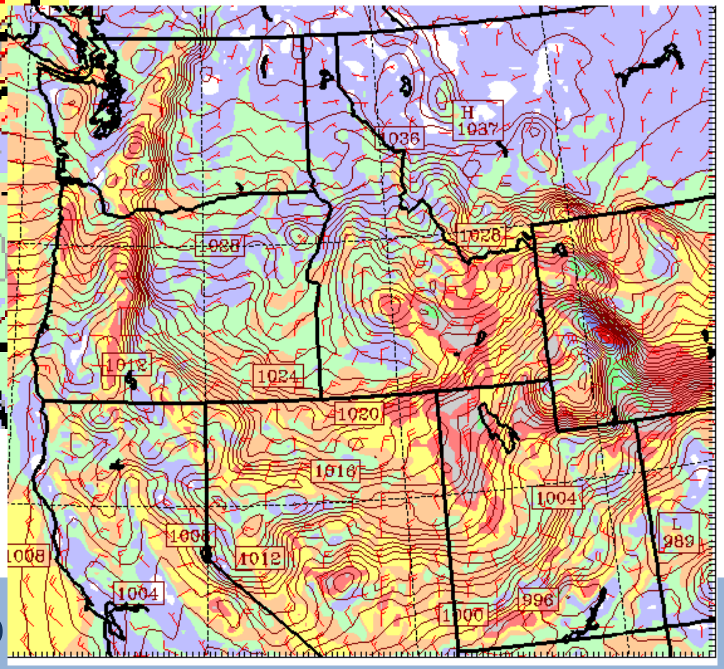


Source: NSRDBv3 (plotted by Elaine Hart)
⇒ Interpolated from MERRA-2
⇒ Approx. 60 km interpolated to 4 km)



Source: UW WRF 36 km Domain

Source: UW WRF 12 km Domain



Where are the actual strongest winds? Surely not here, right?

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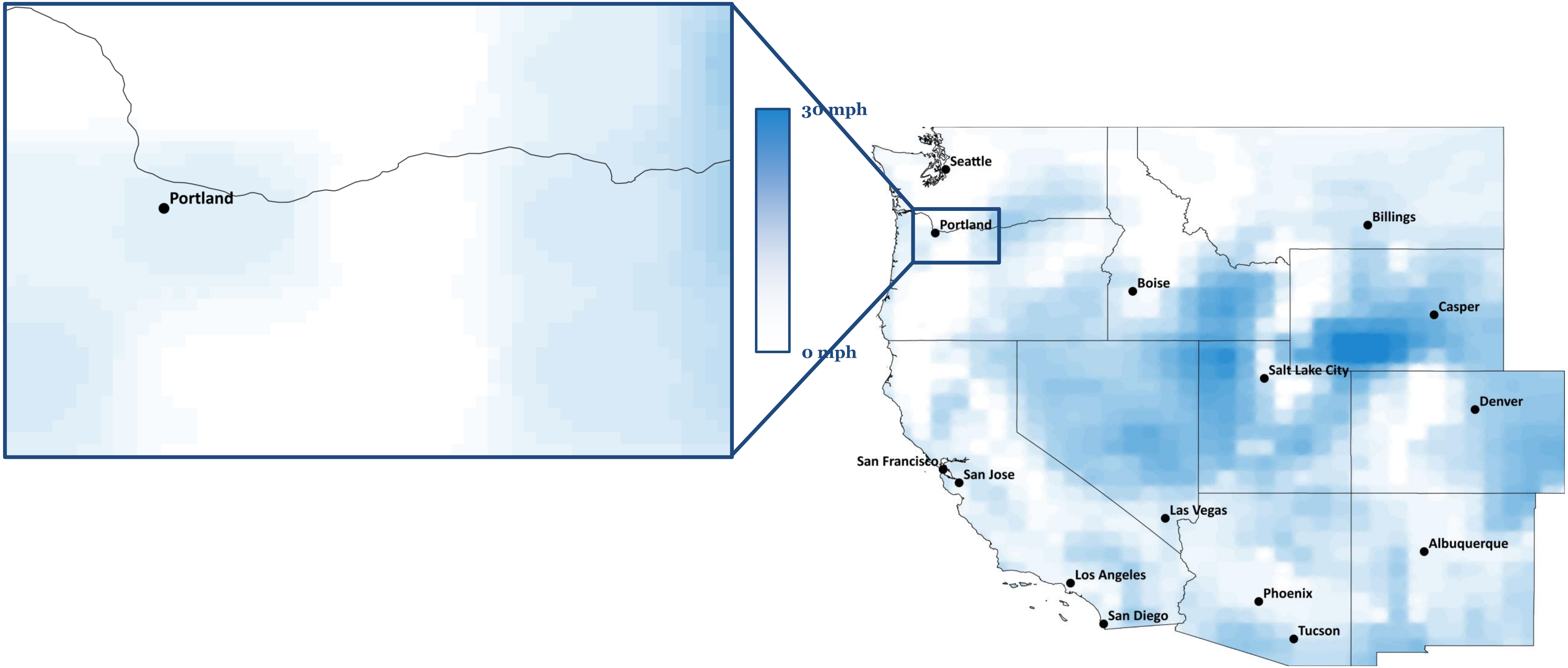

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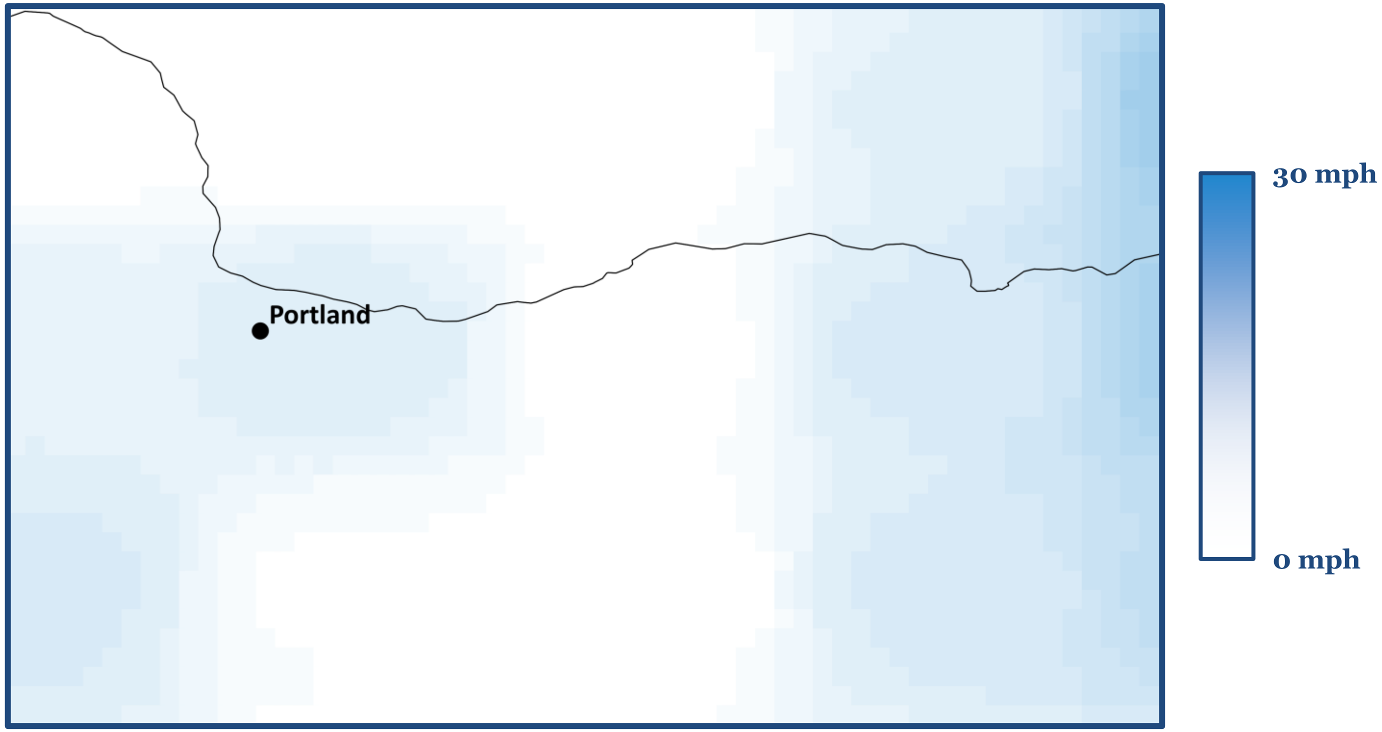

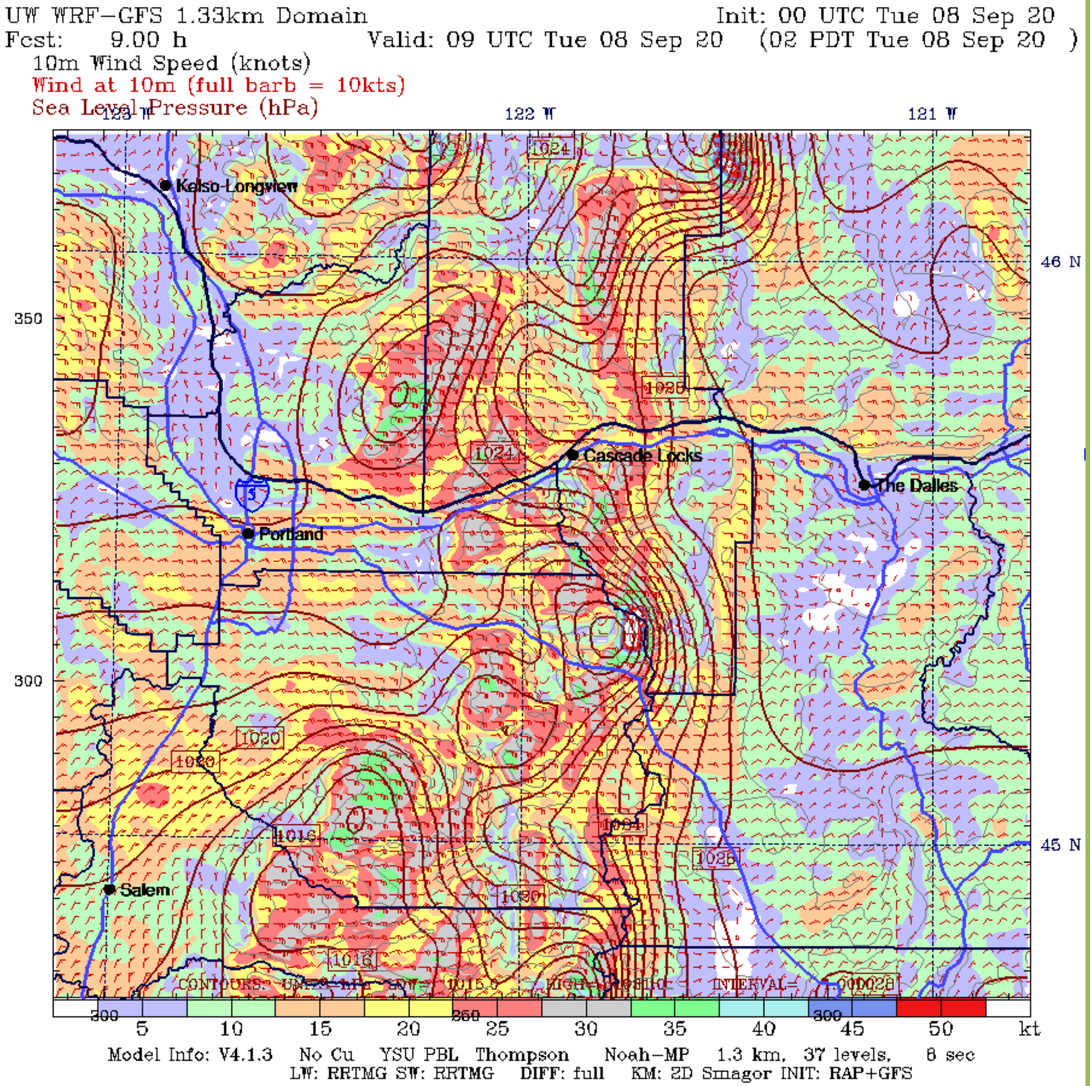

Powerful 100-yr wind event:

⇒ 100 mph+ gusts in bone dry downslope winds

⇒ Devasting fires razed several foothill towns and caused the worst air pollution in the world for days in the Willamette Valley.

⇒ MERRA-2 reanalysis shows almost no wind in affected places

⇒ Resolution is crucial to identify many extreme events

⇒ Oh…BTW, the day has been identified as one of four days from 2007-2020 with resource adequacy risk (T-driven) in a study being conducted for GridLab by Elaine Hart and Ana Mileva using GridPathRA. ***Thanks to Elaine for creating the NSRDB images.***

Best Practices for Modeling Weather, Extreme Events, and Climate Trends

an ESIG System Planning Group Task Force

ESIG

Challenge:

The energy transition is shifting the impact of weather on grid planning and operations, from one where weather (chiefly temperature) plays a primary role in modulating peak load and its timing, to one where weather is instrumental in driving system risks across multiple interconnected dimensions. Impacts include: wind and solar generation, load shape and magnitude, storage charge and discharge, and forced outages (traditional and renewable).

Objective:

To convene a cross-disciplinary group of system engineers and atmospheric scientists to advance the application of weather data in power systems planning and operations and communicate a set of best practices. The focus will be on better use of existing weather inputs in resource adequacy analysis, including for capacity expansion and production cost modeling, and upon determining what is needed from a "next generation" dataset that will serve the needs of the sector throughout the energy transition.

Key Topics:

1. What are the attributes of an ideal "weather inputs" dataset?
2. What "best practices" should be applied to weather inputs, and what practices should be avoided?
   - What are the biggest gaps in weather data right now and how will they evolve?
   - How should high-impact, low-probability events be modeled?
   - Should weather be treated endogenously in power system models or are largely exogenous methods sufficient?
3. How might climate change impact the findings?

Timeline and Deliverables:

Ongoing task force meetings through September 2022

Results communicated via ESIG workshop sessions, blogs, a recommendations memo and year end whitepaper.

More Information:

Formal scope

Contact: justin@sharply-focused.com

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Initial Focus: Defining the Requirements For The Ideal Dataset

- The power systems and energy meteorological communities have been engaged to help flesh out answers to the following questions:
  1. What applications are in the most need of updated weather and climate input datasets?
  2. What are the most important variables and attributes of the required datasets for each application?
  3. What methods can be used to gather and/or synthesize the required data?
  4. What methods should be used to validate the dataset that is produced?
- Promising starting points:
  – Extensions of the WINDTK and improvements in NSRDB
  – CONUS 404 (40 years at 4 km)

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