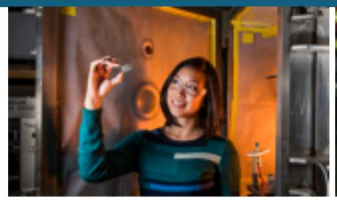
SAND2019-13673C

Sandia National Laboratories

Consequence Modeling for Multi-Sector Resilience Analysis



Andrea Staid

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Resilience Week
San Antonio, TX

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Reliability vs Resilience Analysis

Reliability Analysis

- Single-sector
- Low consequence impacts
- Typically N-1 analysis – can the system handle a single failure?
- Random failures (cause doesn't matter)
- Mandates for reliability standards – known performance targets

Resilience Analysis

- Multi-sector
- High consequence impacts
- Multiple component failures, concurrent and/or cascading
- Cause of failures matters for preparedness, response, and mitigation
- No mandates or agreed-upon definitions of what 'resilient enough' means

Reliability Analysis Provides Tools for Resilience Analysis

What do we need?

- Test system
- Optimization and Simulation software
- Random failures
- Calculation of reliability metrics

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- Realistic failure scenarios
- Calculation of reliability and resilience metrics

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Reliability Analysis → **Resilience Analysis**

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For *all* threats of concern, we need to build models that predict threat-specific failures

Consider unique behaviors of:
- Infrastructure sectors
- Component types
- Demands
- Recovery potential

Impacts are modeled as a function of:
- Weather conditions
- Resource type
- Geographical location
- Time

How Do We Model Threats and Impacts? A few examples…

Using the open RTS-GMLC test system, we simulate threats and determine the resulting failures.

This can be used for overall system analysis, studying performance benefits of resilience investments, evaluating metrics of interest, etc.

Still lots to be done, but we have models to simulate impacts on RTS-GMLC for:

Solar eclipse

- Model area of totality and penumbra through time as the eclipse passes over the system
- PV output drops to zero at a bus during totality, decreases proportionally based on distance from center
- For fun, user has the choice of forecasting the event, or not!
- Can the system handle the surprise disappearance of PV production?

Derecho*

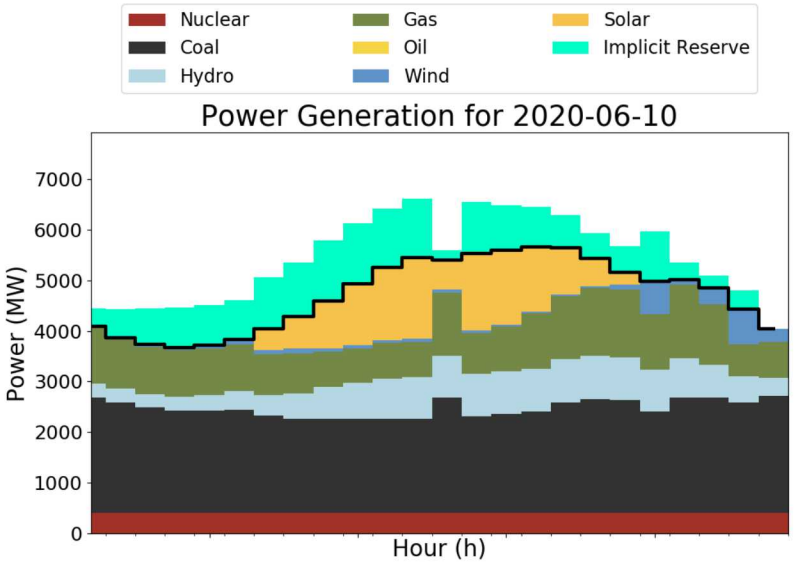
- Model fast-moving stormfront that brings high winds to each bus as it passes through
- Wind production ramps quickly up, but then hits the cut-out velocity and shuts down until the storm passes
- Damage to distribution lines and poles represented by load reductions, with restoration curves defining the load recovery
- Transmission lines can fail in high winds – we can randomly sample forced outages

Polar Vortex*

- Model temperature profiles at each bus over time
- Wind turbines have hard low-temperature cutoffs, so wind production shuts off if thresholds are reached
- Thermal generators have significantly increased forced outages rates due to freezing components, we sample failures based on fuel type and exposed temperatures
- Loads increase from baseline
- Gas supply can be disrupted

*Pretend RTS-GMLC moves to the Midwest

What Can This Look Like?

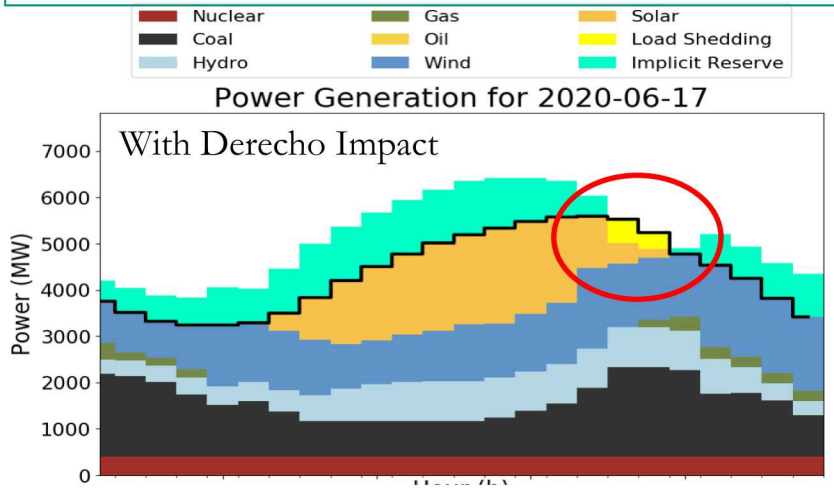


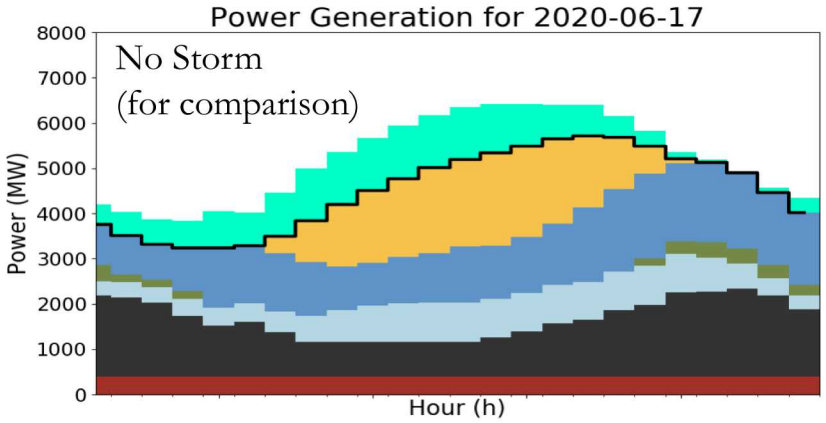
Solar eclipse

- Solar production drops off significantly in the middle of the day
- Coal and gas ramp up to compensate
- No loss of load
- Notably, this is a low-wind day, what would the impacts have looked like on another day?

Derecho

- Wind drops off as turbines reach cutout speed
- Coal ramps up to compensate, but not enough and we shed load
- System demand decreases as distribution components fail





Polar Vortex Events – A bit more interesting

Impacts are multi-sector

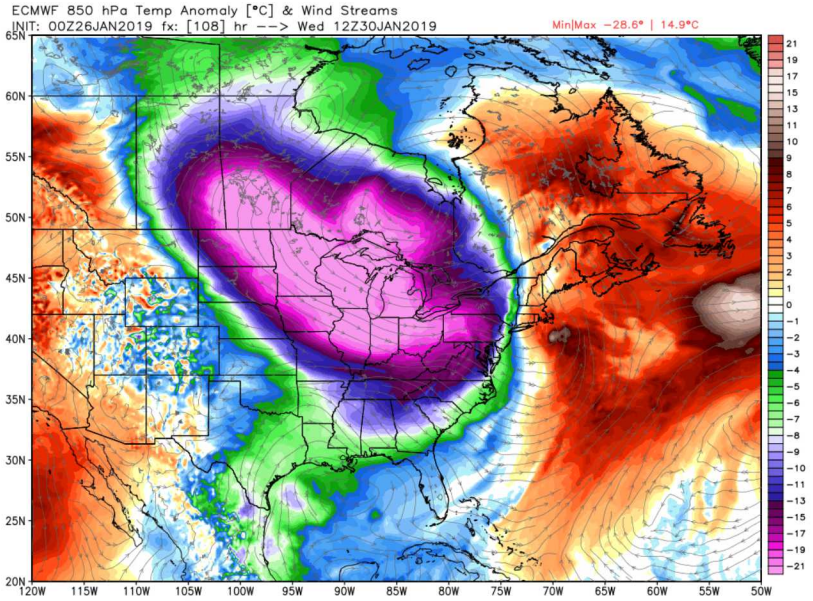
- Failures in natural gas delivery or supply impact electric sector generation
- Extreme cold temps cause vast failures of thermal generators – frozen sensor lines, valves, fuel delivery, etc.

Impacts have spatio-temporal dependencies

- Temperature extremes can impact large areas, evolving through time
- Regions far from the most extreme threat can still see well-below-average temperatures, resulting in impacts in accordance with looser cold-weather design standards

Mitigation strategies have interesting modeling challenges:

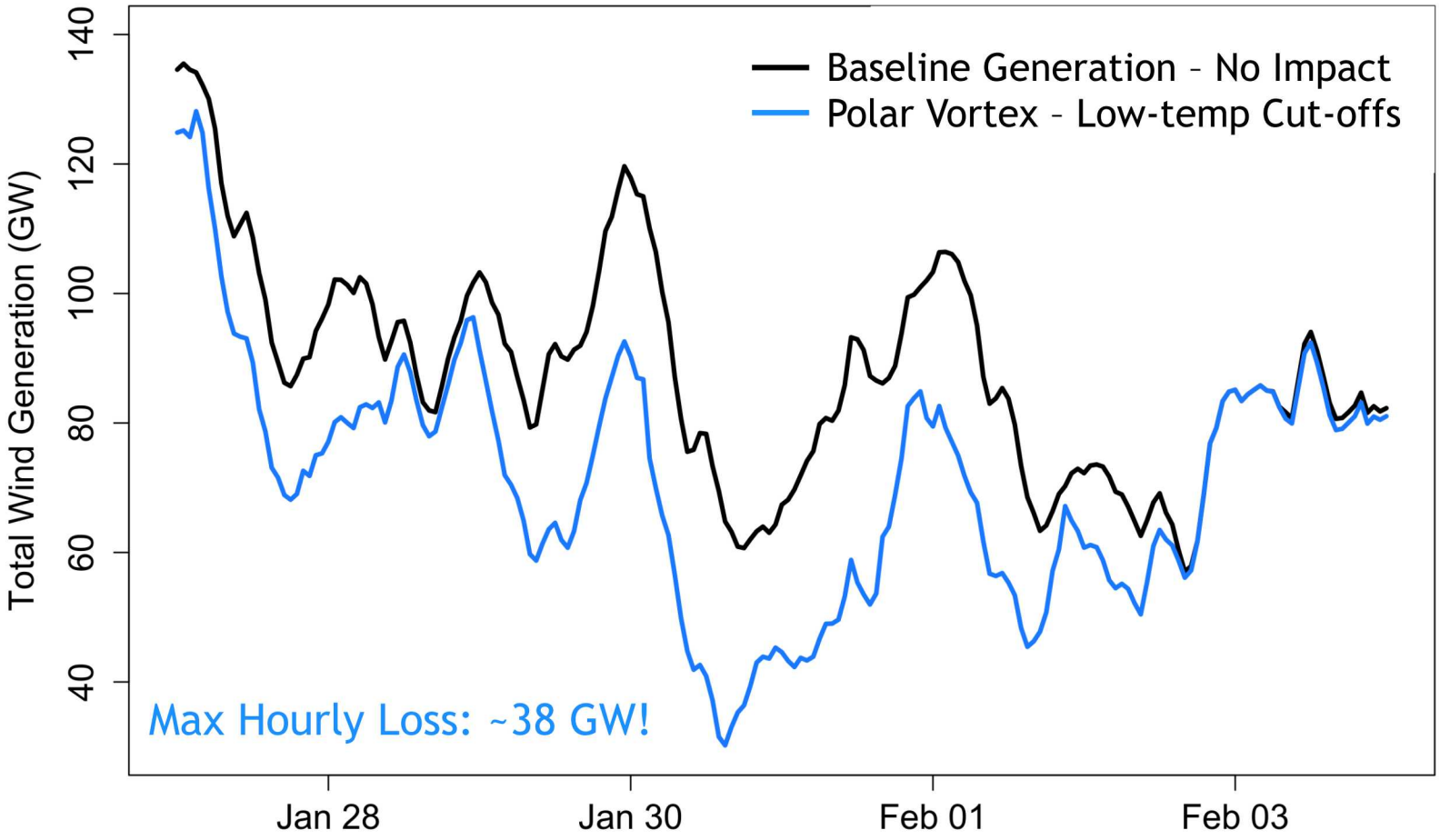
- Dual-fuel capabilities for natural gas generators (See Ben's talk)
- Cold-weather packages on wind turbines
- Changing overall generation mix?



Importance of Accurate Data

Wind turbine low-temperature cut-offs: -10C (14F) or -30C (-22F) with a cold-weather package installed

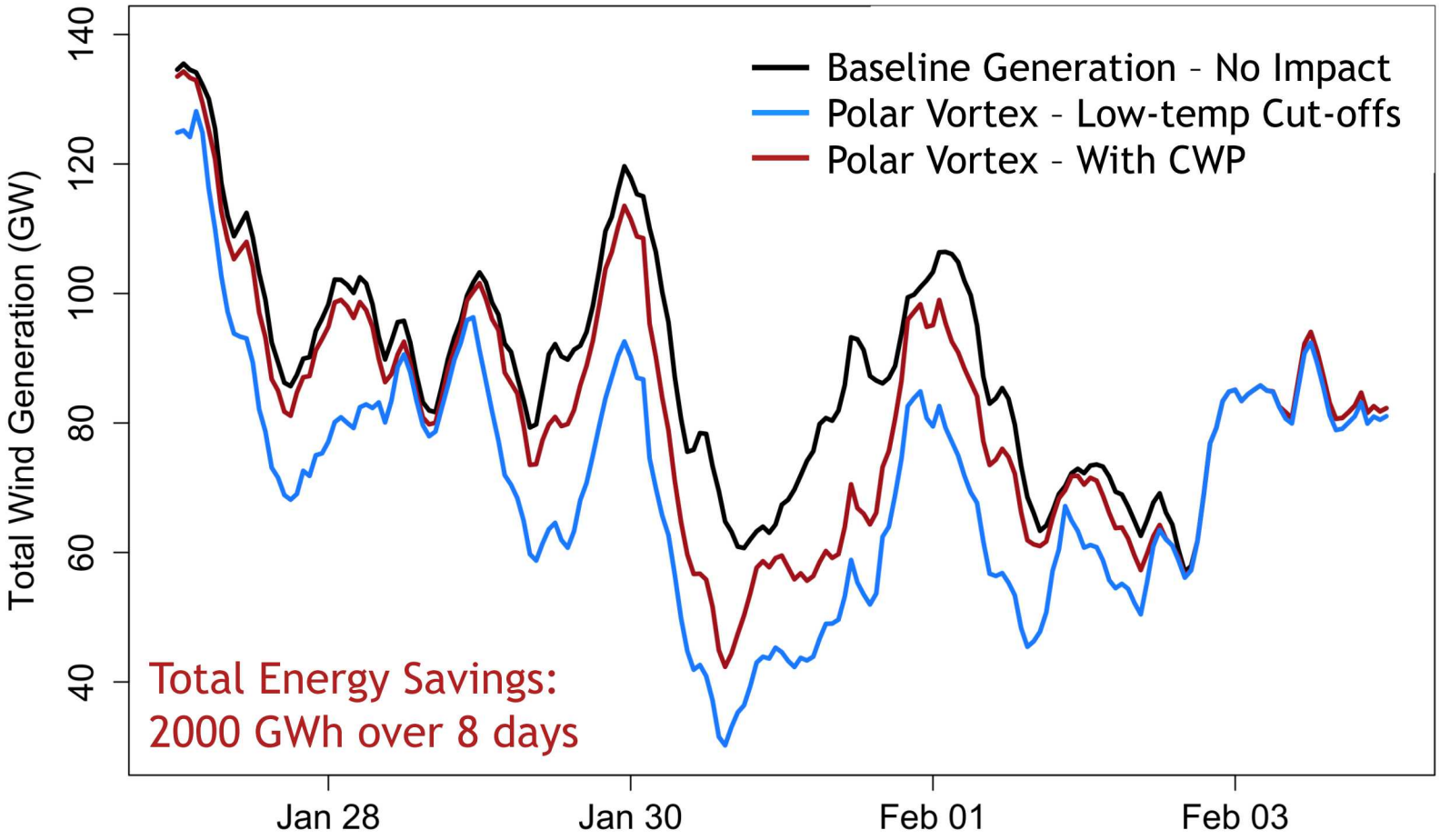
- Impact depends on knowledge of which turbines have cold weather packages and local temperature timeseries



Importance of Accurate Data

We don't know which turbines have a cold-weather package (CWP), but we can create scenarios of varying CWP penetration levels

- With 2/3 of wind sites (~55% of capacity) having CWP, we reduce the max hourly loss from 38 GW to 26 GW



Next Steps

Status:

We are able to create multi-sector impact scenarios for several threat types

- Limited by access to detailed historical data
- However, our models are parameterizable, allowing for exploration of sensitivities and analysis of posited future scenarios
- Quantifiable benefits from resilience enhancement investments, demonstrating the importance of accurate modeling of gas supply and wind power

To-Do's:

Lots to do to improve our impact scenarios, especially as we continue to seek out more/better data sources

Study other threat types and the impacts unique to them:

- Hurricane
- Wildfire
- Flood
- Earthquake