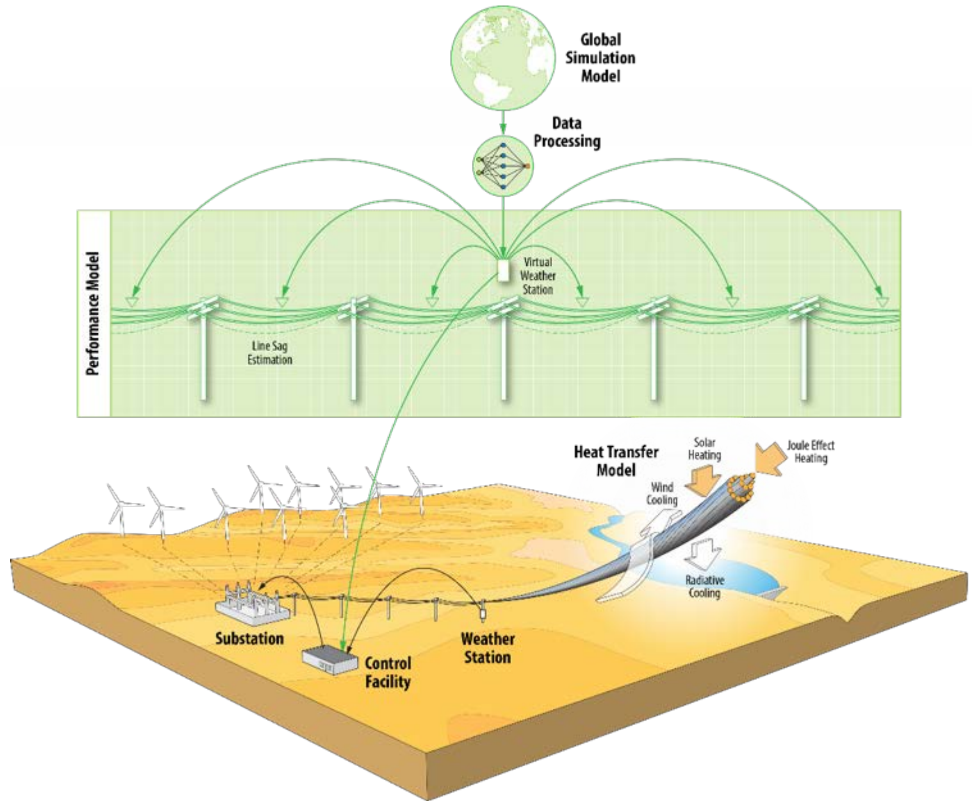
U.S. DEPARTMENT OF
ENERGY
Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY



Operational and Strategic Implementation of Dynamic Line Rating for Optimized Wind Energy Generation Integration

31287 M3

Jake P. Gentle

Idaho National Laboratory

FY17-FY18 Wind Office Project Organization

"Enabling Wind Energy Options Nationwide"

Technology Development	Market Acceleration & Deployment
Atmosphere to Electrons	Stakeholder Engagement, Workforce Development, and Human Use Considerations
Offshore Wind	Environmental Research
Distributed Wind	Grid Integration
Testing Infrastructure	Regulatory and Siting
Standards Support and International Engagement	
Advanced Components, Reliability, and Manufacturing	

Analysis and Modeling (cross-cutting)

Project Overview

Idaho National Laboratory

M3: Operational and Strategic Implementation of Dynamic Line Rating (DLR) for Optimized Wind Energy Generation Integration

Project Summary

A “cool” way to (1) Increase the utilization of existing transmission and distribution infrastructure with dynamic line rating, and (2) Improve the optimization of new infrastructure developments using the Transmission Route Engineering Analysis and Design (TREAD) Toolkit

Project Objective & Impact

Develop an affordable and effective implementation of real-time weather- and forecast-based dynamic line rating of overhead transmission lines by mitigating transmission congestion and optimizing the use of electricity infrastructure for the integration of wind energy to enhance the nation’s energy portfolio.

Provide science-based methodologies and solutions that are readily adopted and usable by a regulated industry.

Provide industry with a low-cost, robust solution set, and enable human operators to make informed decisions and take appropriate actions without being overwhelmed by data.

Project Attributes

Project Principal Investigator(s)

Jake P. Gentle
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208-526-1753

DOE Lead

Charlton Clark
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202-586-8040

Project Partners/Subs

NOAA
WindSim
Stantec
Forbidn Engineering
FERC
NERC

See more on next slides

Project Duration

GMLC WIND-0253
June 2016 – March 2019

INL Project Leads

Jake P. Gentle
Principal Investigator

Tim McJunkin
Electrical Engineer

Dr. Katya Le Blanc
Human Factors Psychologist

Dr. Alex Abboud
Computational Fluid Dynamics

Jacob Lehmer
Software Development

Major Partners and Collaborators

Idaho National Laboratory

- WindSim
- Idaho Power – An IDACORP Company
- AltaLink
- National Oceanic and Atmospheric Administration
- FERC – Federal Energy Regulatory Commission
- NERC – North American Electric Reliability Corporation
- ESIG – Energy Systems Integration Group
- WECC
- Bonneville Power Administration
- pjm
- aeso – Alberta Electric System Operator
- SPP – Southwest Power Pool
- OG&E
- Forbidn Manufacturing
- Durham University
- Idaho State University
- Boise State University
- Montana Tech
- University of Idaho
- Stantec
- POWER Engineers
- Vaisala
- StormGeo
- LineVision
- Lindsey
- USi
- Genscape
- Southwire
- ResilientGrid
- OSIsoft
- Heimdall Power
- TechFlow

Interactions with U.S. Government Industry & Academia

- 75+ INL|DOE|Energy Systems Integration Group Dynamic Line Rating Workshop attendees
- 15+ Non-Disclosure Agreements,
- 3 Software Copyrights (GLASS, SAND, TREAD)
- 2 CRADA Projects Completed (AltaLink, WindSim AS)
- 1 Memorandum of Understanding (NOAA)
- 1 Strategic Partnership Project Agreement Completed (Idaho Power)
- 1 CRADA Project ongoing (WindSim Americas)
- 1 Special Use license with a utility partner for GLASS Endurance Testing
- 1 Beta Use License during CRADA development
- 1 Report to Congress on status of Dynamic Line Rating technologies and system impacts

Technical Merit and Relevance

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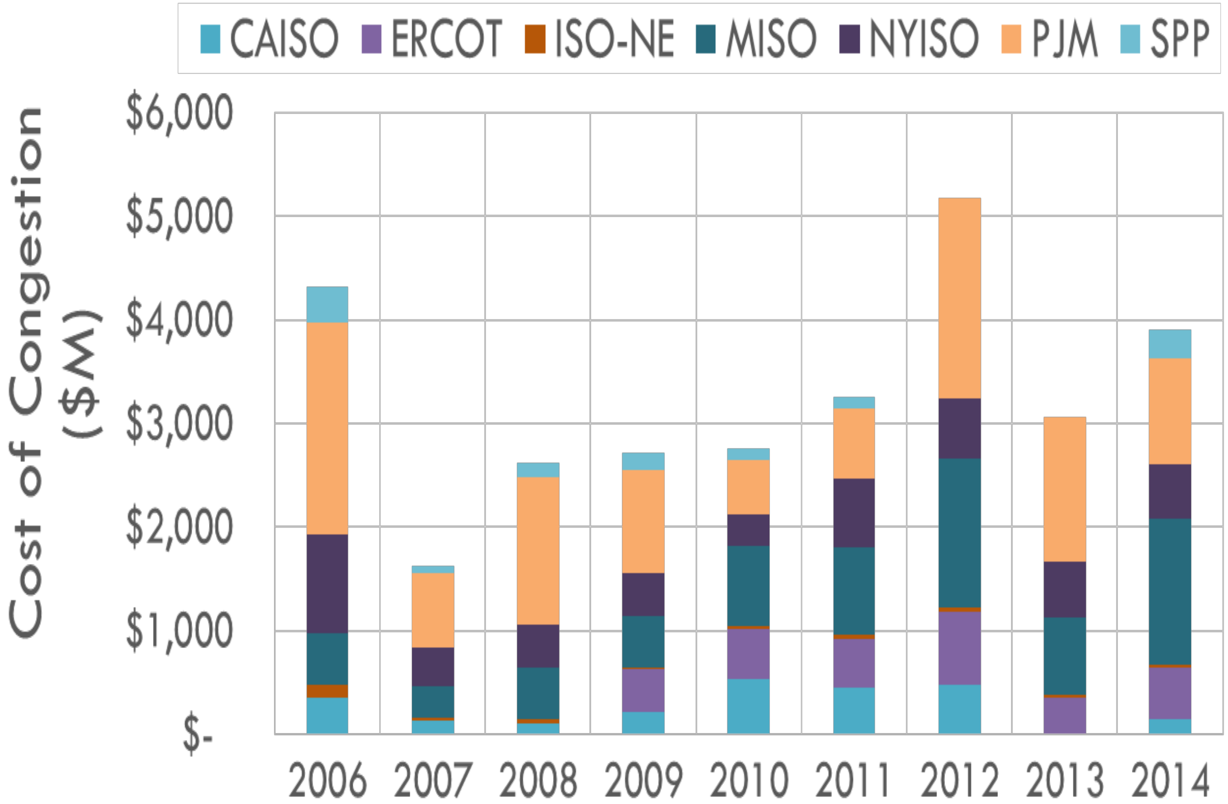
DLR Helps Relieve High Congestion Costs

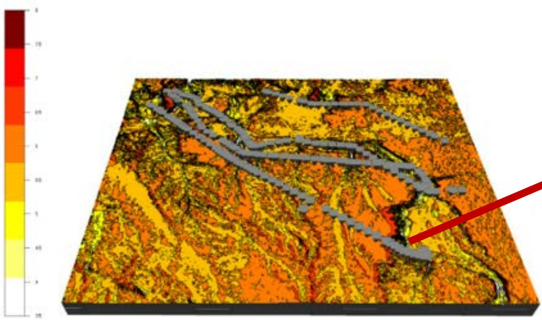


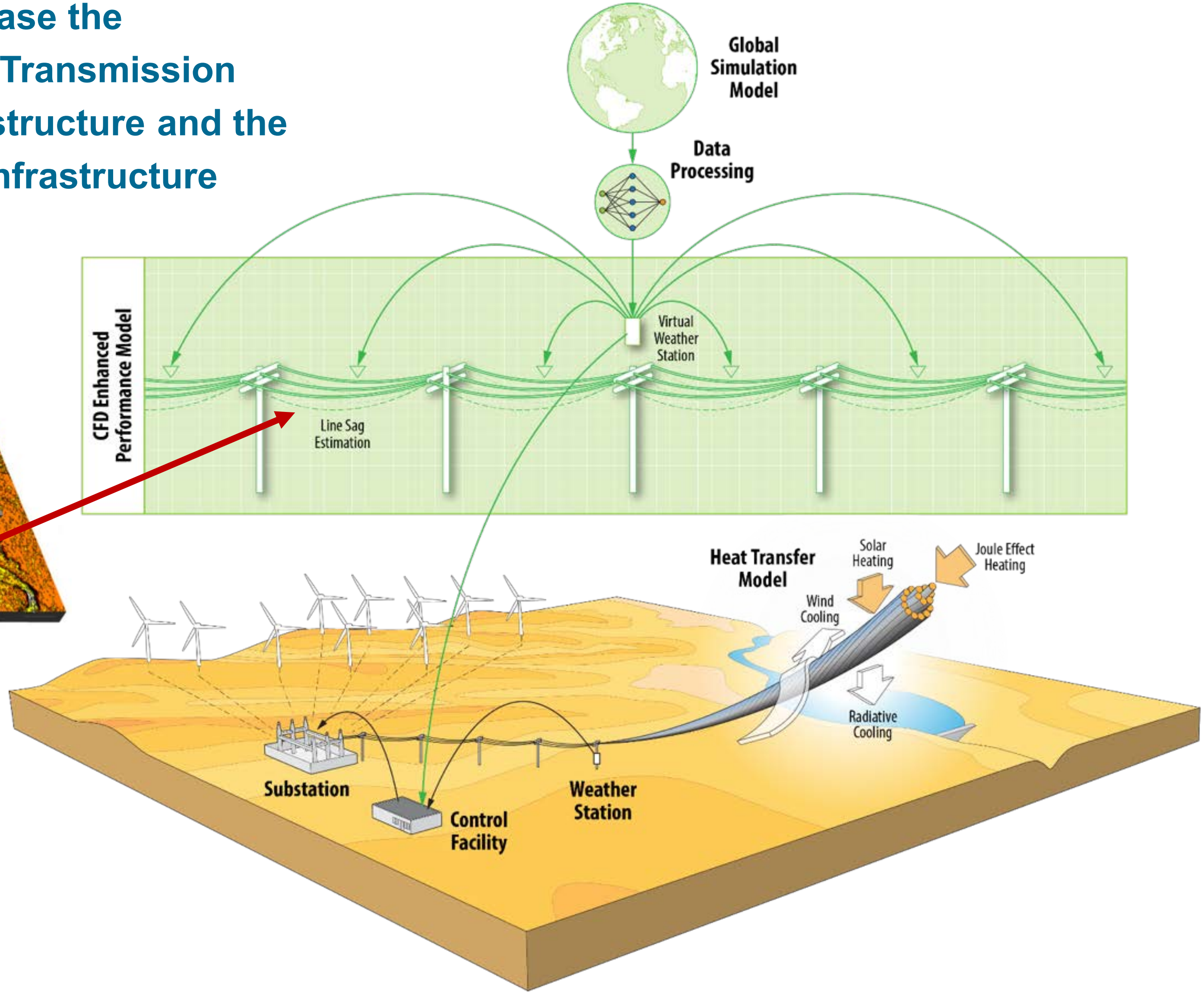
- Relieves transmission congestion,
- Improves transmission flexibility,
- Enables higher wind penetration.

Data Sources: Multiple sources. Go to www.advancedtransmission.org for more information

Approach and Methodology

A "Cool" Way to Increase the Utilization of Existing Transmission and Distribution Infrastructure and the Optimization of New Infrastructure Developments





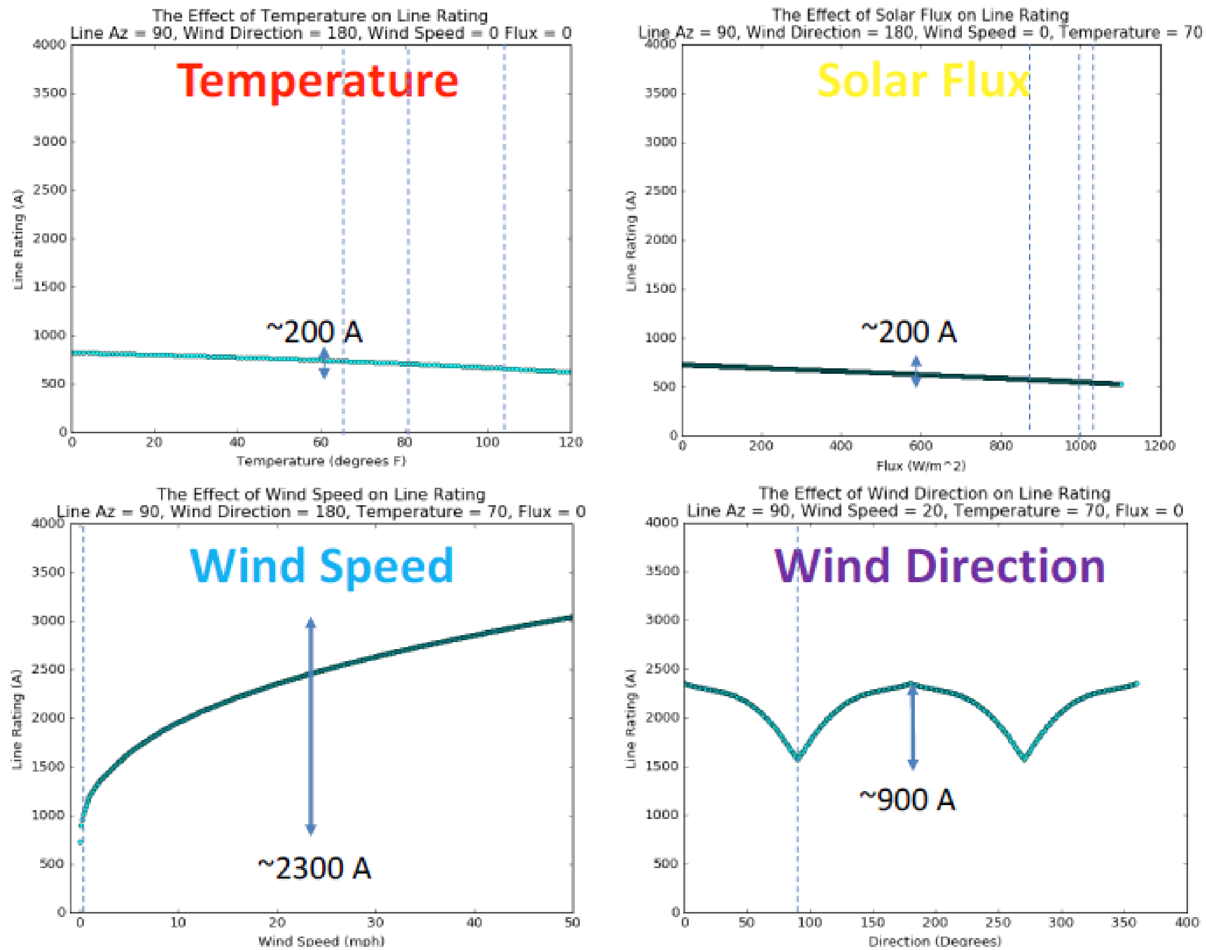
Simulation of up to 36 wind-directions and creation of look-up tables that allow a fast statistical-dynamical down-scaling when the weather station information/forecasting arrives in the system

CFD-Based Dynamic Line Rating Matters

Sensitivity Analysis

CFD = Computational Fluid Dynamics

Seasonal values are conservative

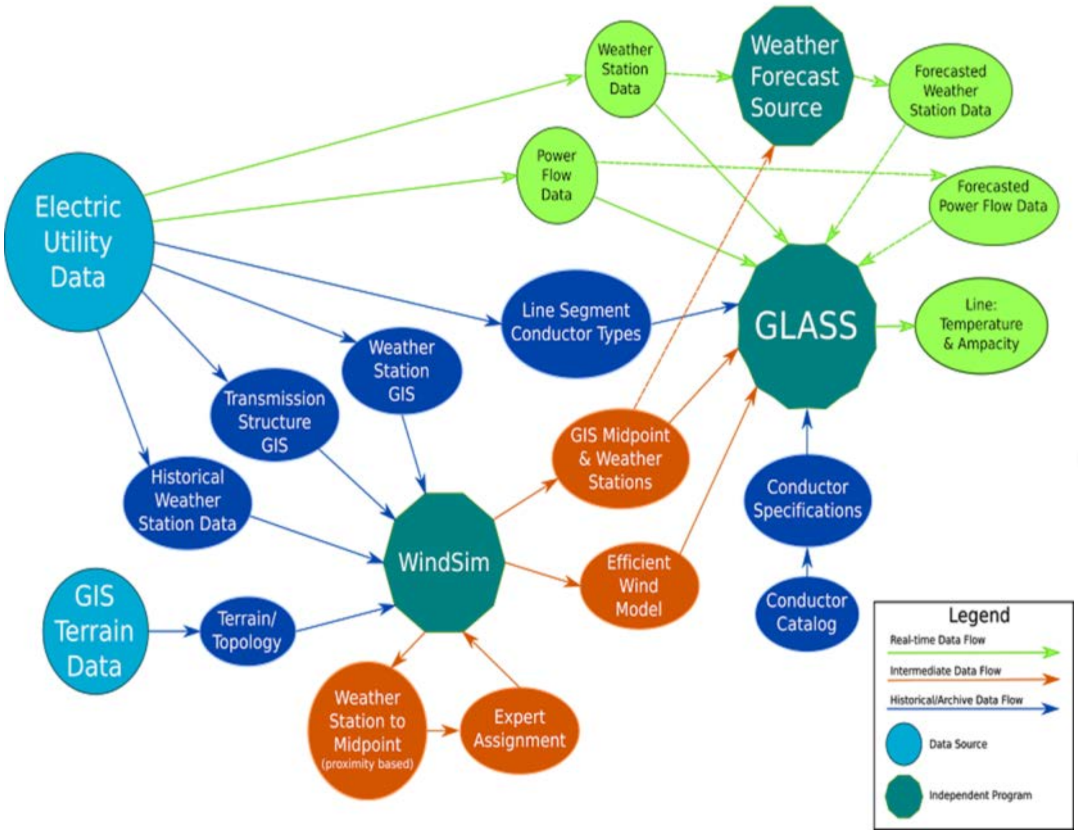


<u>Seasonal Rating Values</u>
(Summer, Winter, Transition)
Temperature = 40℃, 18℃, 27℃
Wind Speed = 0.6 m/s
Wind Direction = 90° (parallel to line azimuth)
Solar Flux = 1030 W/m², 850 W/m², 1000 W/m²

Kenneth R. Fenton Jr., Matthew S. Wandishin, Melissa A. Petty, Melinda Marquis, Timothy R. McJunkin, Alexander W. Abboud, and Jake P. Gentle, 2017, DYNAMIC LINE RATING USING THE HIGH RESOLUTION RAPID REFRESH (HRRR) MODEL. DLR Workshop Idaho.

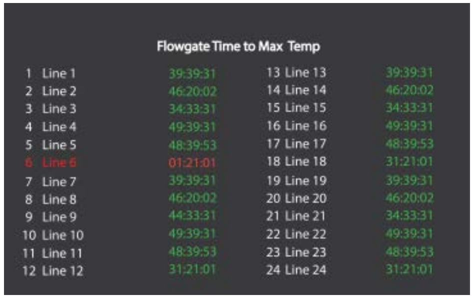
Technical Approach

Use computational fluid dynamics and real-time weather data to deploy an industry standard line rating methodology to open up marked increases in power carrying capacity of existing overhead lines and seamlessly implement it into the control room.



Implementing the technology into control center:

Human Factors Approach



Flowgate Time to Max Temp

1	Line 1	39:39:31	13	Line 13	39:39:31
2	Line 2	46:20:02	14	Line 14	46:20:02
3	Line 3	34:33:31	15	Line 15	34:33:31
4	Line 4	49:39:31	16	Line 16	49:39:31
5	Line 5	48:39:53	17	Line 17	48:39:53
6	Line 6	01:21:01	18	Line 18	31:21:01
7	Line 7	39:39:31	19	Line 19	39:39:31
8	Line 8	46:20:02	20	Line 20	46:20:02
9	Line 9	44:33:31	21	Line 21	34:33:31
10	Line 10	49:39:31	22	Line 22	49:39:31
11	Line 11	48:39:53	23	Line 23	48:39:53
12	Line 12	31:21:01	24	Line 24	31:21:01

Accomplishments and Progress

Key Software

GLASS: General Line Ampacity State Solver.
Computational engine to consume historical, real time, and forecasted weather and line current data to produce maximum current a line can carry.

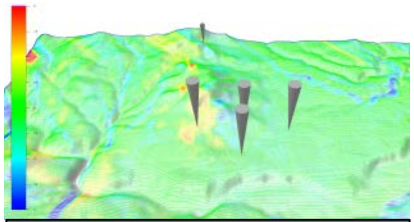
SAND: Systematic Analyzer of Numerical Data.
Organize historical weather data and drive GLASS computation.

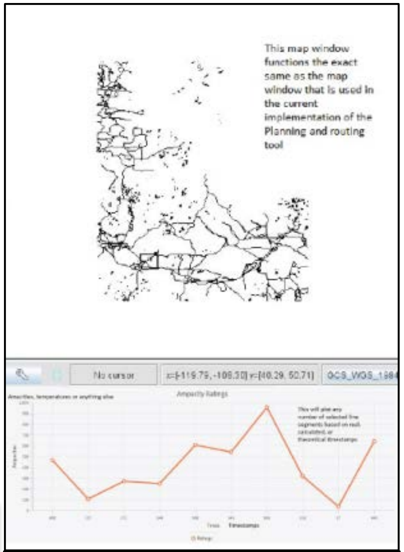
CRYSTAL:
Organize forecast (predicted) weather data and drive GLASS computation.

TREAD: Transmission Route Engineering Analysis and Design:
An easy-to-use application to utilize DLR data to find the least cost power line path through a variety of terrain.

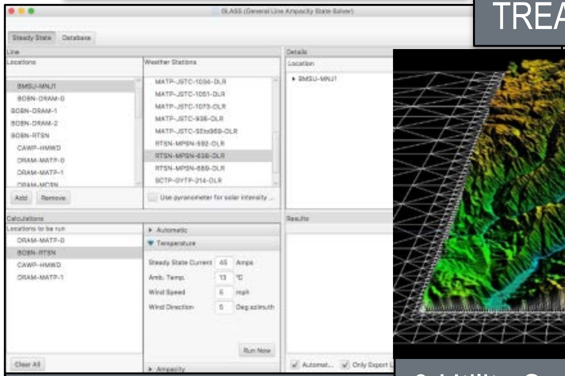
2017 R&D 100 FINALIST

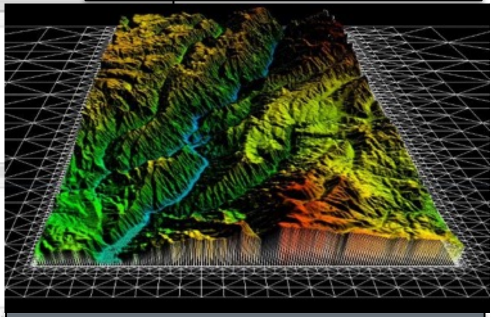
2018 R&D 100 FINALIST


CFD



TREAD


GLASS


3 Utility Supported Test Areas

Accomplishments and Progress

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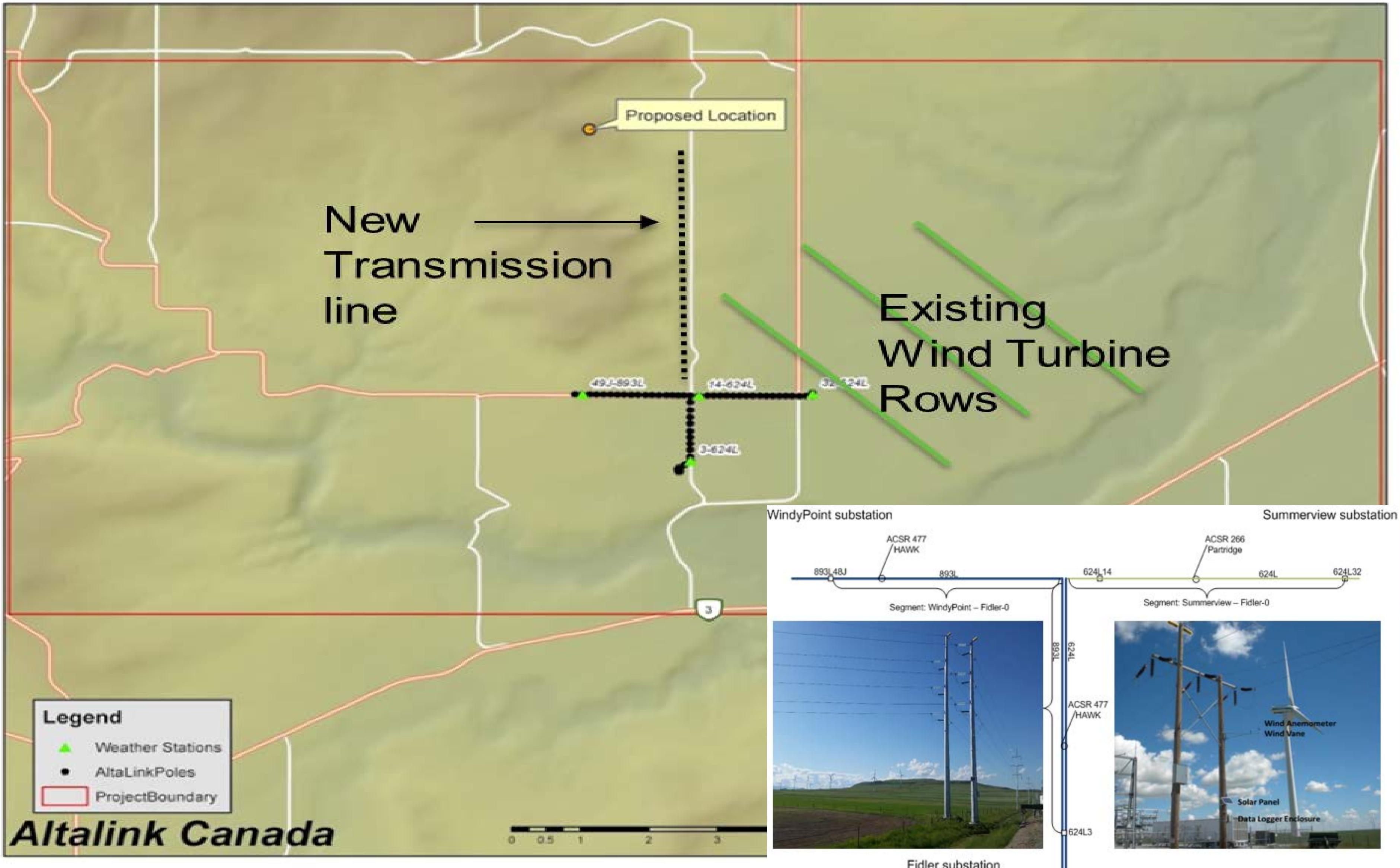
Where is the "critical span"?

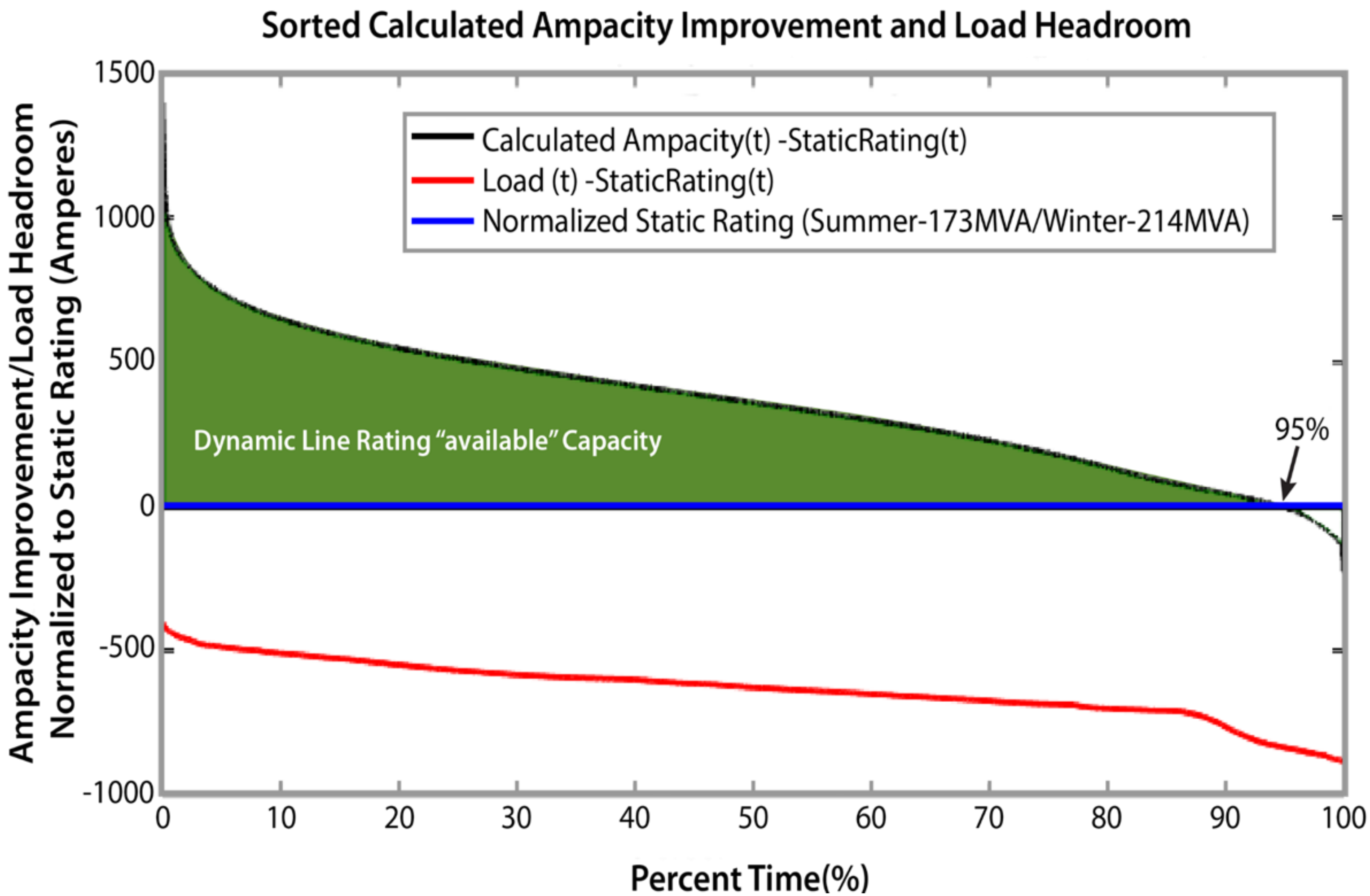
June 27th-29th, 2016

CRADA: Wind Expansion AltaLink, Canada

Idaho National Laboratory



Validation of Dynamic Line Rating with CFD

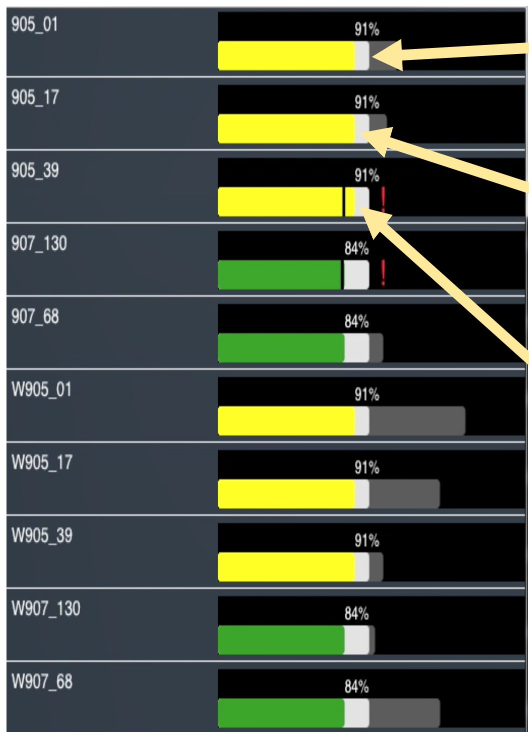


Bhattarai, Bishnu P., Gentle, Jake P., Hill, Porter, McJunkin, Tim, Myers, Kurt S., Abbound, Alex, Renwick, Rodger, and Hengst, David. *Transmission Line Ampacity Improvements of AltaLink Wind Plant Overhead Tie-Lines Using Weather-Based Dynamic Line Rating*. IEEE PES General Meeting 2017, Chicago, IL, USA.

DLR Visualizations

Integration of Solutions and Human Factors

me Operations -- Alerts



Accomplishments and Progress

Milestone	2017				2018			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Develop "True" Dynamic Line Rating within GLASS	100							
Analyze results of Hells Canyon project	100							
Historical comparison against industry supplied forecast data	100							
Demonstrate "True" DLR with industry supplied forecast data		100						
Begin module in GLASS for direct measurement sensor data		100						
Human Factors informed visualizations		100						
Demonstrate Human Factors prototype in HSSL		100						
Implement direct measurement sensor data with forecasted line ratings			100					
Implement revised public opinion survey component into Planning & Routing Toolkit			100					
Evaluate the automation of DLR data into OSI PI, SCADA, or EMS				100				
Eval test cases using public survey features & summarize cost implications of P& R Toolkit				100				
Integrate forecast-to-WS mapping using closest/best NOAA HRR model points					100			
Create initial report detailing GLASS cyber vulnerabilities					100			
Initiate TREAD survey discussing cost calculations and share with utilities					100			
Develop use cases and requirements for forecast line ratings					100			
Analyze and assess results of NOAA/INL forecast to real-time data evaluation						100		
Prepare protocol and methodology for evaluating DLR prototypes in HSSL						100		
Begin implementation of cyber vulnerability solution and GLASS optimization						100		
Process initial TREAD survey results and evaluate next steps for cost calculations						100		
Develop static prototypes to present forecast line ratings						100		
Develop deployable prototype of GLASS including forecasts base on NOAA HRRR input							100	
Write User Manual for GLASS and SAND							100	
Complete evaluation of the dynamic real time DLR prototype displays							100	
Continue to support cyber vulnerability solution and configuration best practices							100	
Complete User Manual for SAND								100
Analyze TREAD cost calculation results from survey and provide best practices								100
Establish best practices for GLASS system communication protocols								100
Complete the analysis of real-time DLR dynamic prototypes and present conceptual designs								100

Communication, Coordination, and Commercialization

Idaho National Laboratory

Institute for Electrical and Electronic Engineers (IEEE)

- Subcommittee 15.11: Overhead Lines Subcommittee
- Task Force - Line Ratings (Risk & Prediction)
- Working Group on Transmission and Distribution Overhead Conductors and Accessories—15.11.02/06
- Working Group on Construction of Overhead Lines—15.11.03
- Working Group on Management of Existing Overhead Transmission Lines—15.11.09
- Working Group on Wind and Solar Plant Collector System Design

Presented and updated on report contributions in Memphis, TN and Boston, MA

IEEE Transmission & Distribution Committee
IEEE Power & Energy Society

International Council on Large Electric Systems (CIGRE)

- Full & Corresponding Member: U.S. Representative
  - Jake P. Gentle (INL)
- Working Group - Corresponding Member: A3.36—Application and Benchmark of Multi Physic Simulations and Engineering Tools for Temperature Rise
- Working Group - Full Member: B2.59—Forecasting Dynamic Line Ratings
  - **Technical Brochure will be published in 2019

Presented and updated on WG Report in Montreal, Canada and Paris, France

SC B2
Overhead Lines

Communication, Coordination, and Commercialization

With more than 75 attendees from electric utilities, commercial solution providers, local, state, and federal regulatory and policy bodies, and academic institutions from around the globe, the Dynamic Line Rating Workshop provided attendees the opportunity to learn from the world's best, share common interests and concerns, and engage in peer-to-peer networking. Idaho National Laboratory was proud to host the 2017 Dynamic Line Rating Workshop and facilitate active discussions around industry needs and how to meet these needs with support from the U.S. Department of Energy's Wind Energy Technologies Office and the Utility Variable-Generation Integration Group (now Energy Systems Integration Group).

Top Five Notable Publications

- **Coupling computational fluid dynamics with the high resolution rapid refresh model for forecasting dynamic line ratings**
  - *Electric Power Systems Research* 170 (2019): 326-337.
- **Using Computational Fluid Dynamics to Assess Dynamic Line Ratings in Southern Idaho**
  - Presented at CIGRE 2018 Grid of the Future Symposium, available online
- **Improvement of Transmission Line Ampacity Utilization by Weather-Based Dynamic Line Rating**
  - IEEE Transactions on Power Delivery 33, no. 4
- **Using Computational Fluid Dynamics of Wind Simulations Coupled with Weather Data to Predict Dynamic Line Ratings**
  - *IEEE Transactions on Power Delivery*
- **Forecasting Dynamic Thermal Line Ratings**
  - CIGRE working group B2.59 Technical Brochure

Communication, Coordination, and Commercialization

Additional Dynamic Line Rating Accomplishments

- **DLR Report to Congress**
- **Standards –** Significant participation in IEEE and CIGRE standard working groups and task forces. PI is one of two U.S. Delegates on CIGRE Working Group B2.59: Forecasting Variable Line Ratings.
- **Publications/Awards – 10+** peer reviewed journal articles, **25+** conference proceedings, **50+** invited presentations, Best Conference Paper on Markets, Economics, and Planning (IEEE PES GM), IEEE Transactions on Power Delivery (2018); Two-time R&D 100 Award Finalist.
- **Integration with NOAA** – Initiated algorithm development for line rating forecasts with higher fidelity and accuracy using NOAA's High-Resolution Rapid Refresh (HRRR) atmospheric model.
- **Commercialization – (3)** Copyrights asserted, DOE Energy I-Corps (2x), DOE Technology Commercialization Fund (active), CRADAs, active licensees for real-time GLASS.

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ENERGY I-CORPS U.S. Department Of Energy

Mesoscale to Microscale with CFD for DLR

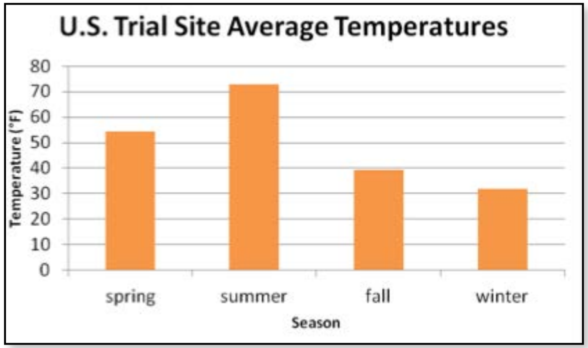
DLR Forecasting Decision Guidance

Suggested Timeline

1. Instantaneous
2. Short-term: Thermal Inertia
3. Short-term look ahead
4. Daily Peak Loading, Generation Dispatch
5. Maintenance, Power Marketing
6. Maintenance, Marketing, Construction
7. Construction, Refurbishment, Voltage Upgrades

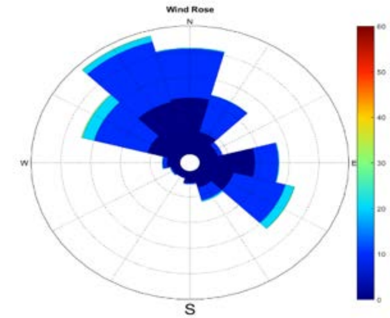
1 — 2 — 3 — 4 — 5 — 6 — 7 → Time

1. t
2. $15\min \le t \le 60\min$
3. $60\min \le t \le 4hr$
4. $4hr \le t \le 24hr$
5. $24hr \le t \le 48hr$
6. $3days \le t \le 7days$
7. $t \ge months$



Visualization Suggestions

- What to look for in forecasts
- Key Information to glean from data



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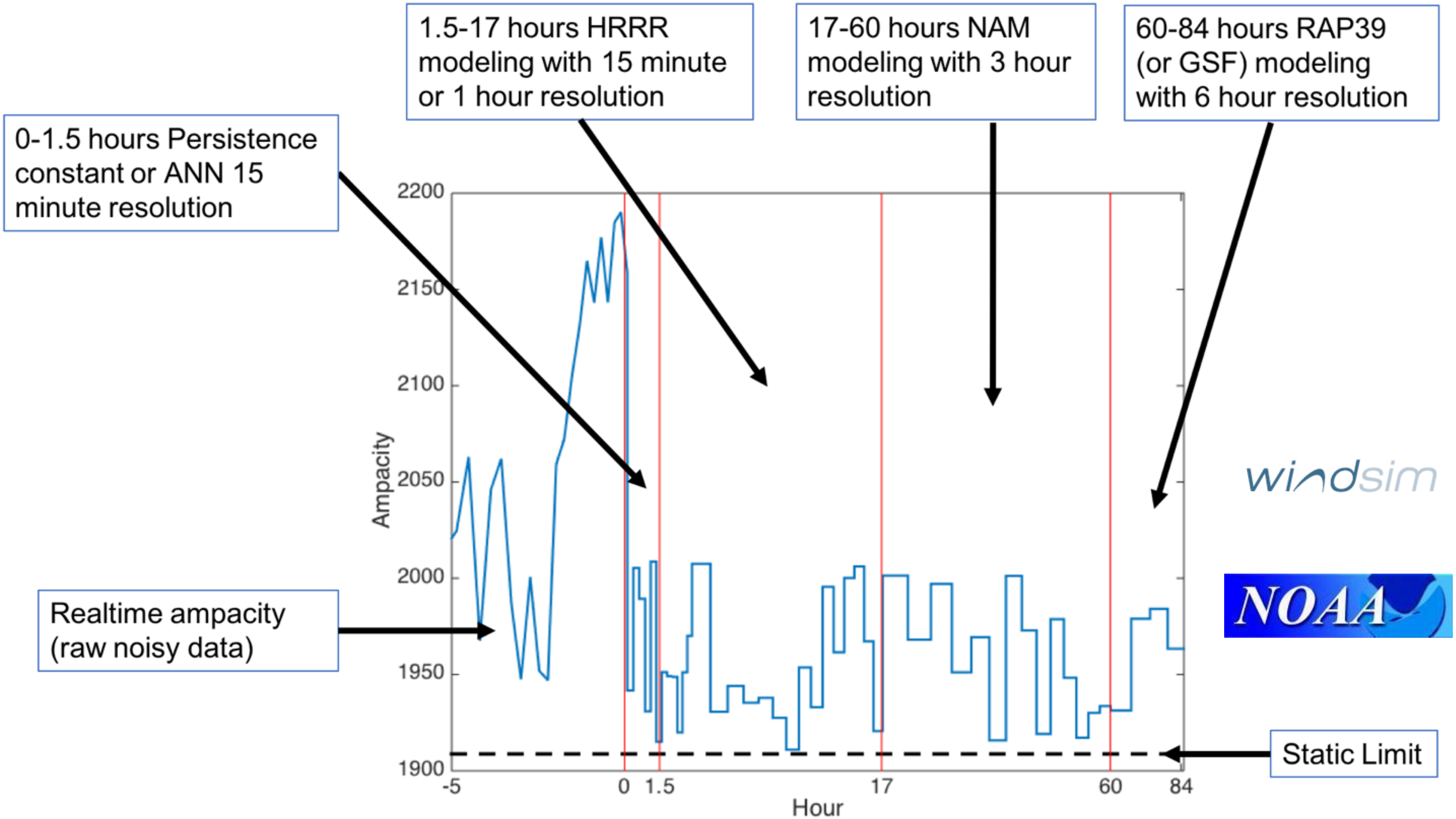
Mesoscale to Microscale with CFD for DLR

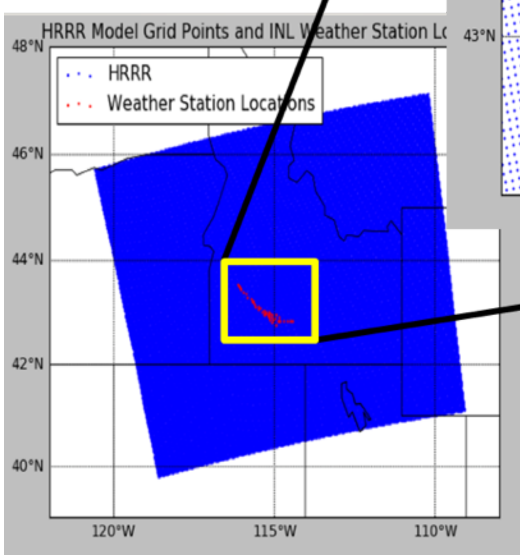
Forecasts Possibilities

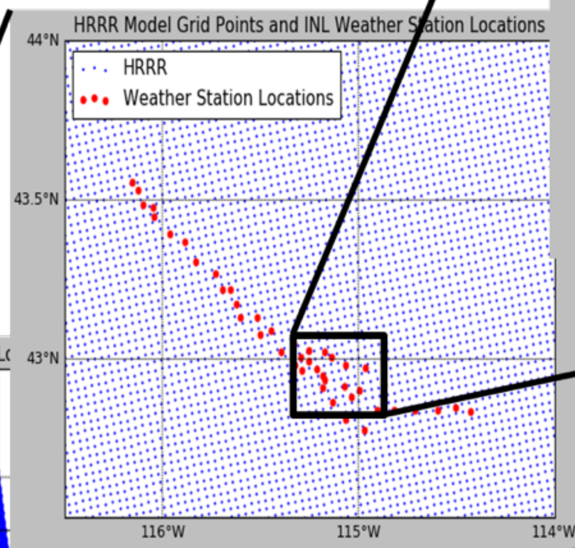


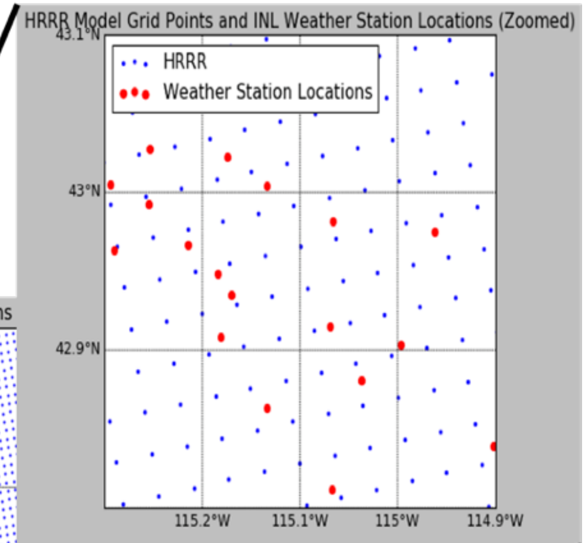
Mesoscale to Microscale with CFD for DLR

NOAA HRRR Grid and INL Collaboration Early Results

High-Resolution Rapid Refresh (HRRR)







- HRRR output is available on a 3 km grid
  - Temperature
  - Wind speed and direction
  - Insolation


INL
Idaho National Laboratory
WIND INTEGRATION R&D
Concurrent Cooling, Dynamic Line Rating
Jake P. Gentle – jake.gentle@inl.gov