WindSim Power Line

A cool way to increase power line capacity

2020 MGA and OMS Transmission Summit

November 16, 2020

Windsim & New York Power Authority

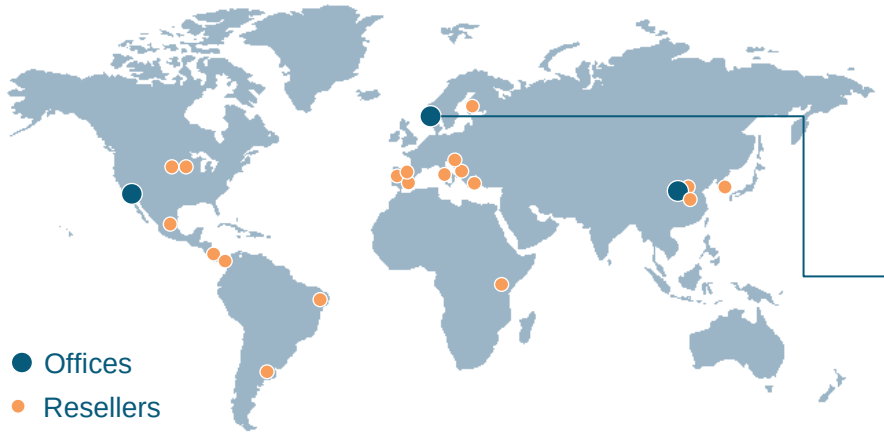
Charlton I. Clark, MSEE

windsim

NEW YORK STATE OF OPPORTUNITY. | NY Power Authority

Company overview

- Company established in 1993, privately held, ventured backed
- Value proposition - Increase power production from wind turbines through optimal placement and operation by means of wind modeling - **WIND KNOWLEDGE** | IS WIND POWER
- Business area - Software solutions, consulting services and training within wind energy assessment and wind farm simulations

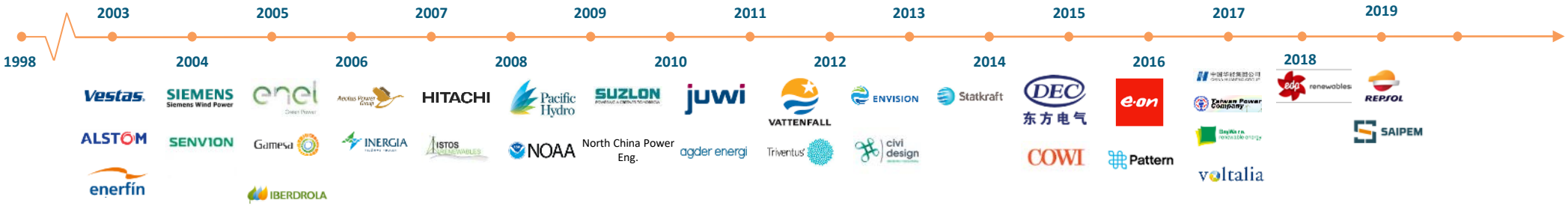


WindSim has offices in Norway (HQ), China and USA

WindSim HQ in Tønsberg, Norway

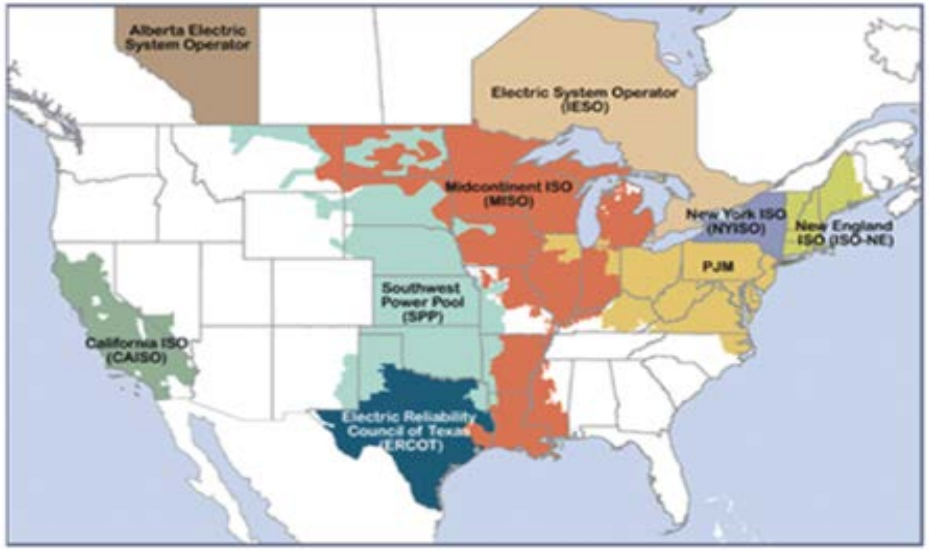
Market

- WindSim has customers in over 50 countries
- Top ten countries comprises of China, Spain, Germany, Italy, South Korea, USA, Norway, Turkey, Greece, Sweden and India
- Customer segments:
  - Turbine manufactures
  - Wind farm developers, owners and operators
  - IPPs
  - Engineering and consulting companies
  - Research institutes
  - Universities



Key customer wins

Under-utilized transmission capacity



As shown in the table below, reported congestion costs increased by 9% from 2016 to 2017, and by 22% from 2017 to 2018:

RTO	2016	2017	2018
ERCOT	497	976	1,260
ISO-NE	38.9	41.4	64.5
MISO	1,400	1,500	1,400
NYISO	529	481	596
PJM	1,023.7	697.6	1,310
SPP	273.7	405.3	380.9
Total	**3,762.3**	**4,101.3**	**5,011.3**

Table 1: Transmission Congestion Costs ($ millions) for RTOs from 2016-2018

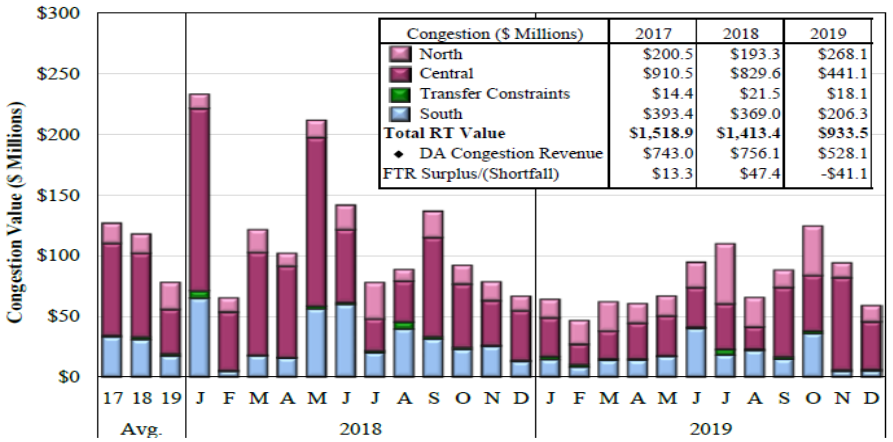
- **U.S. Congestion costs ~ 6B/year.**
- Renewable energy curtailment
- Grid reliability (N-1 contingencies)
- Suboptimal generation dispatch
- Asset utilization (sag, clearance violations, etc.)
- Inefficiencies cost the consumer

What is the cost of Congestion?

"…if transmission owners develop and submit ratings adjusted for temperature or other relevant ambient conditions, they would allow MISO to operate to higher transmission limits and achieve substantial production costs savings."

2019 MISO State of the Markets Report

Figure 24: Value of Real-Time Congestion and Payments to FTRs
2018–2019



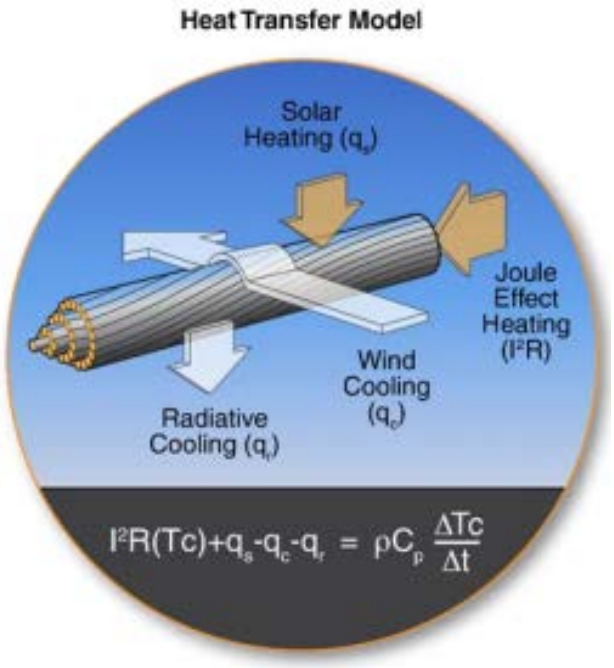
Congestion ($ Millions)	2017	2018	2019
North	$200.5	$193.3	$268.1
Central	$910.5	$829.6	$441.1
Transfer Constraints	$14.4	$21.5	$18.1
South	$393.4	$369.0	$206.3
Total RT Value	**$1,518.9**	**$1,413.4**	**$933.5**
◆ DA Congestion Revenue	$743.0	$756.1	$528.1
FTR Surplus/(Shortfall)	$13.3	$47.4	-$41.1

Table 8: Benefits of Ambient-Adjusted and Emergency Ratings
2018–2019

		Savings ($ Millions)			# of Facilites for 2/3 of Savings	Share of Congestion
		Ambient Adj. Ratings	Emergency Ratings	Total		
Total Estimated Benefits						
2018	Midwest	$77	$48	$125	19	12.7%
	South	$7	$18	$25	2	7.1%
	Total	**$85**	**$66**	**$150**	**21**	**11.2%**
2019	Midwest	$62	$36	$98	18	14.5%
	South	$4	$12	$16	3	8.0%
	Total	**$66**	**$48**	**$114**	**21**	**13.0%**

https://www.potomaceconomics.com/wp-content/uploads/2020/06/2019-MISO-SOM_Report_Final_6-16-20r1.pdf

Static Vs. Dynamic Line Rating Methodology



Static rating

Static rating considers a worst-case scenario of conditions or historical averages for calculating a steady state declared transmission capacity of a line

- High temperature
- Low wind speed
- High solar radiation

Ambient Adjusted rating

Ambient Adjusted rating uses current air temperature for calculating capacity

- Air temperatures

Dynamic rating

Dynamic rating uses actual operating conditions to calculate the capacity of lines. Parameters includes

- Air temperatures
- Wind speed
- Wind direction
- Solar radiation

How Weather Affects Heat Transfer Equations

- Heat balance of convective cooling, radiative heat loss, joule heating solar heating
- In order to solve the steady state equation, we need:

$$I = \sqrt{\frac{q_c + q_r - q_s}{R(T_C)}}$$

$$T_{film} = \frac{T_s + T_a}{2}$$

$$q_{c1} = K_{angle} \cdot \left[1.01 + 1.35 \cdot N_{Re}^{0.52}\right] \cdot k_f \cdot (T_s - T_a)$$

$$q_{c2} = K_{angle} \cdot 0.754 \cdot N_{Re}^{0.6} \cdot k_f \cdot (T_s - T_a)$$

$$q_{cn} = 3.645 \cdot \rho_f^{0.5} \cdot D_0^{0.75} \cdot (T_s - T_a)^{1.25}$$

$$N_{Re} = \frac{D_0 \cdot \rho_f \cdot V_w}{\mu_f}$$

$$k_f = 2.424 \cdot 10^{-2} + 7.477 \cdot 10^{-5} \cdot T_{film} - 4.407 \cdot 10^{-9} \cdot T_{film}^2$$

$$K_{angle} = 1.194 - \cos(\phi) + 0.194 \cdot \cos(2\phi) + 0.368 \cdot \sin(2\phi)$$

$$\rho_f = \frac{1.293 - 1.525 \cdot 10^{-4} \cdot H_e + 6.379 \cdot 10^{-9} \cdot H_e^2}{1 + 0.00367 \cdot T_{film}}$$

$$\mu_f = \frac{1.458 \cdot 10^{-6} \cdot (T_{film} + 273)^{1.5}}{T_{film} + 383.4}$$

$$q_r = 17.8 \cdot D_0 \cdot \varepsilon \cdot \left[\left(\frac{T_s + 273}{100}\right)^4 - \left(\frac{T_a + 273}{100}\right)^4\right]$$

$$q_s = \alpha \cdot Q_{se} \cdot \sin(\theta) \cdot A'$$

$$R(T_{avg}) = \left[\frac{R(T_{high}) - R(T_{low})}{T_{high} - T_{low}}\right] \cdot (T_{avg} - T_{low}) + R(T_{low})$$

$$\theta = \arccos\left[\cos(H_c) \cdot \cos(Z_c - Z_1)\right]$$

$$\delta = 23.46 \cdot \sin\left[\frac{284 + N}{365} \cdot 360\right]$$

$$H_c = \arcsin\left[\cos(Lat) \cdot \cos(\delta) \cdot \cos(\omega) + \sin(Lat) \cdot \sin(\delta)\right]$$

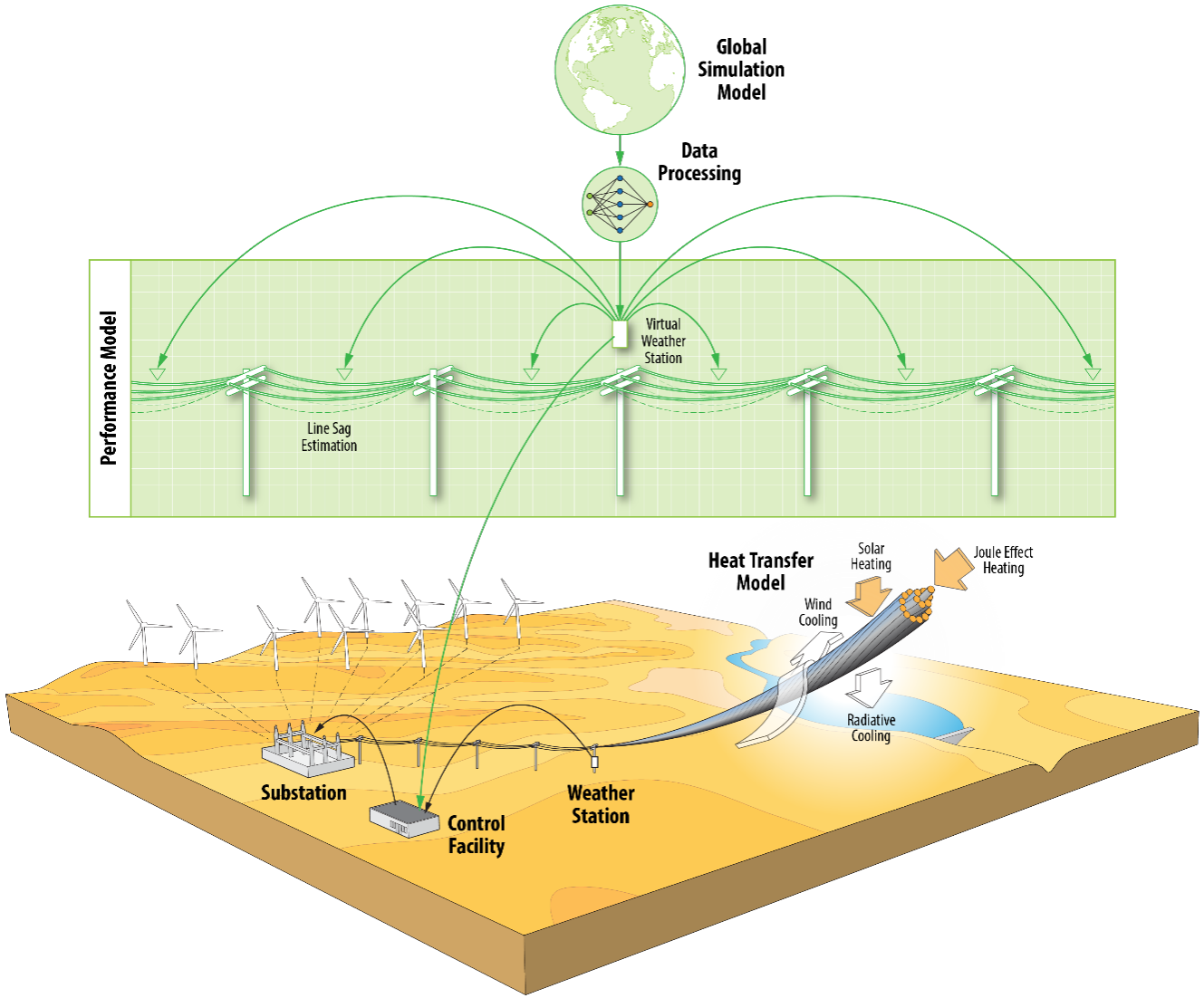
$$Z_c = C + \arctan(\chi)$$

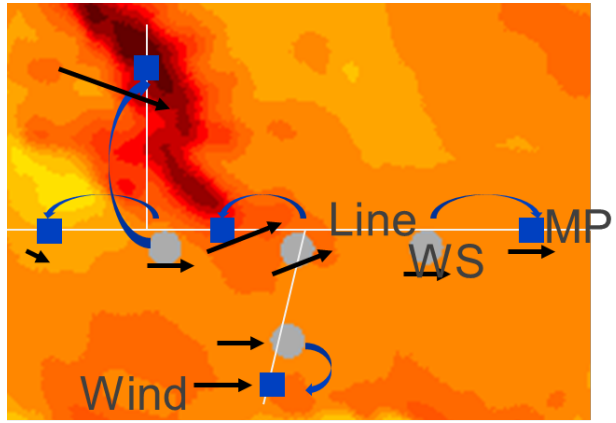
$$\chi = \frac{\sin(\omega)}{\sin(Lat) \cdot \cos(\omega) - \cos(Lat) \cdot \tan(\delta)}$$

Where weather enters the equations directly

WindSim Power Line – Available Now

Computational Fluid Dynamics Informed Weather Based Dynamic Line Rating





Use CFD to calculate relative speed and direction from measured (or forecasted) locations to spans

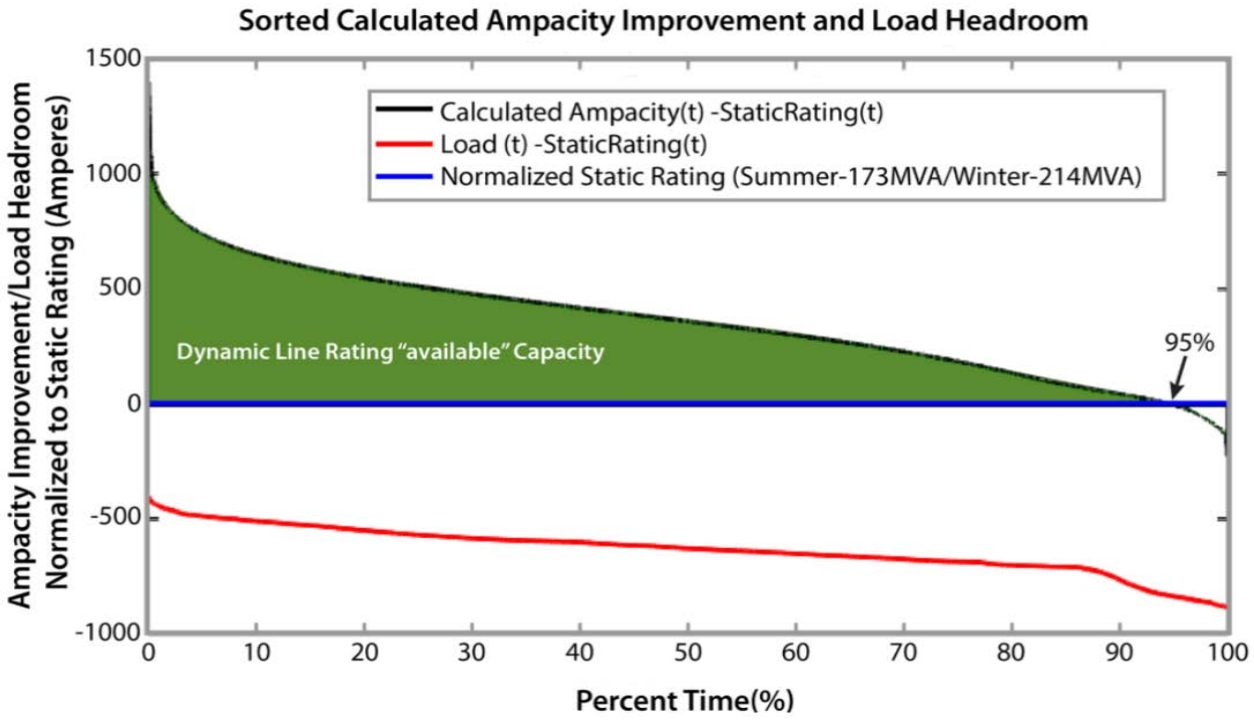
https://youtu.be/X8IaVYN6tUw

Two-time Finalist for R&D 100 Awards (2017, 2018)

Our past performance

The Dynamic Line Rating Pilot is complete. The concept of using computational fluid dynamics augmented weather based dynamic line rating was proven successful as documented in the paper submitted by INL to the CIGRÉ US National Committee 2018 Grid of the Future Symposium. The results of the pilot were presented to Idaho Power in 2018. The usefulness of DLR has been demonstrated and has the potential to be a tool to be used by the Idaho Power System Planning and Load Serving Operations departments when additional line capability is needed.

https://docs.idahopower.com/pdfs/aboutus/companyinformation/smartgrid/2019OregonSmartGridReport_Final.pdf



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.

Our Products

“Right-sizing” of windfarm interconnections

- Build only what you need

Full-scale Dynamic Line Rating Integration

- Actionable information for system operators and transmission owners
- Line sag calculation
- “Hot-spot” identification

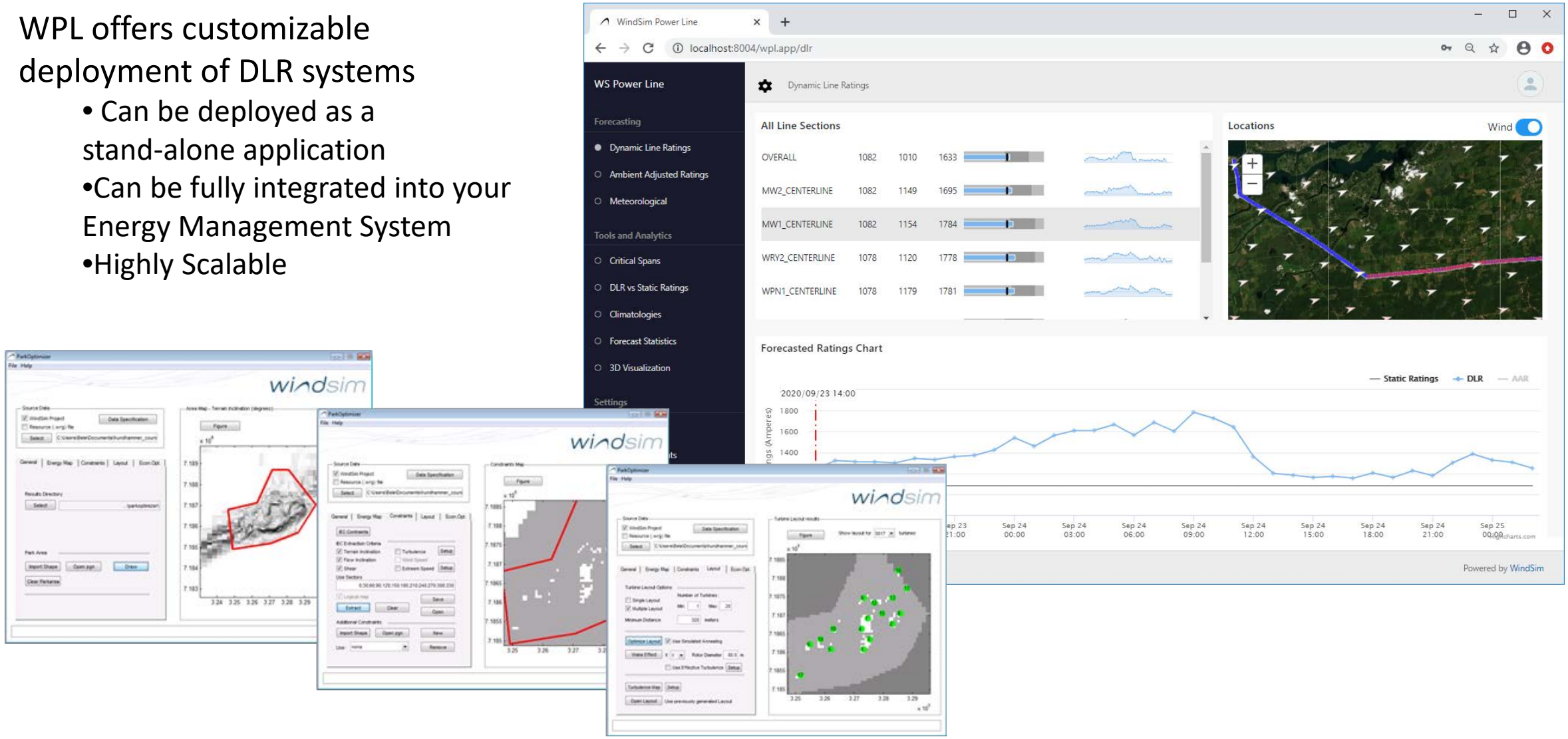
DLR Forecasting

- Merging DLR with electricity market operations

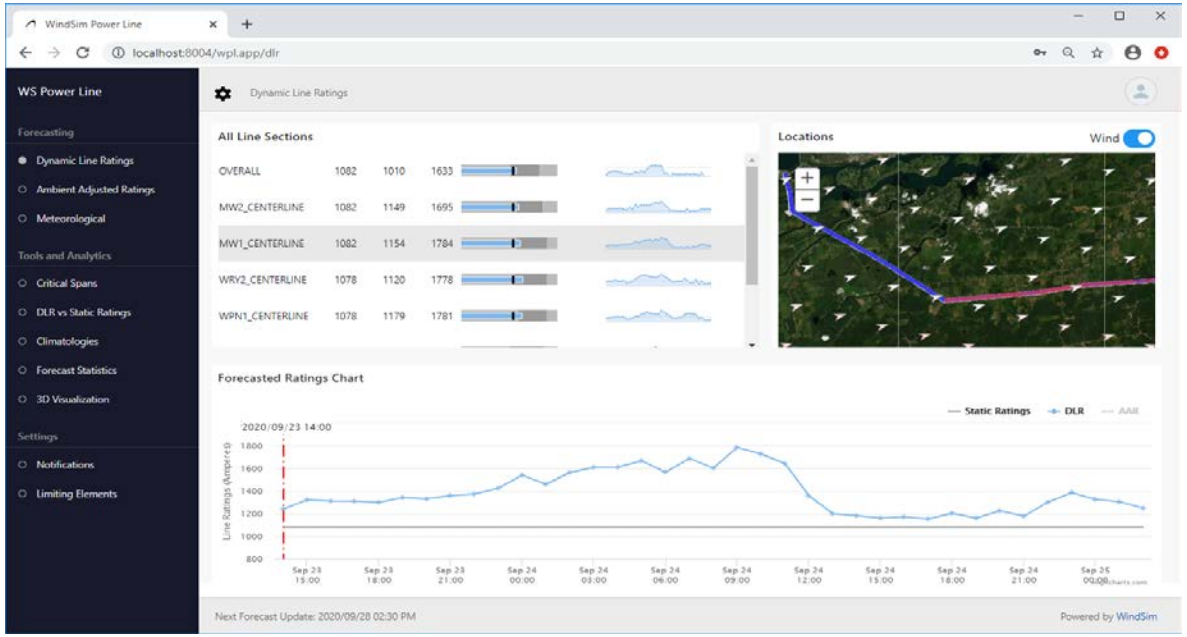
Our Products - Full-scale Dynamic Line Rating Integration

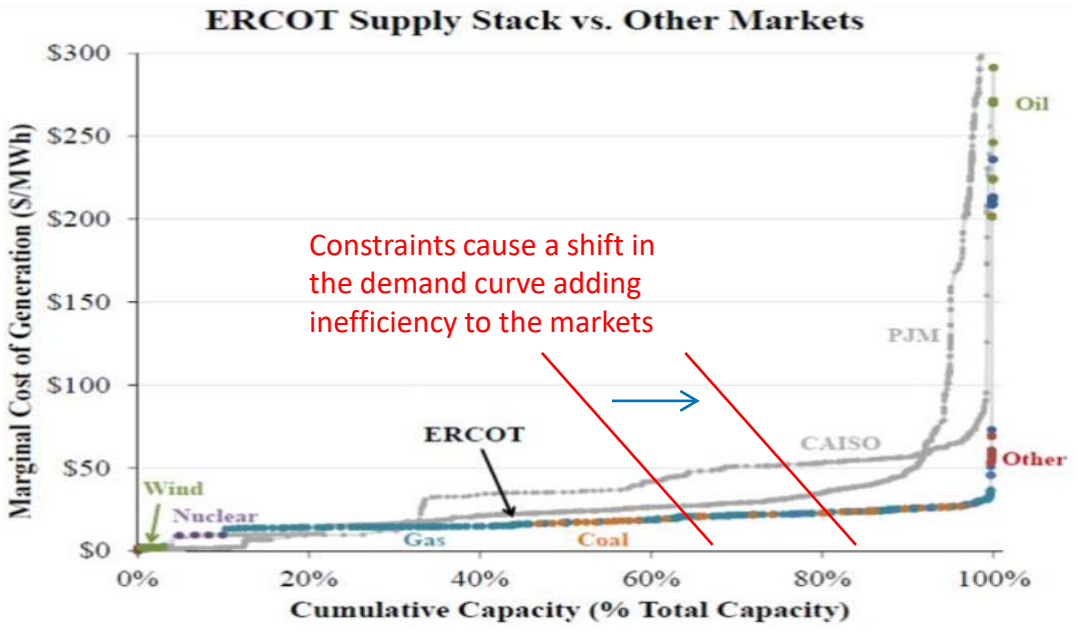
WPL offers customizable deployment of DLR systems

- Can be deployed as a stand-alone application
- Can be fully integrated into your Energy Management System
- Highly Scalable



Our Products - Dynamic Line Rating Forecasting





The optimum application of DLR can only be achieved if it can impact electricity markets in the day-ahead time-frame

- WPL's use of large-scale weather forecasts allows us to estimate additional capacity in a time-frame to make useful

NYPA Pilot Project | Funded by NYSERDA

- **About NYSERDA**

The New York State Energy Research and Development Authority, known as NYSERDA, promotes energy efficiency and the use of renewable energy sources. These efforts are key to developing a less polluting and more reliable and affordable energy system for all New Yorkers. Collectively, NYSERDA's efforts aim to reduce greenhouse gas emissions, accelerate economic growth, and reduce customer energy bills.

- **Demonstrate a WindSim Computational Fluid Dynamics (CFD)-enhanced forecast /real-time transmission line rating system** that provides more stable line ratings and helps enhance the capacity of existing transmission infrastructure.
- **Validate the DLR forecasting** methodology into a utility's operational environment, specifically validating that reliably forecasted line ratings are possible using available weather forecasts and CFD enhanced weather analytics.
- **Improve system planning and operations** by providing an optimized forecasting solution
  - Many of the transmission lines were built back in the 60s and 70s, and with growing electricity demand there are bottlenecks in the transmission system

Transmission line evaluated in NYPA/WindSim project. The lines extend approximately **72 miles (114 km).**

The nearby river to the north, mountains to the south, nearby lakes, and dense vegetations influence the wind fields and will likely pose some challenges to the wind field modelling.

New York Power Authority History and Charter

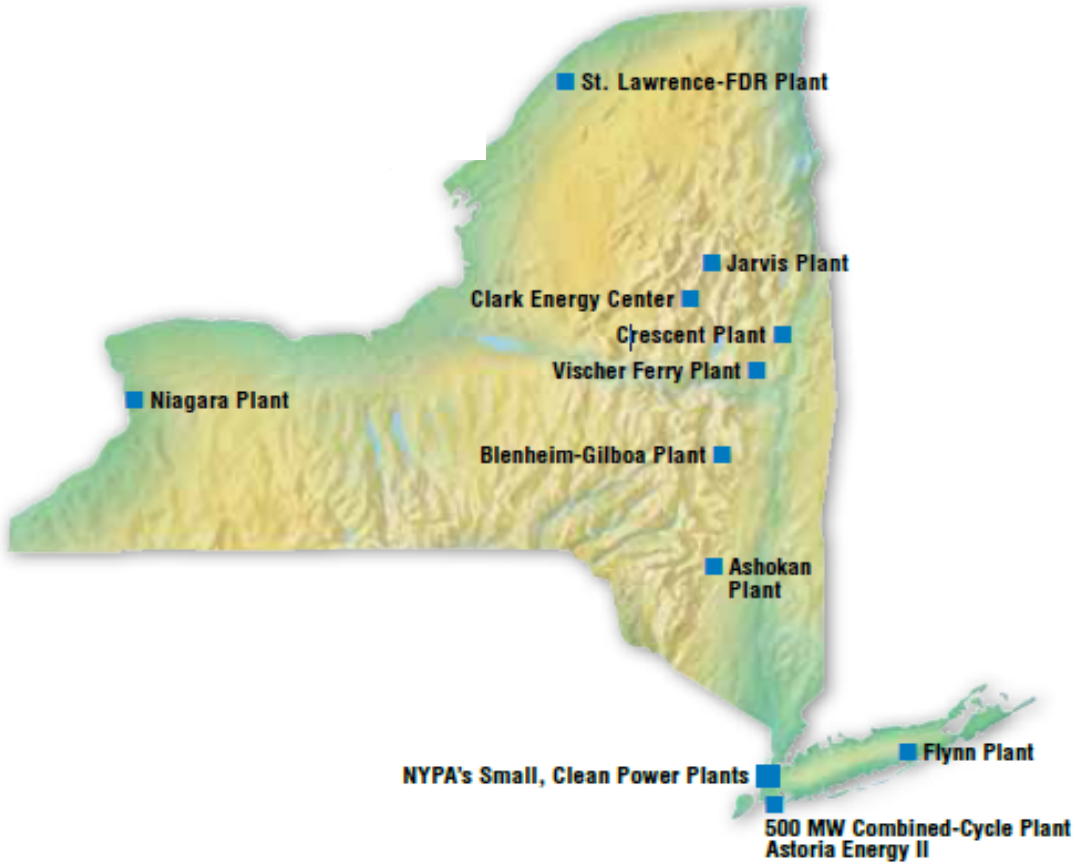
- Established by the NY State Legislature in 1931.
- Largest state public electric utility in the United States.
- Wholesale power supplier throughout New York State and neighboring states as required by law.
- Provides, with generation and power purchases, about 25% of New York State's electricity. No Distribution System
- 2018 Net Generation: 30.1 million MWh; 70% hydro; 30% gas/oil
- Transmission lines: 1,400+ circuit miles; 115kV, 230kV, 345kV & 765kV
- New York State Canals is a subsidiary
- Non-profit energy corporation, does not use tax revenues or state credits, finances projects through bond sales and cash from operations
- Model for TVA

New York Power Authority Transmission

- 765 kV Transmission **~155 circuit miles**
- 345 kV Transmission, **~928 circuit miles**
- 230 kV Transmission, **~338 circuit miles**
- 115 kV Transmission, **~35 circuit miles**
- Total Transmission, **~1,456 circuit miles**
- Bulk Transmission Substations
  21 substations
- Portion of Bulk NYS Grid
  ~13% (>115kV)
  ~34% (>230kV)

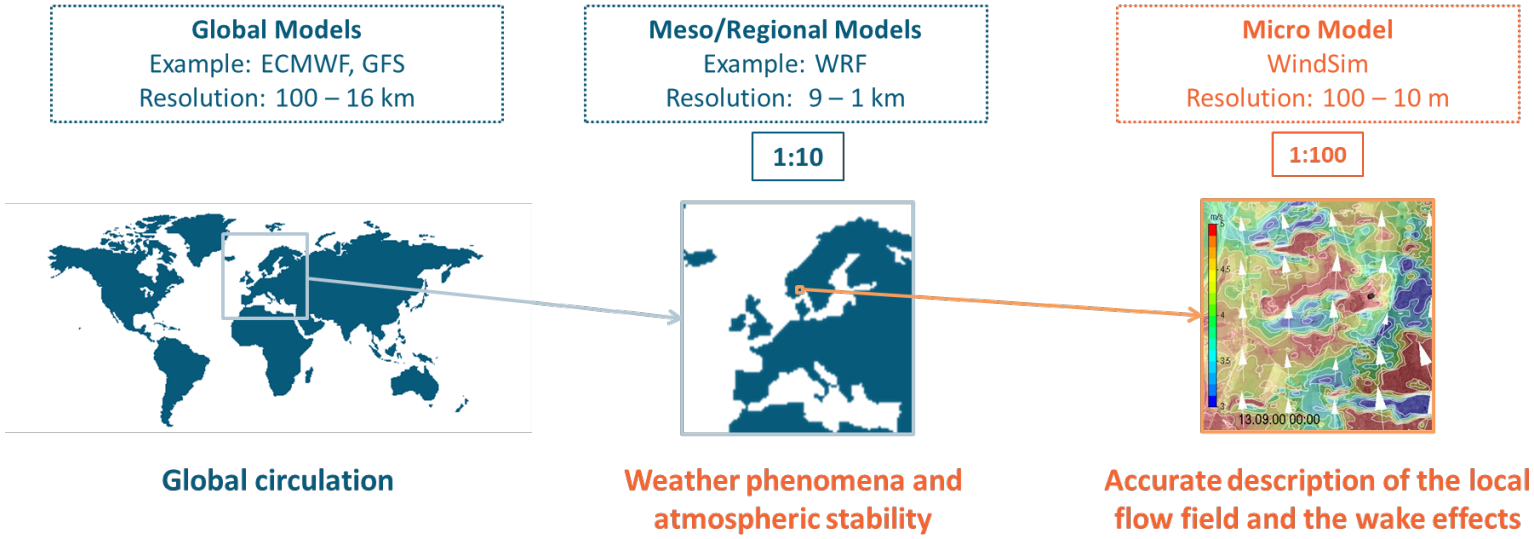
New York Power Authority Generation

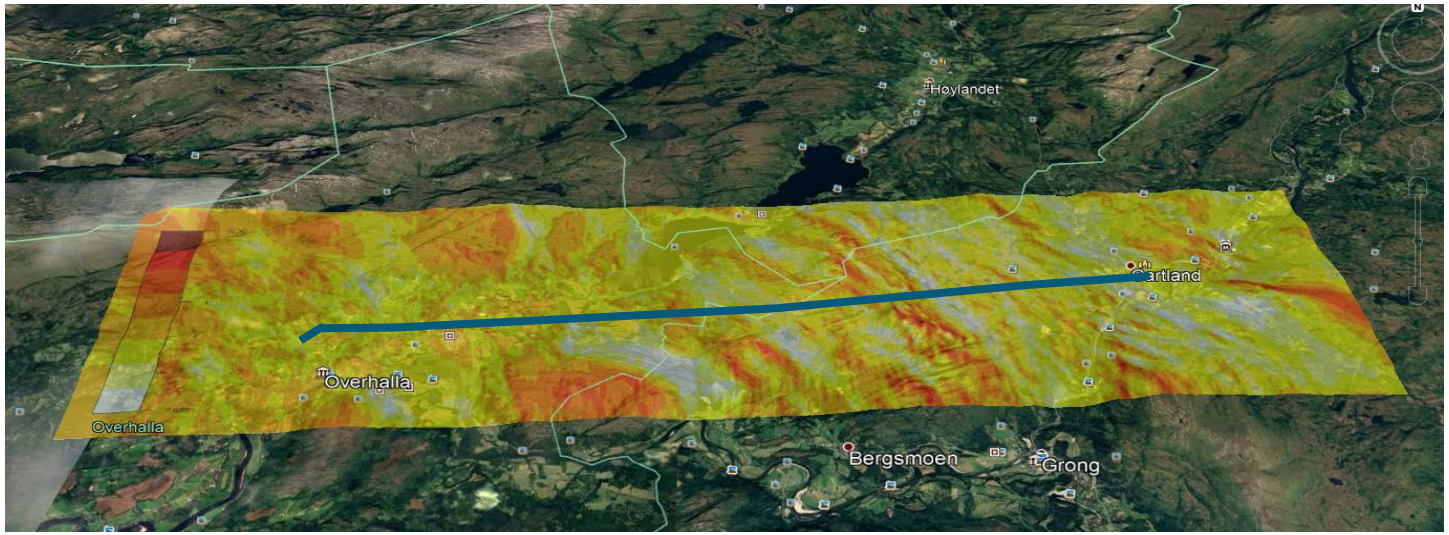
- Niagara Power Project **~2,675 MW**
- St. Lawrence Power Project, **~800 MW**
- Blenheim-Gilboa, **~1,160 MW**
- Flynn Power Plant, **~167 MW**
- Astoria CC Plant, **~500 MW**
- Small Hydro Plants, **~83 MW**
- Small Clean Power Plants, **~461 MW**



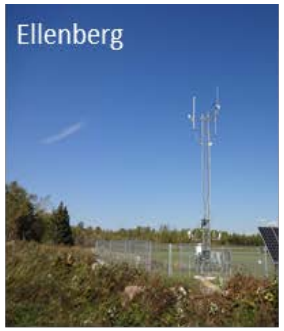
Forecasting Dynamic Line Ratings

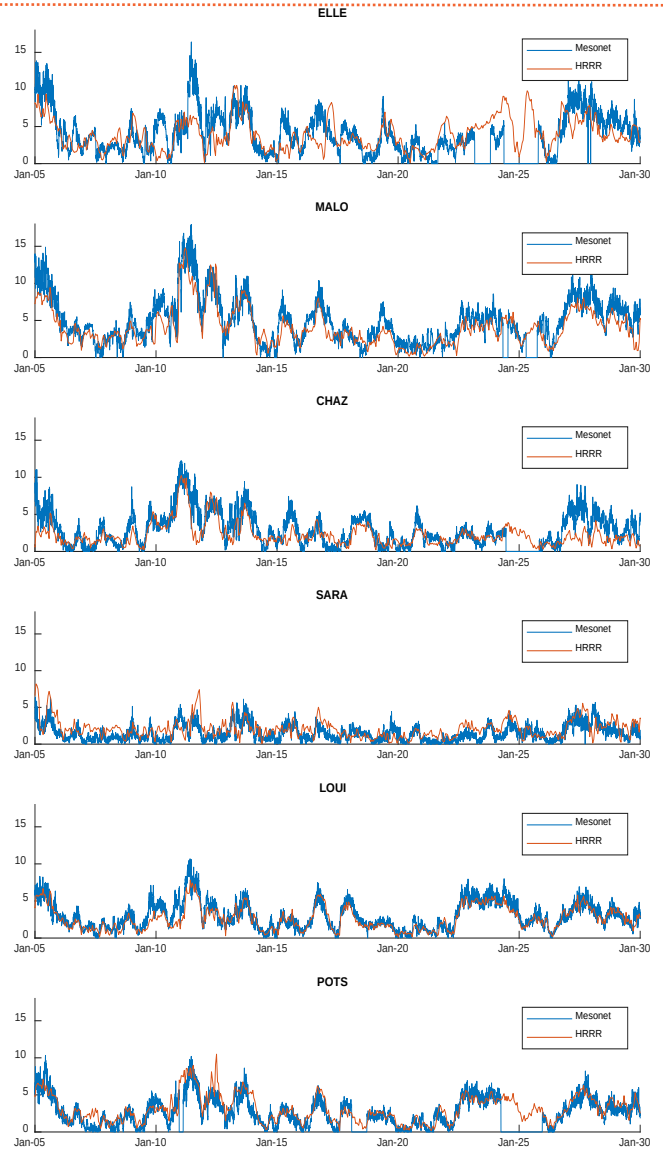
- DLR requires a high-resolution wind forecast
- Global and Meso/Regional Models cannot capture the detailed wind variability required for DLR.
- Micro Models are produced in WPL to yielding a DLR forecast.
- DLR forecasts are produced for every span.
- The **limiting** span contributes to the overall DLR value for the entire line.





Initial Assessment Using Publicly Available Monitoring Data

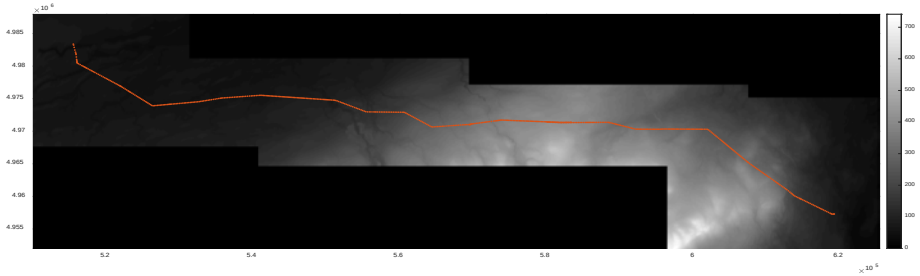




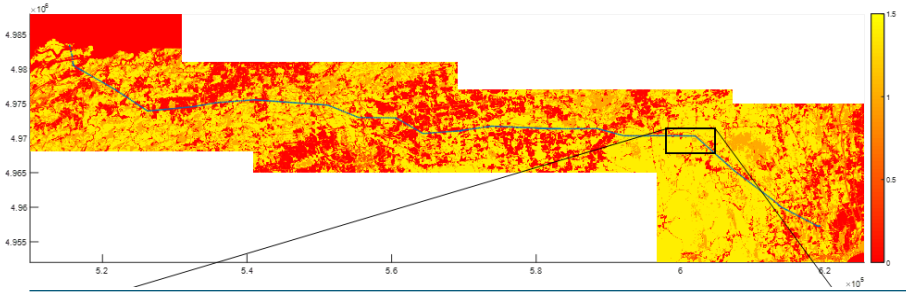
Data Collection and Initial Assessments – Full Year 2017

Transmission lines – Satellite view

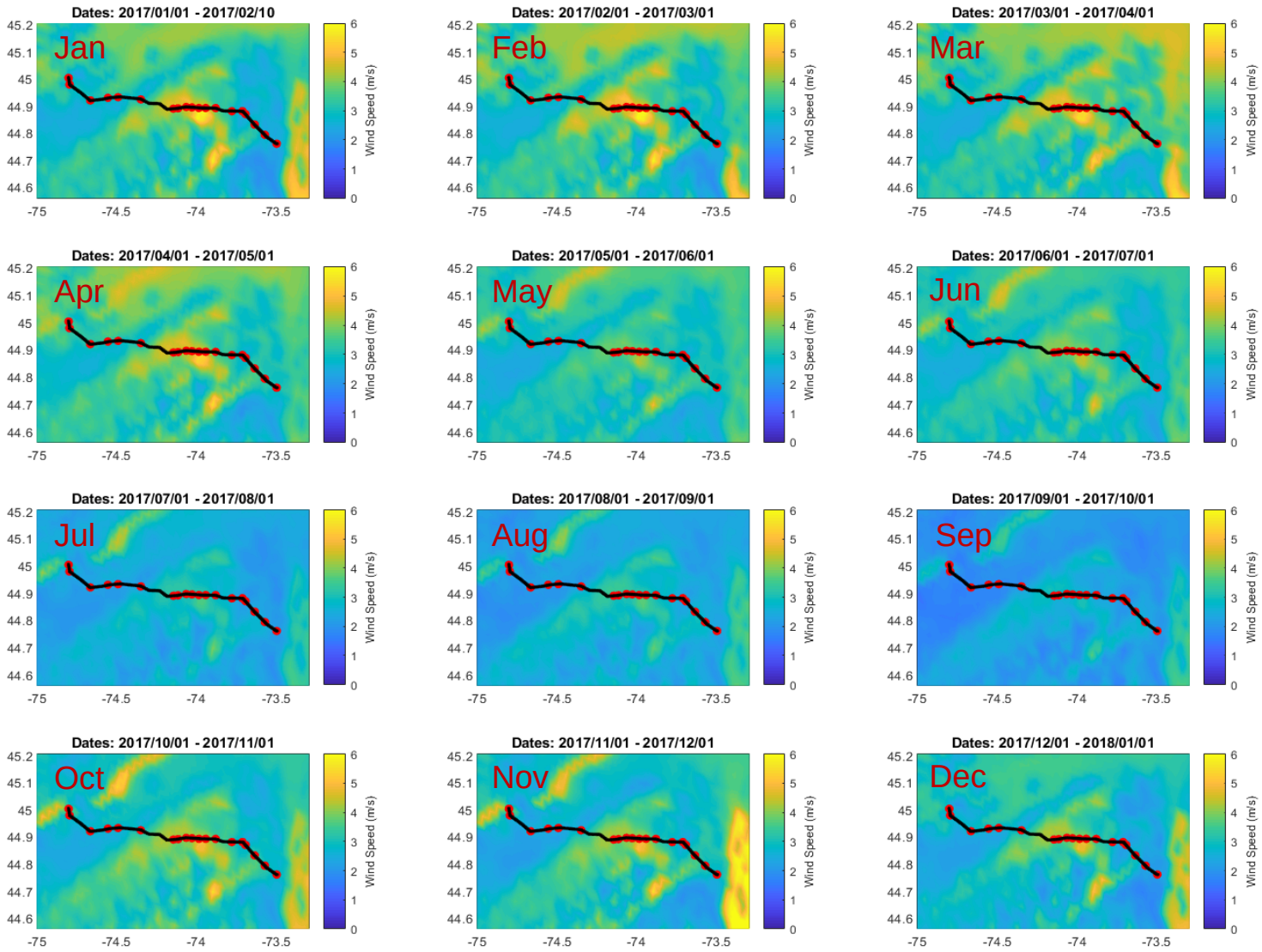
Terrain Elevation



Surface Roughness

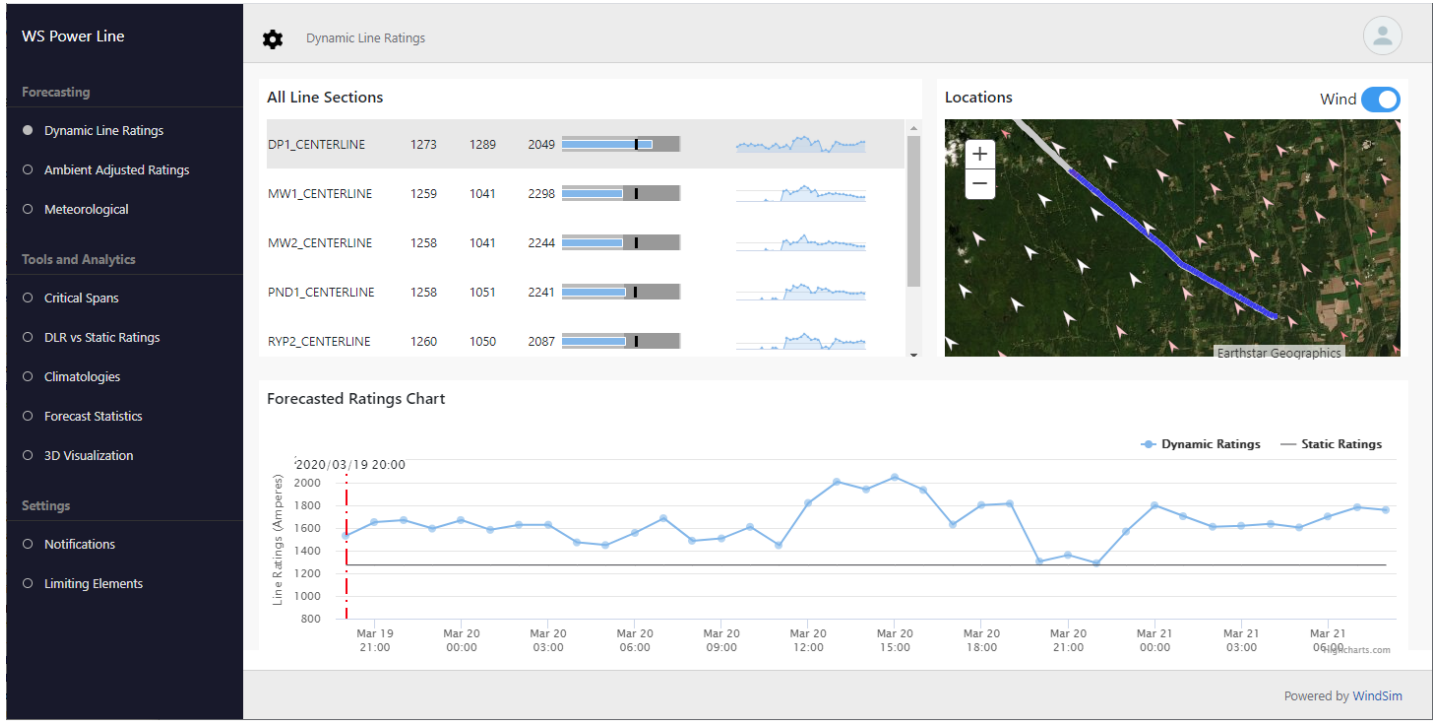


Wind Fields Averaged By Month



Initial Results

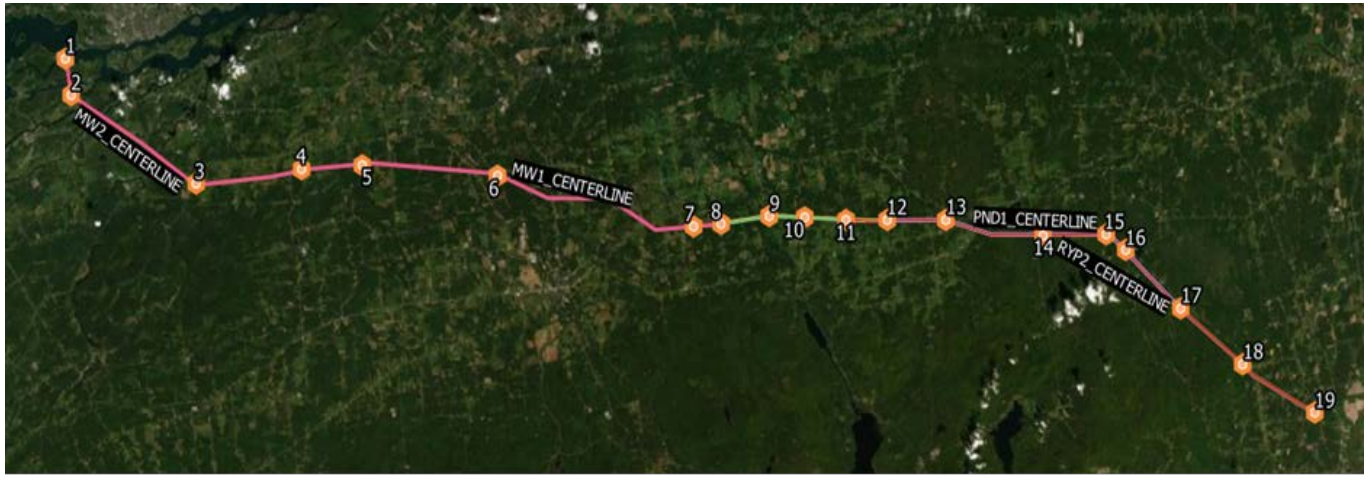
- WPL installed on a local test server in NYPA
- Modeling is based on initial data sets. Further model calibration will be done when stations are installed.
- Forecasts are produced for 36 hours ahead every 4 hours
- Includes **Dynamic Line Ratings and Ambient Adjusted Ratings**
- Includes Forecasted Weather
- Enables view of critical spans based on the time-step

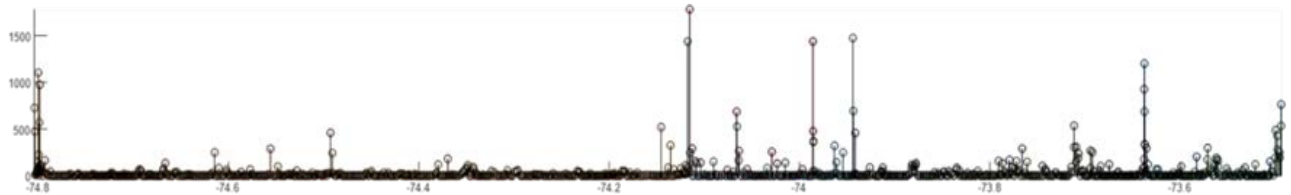


WPL web user interface for end-users to view forecasted dynamic and ambient adjusted ratings, meteorological data, and other statistical information.

Next Steps

- **Install Weather Monitoring Stations**
  - 17 Weather stations will be available
- **Further calibrate CFD models**
  - Ideal density is about 1 weather station every 2-10 miles, depending on terrain
- **Uncertainty Assessment**
  - For prediction intervals, e.g. 95%
- **Evaluate Multiple Mesoscale Forecast Services**
  - Currently using HRRR
  - Project will consider other forecast service providers





Frequency of limiting span counts. A count is based on an instance when the span was limiting (had the lowest value). This figure was produced in HRRR data over the year 2017.

Thank you

WindSim Power Line

http://windsim.com/power-line/windsim-power-line.aspx

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