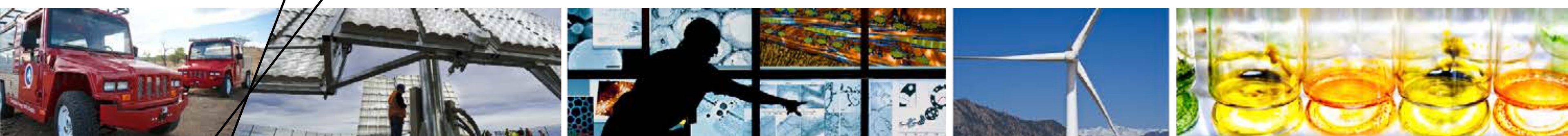
Combining Wind Plant Control With Systems Engineering



2015 Wind Energy Systems Engineering Workshop, Boulder, Colorado

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National Renewable Energy Laboratory

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Overview

- **Wind plant controls research**
- **Combining optimization**
- **Case study: Princess Amalia Wind Park**
- **Conclusions.**

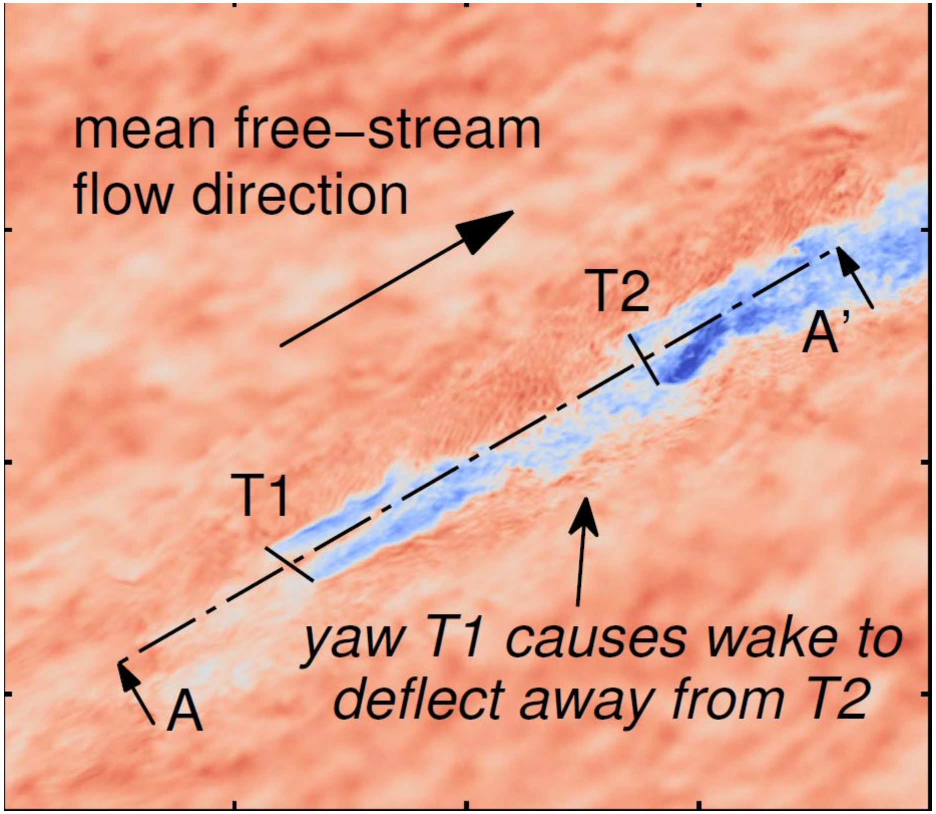
Wind Plant Control

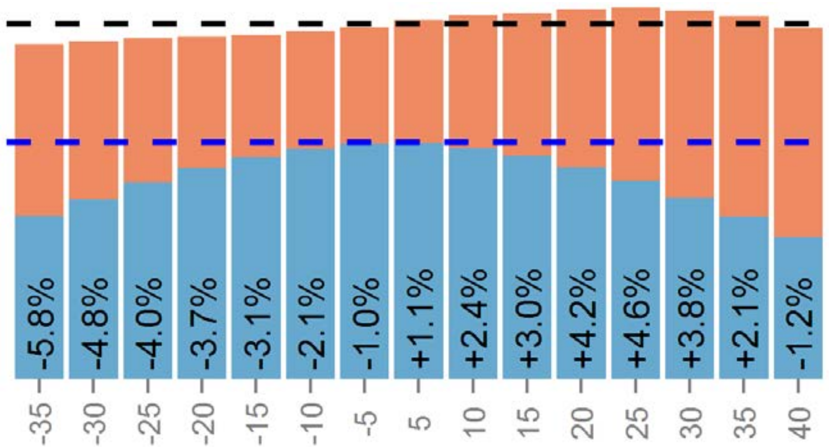
- **Recent research has focused on improving wind plant performance by coordinating the control of individual turbines.**

Photo from Uni-Fly A/s

Yaw-Based Wake Redirection Control

- **One promising approach uses intentional yaw misalignment to redirect wakes away from downstream turbines.**

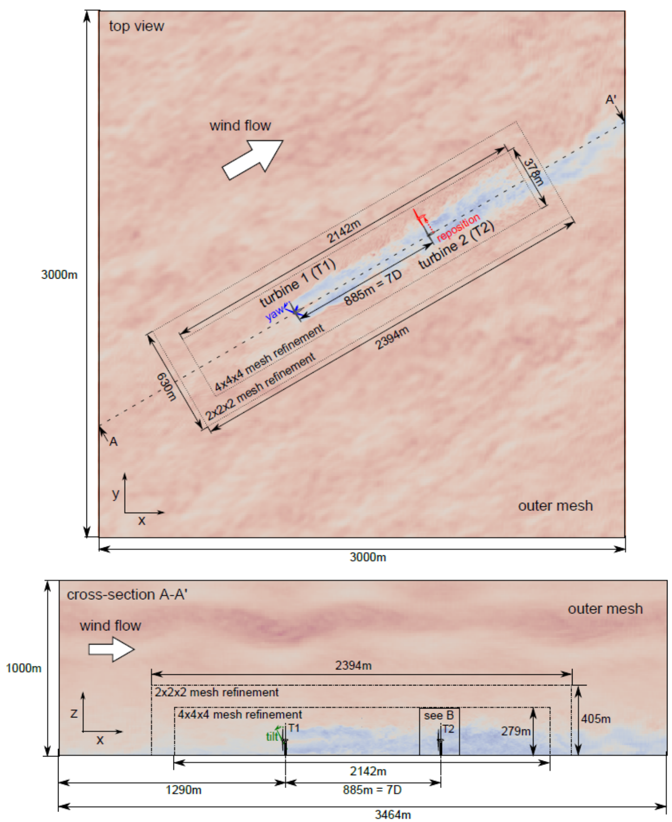


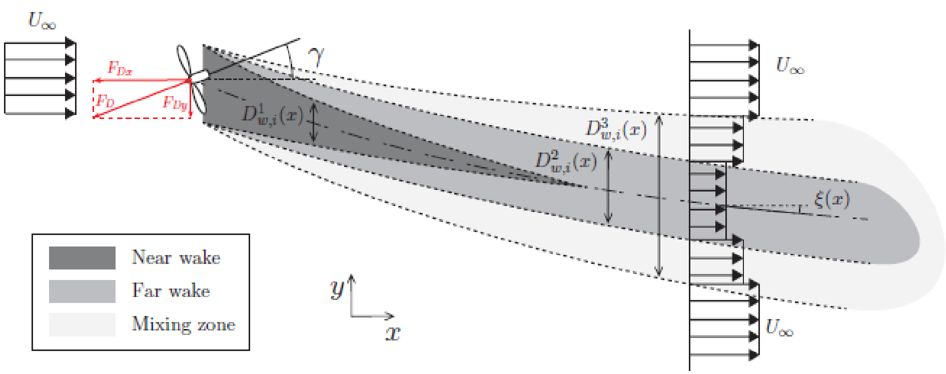


Illustrations from Fleming, P.; Gebraad, P.; Lee, S.; van Wingerden, J.W.; Johnson, K.; Churchfield, M.; Michalakes, J.; Spalart, P.; Moriarty, P. (2014). "Simulation comparison of wake-mitigation control strategies for a two-turbine case." *Wind Energy.*

Model Development

- Work has used high-fidelity simulation to study the control systems (Simulator for On/Offshore Wind Farm Applications, or SOWFA)
- Additionally, control-oriented engineering models have been developed for control design (FLOw Redirection and Induction in Steady-state, or FLORIS).





Gebraad, P. M. O.; Teeuwisse, F. W.; van Wingerden, J. W.; Fleming, P. A.; Ruben, S. D.; Marden, J. R.; Pao, L. Y. (2014). “Data-Driven Model for Wind Plant Power Optimization by Yaw Control.” *Proceedings of the 2014 American Control Conference (ACC)*; June 4-6, 2014, Portland, Oregon. NREL/CP-5000-61405. Piscataway, NJ: Institute of Electrical and Electronics Engineers; pp. 3128-3134.

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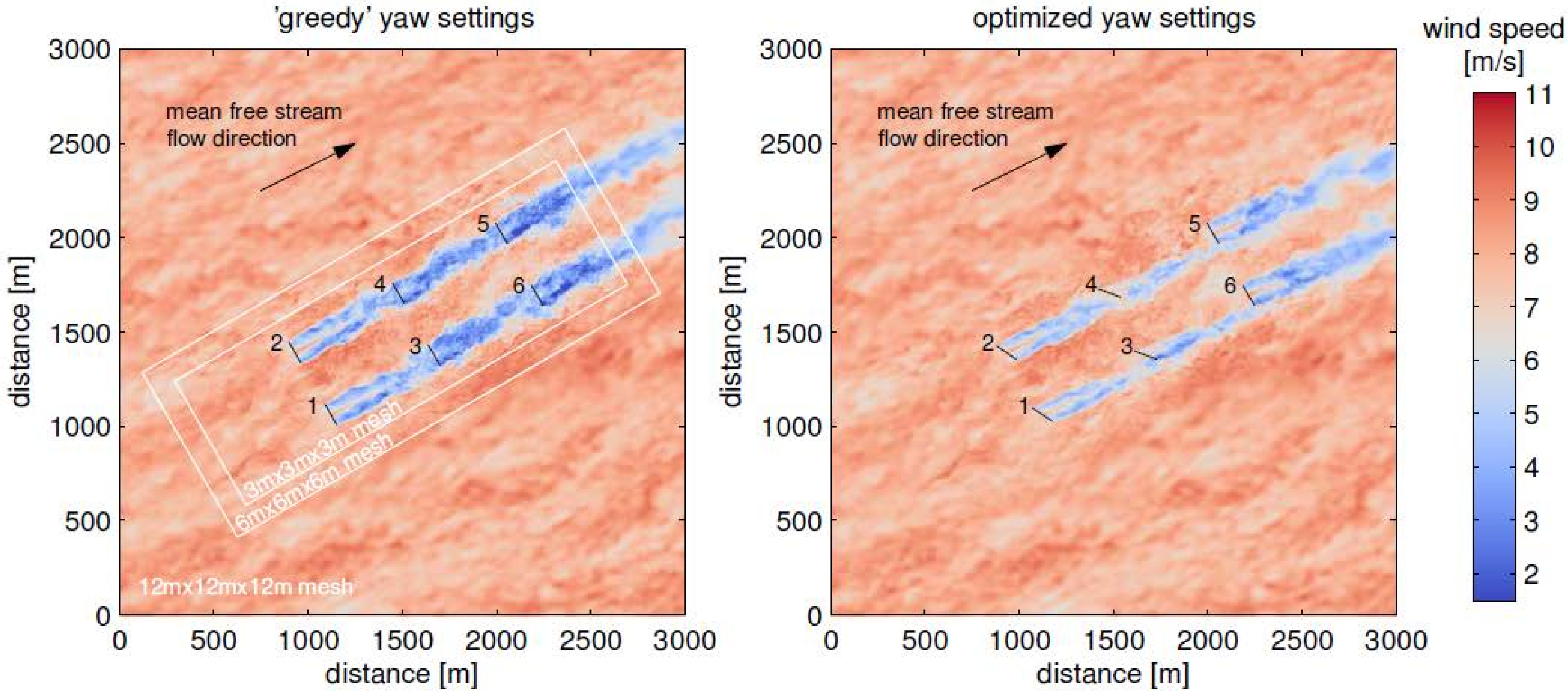
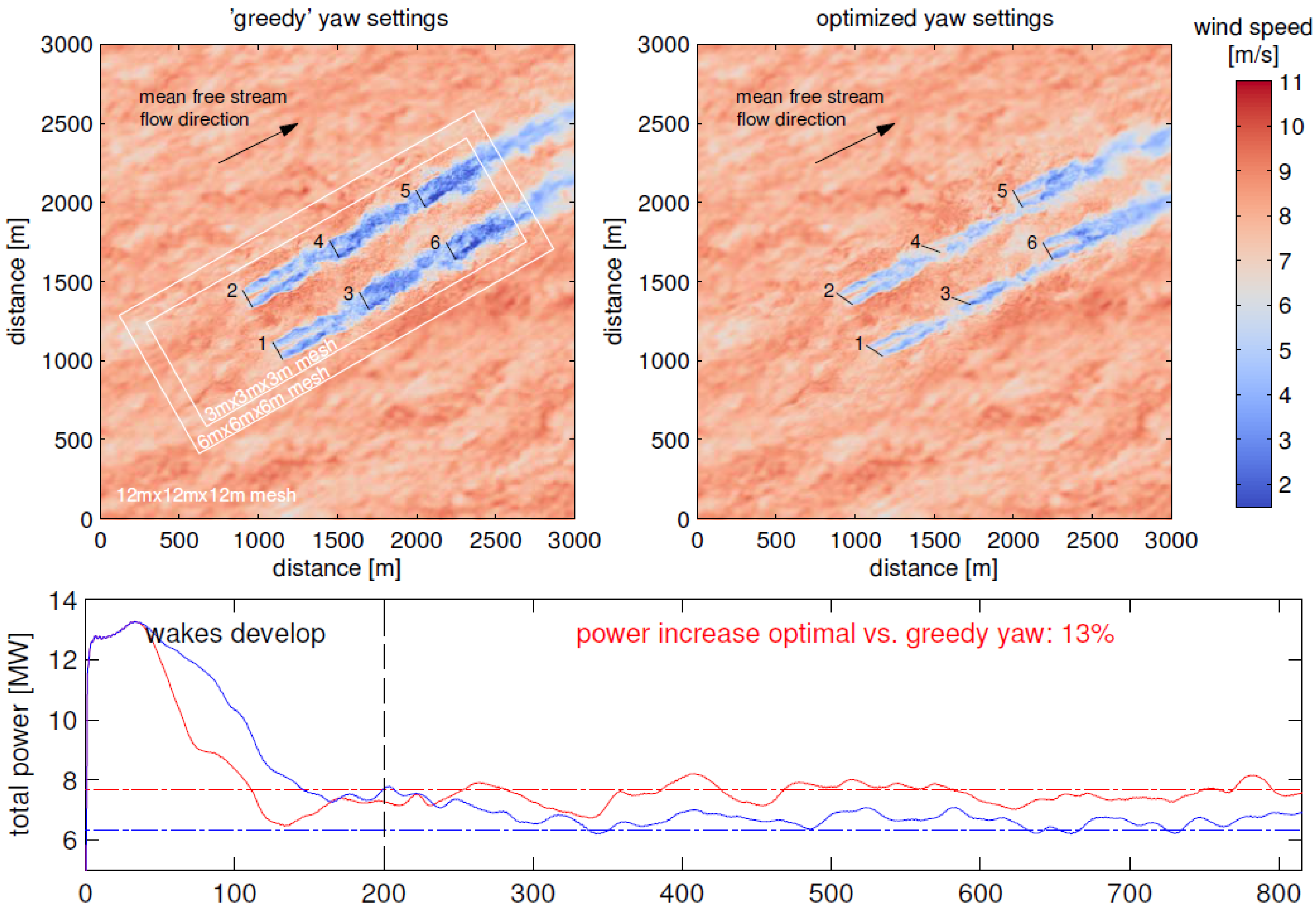
Model-Based Control

- **Using engineering-level model:**
  - Optimize yaw angles within this model.
- **Test selected values in SOWFA.**



Model-Based Control



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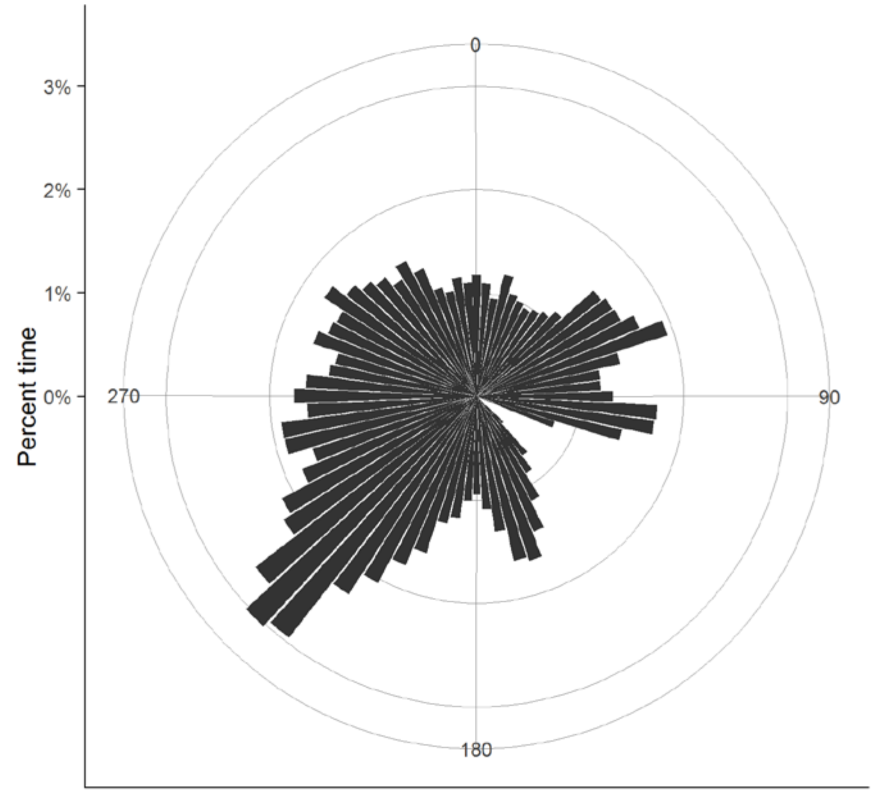
Combined Optimization

- The previous work assumes a fixed plant layout, turbine design, and so on
- Perhaps the benefit of wind plant control could be amplified if accounted for during the early phase of design
- In this work, a proof-of-concept study was performed in which wind plant controls and layout were optimized.

Case Study: Princess Amalia Wind Park

- **Given baseline layout of real wind plant, compare:**

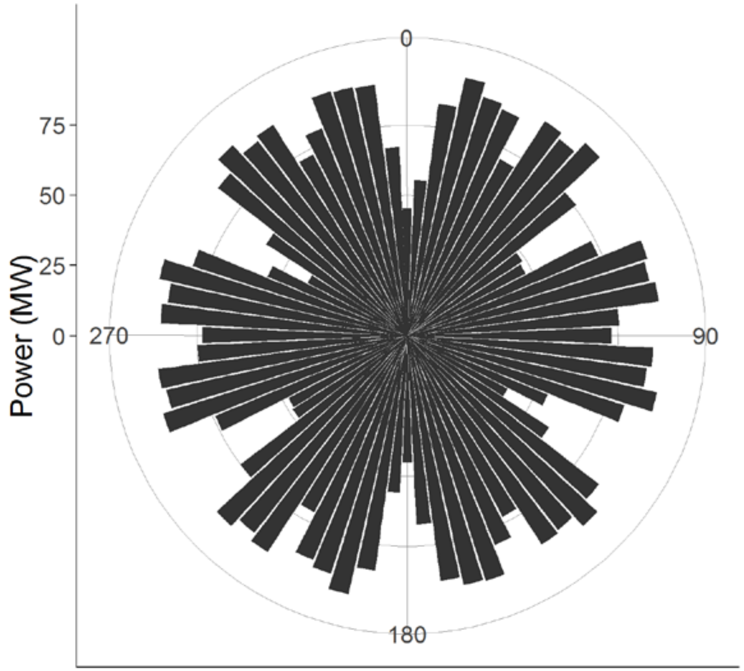
- **Baseline**: fixed (original) positions, turbines all yawed in mean wind direction
- **Optimized yaw**: fixed (original) positions, turbines optimally yawed for each wind direction
- **Optimized location**: position optimized, turbines all yawed in mean wind direction
- **Combined optimization**: simultaneously optimized position and yaw for each wind direction.



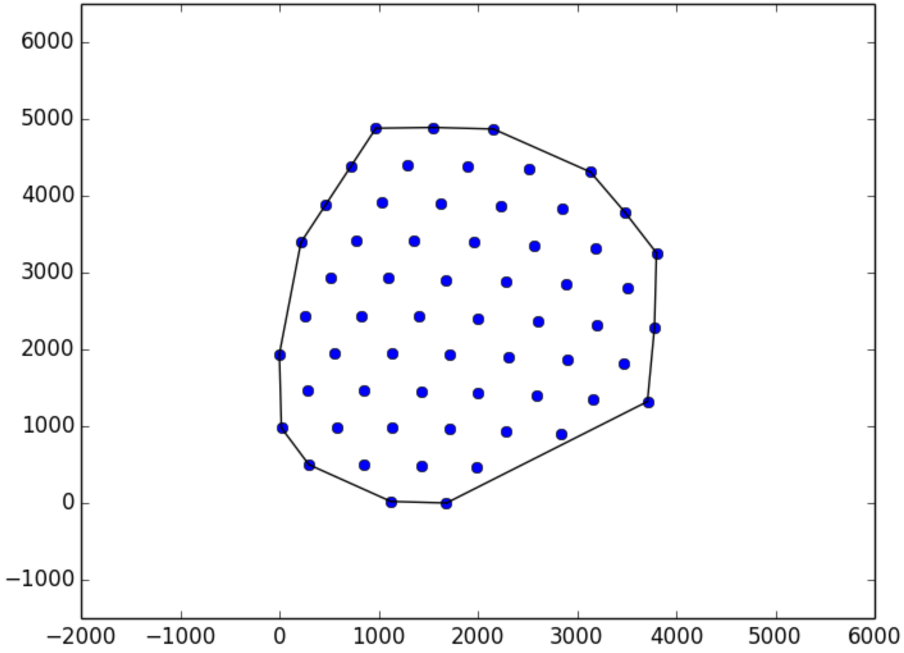
- **Use as a proxy metric of COE the power density of the wind farm (W/m^2)**
- **Note 1: Full paper (under review in Wind Energy) considered cable length and boundary limitations as well**
- **Note 2: NREL's 5-megawatt (MW) turbines were used in place of ~2-MW turbines, making baseline spacings closer**
- **Note 3: All following figures from upcoming full paper.**

Baseline

Power Output



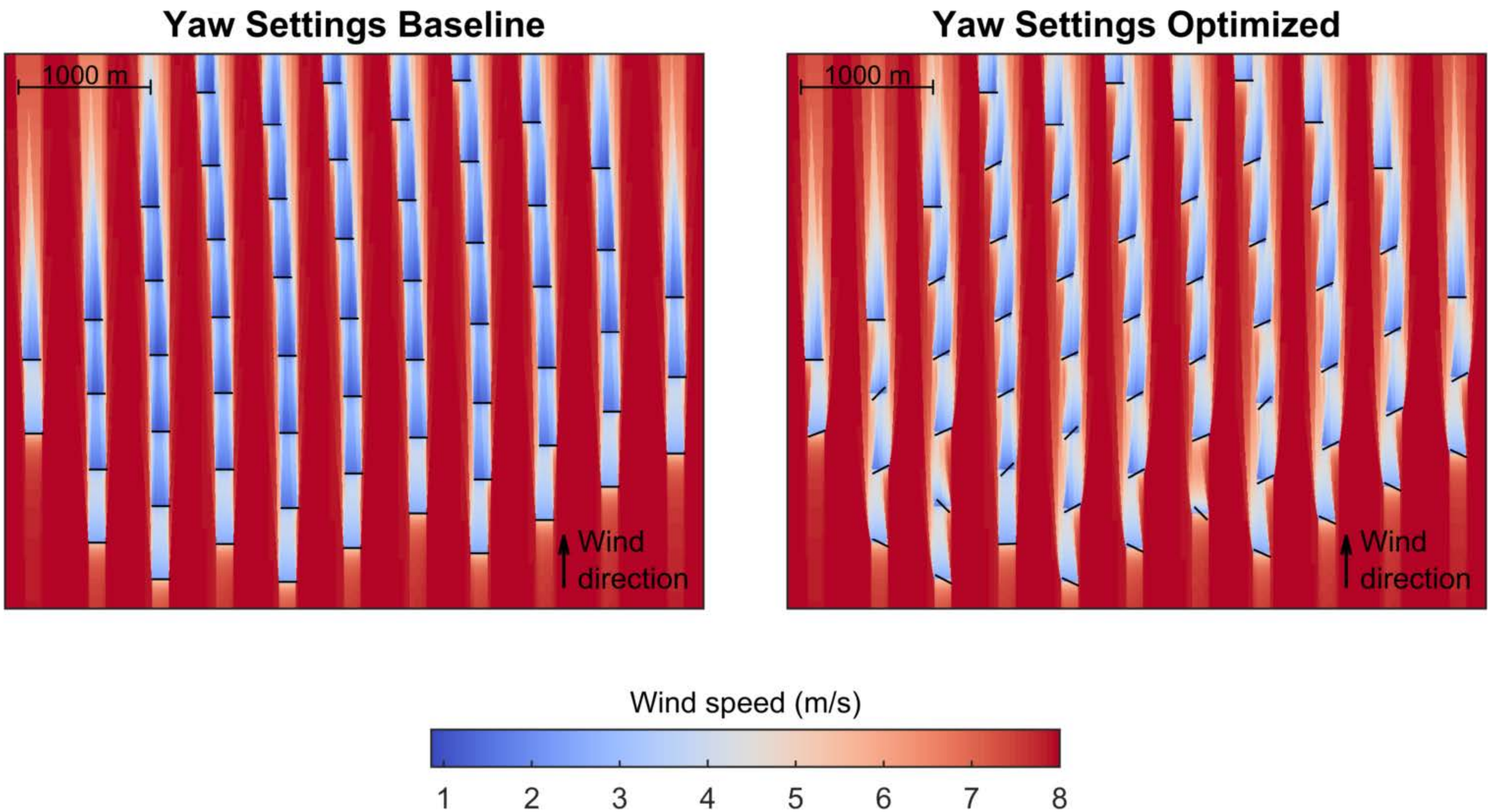
Layout



	Baseline
Mean power (MW)	78.86
Area (km^2)	14.53
Power density (W/m^2)	5.43

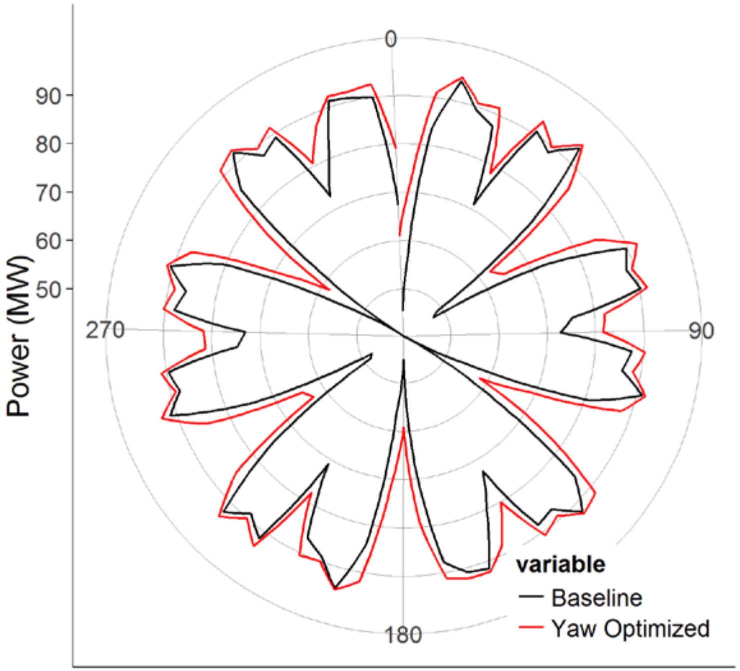
Yaw Control

Optimized yaw angles for the 180^o case

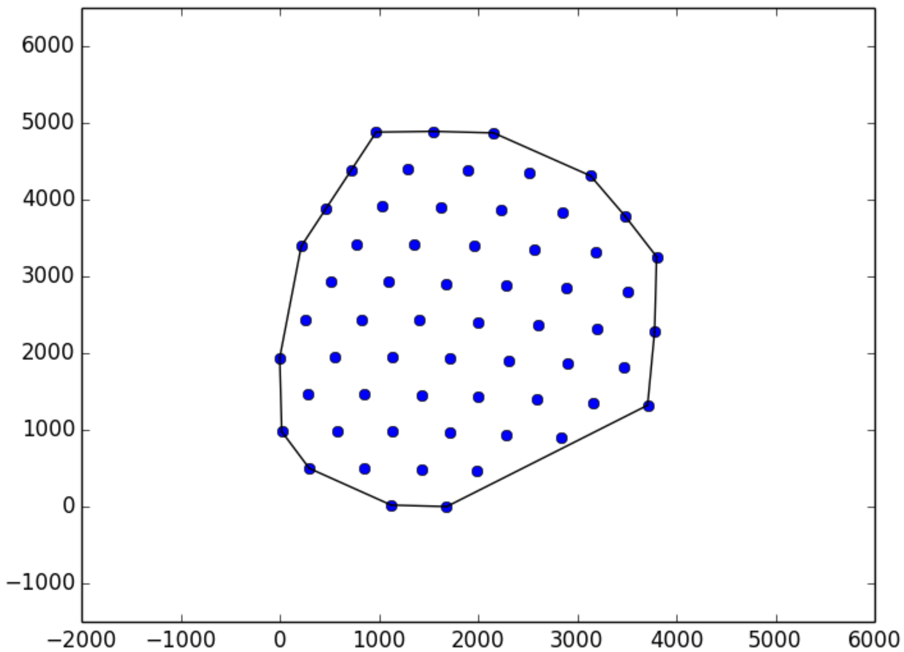


Yaw Control

Power Output



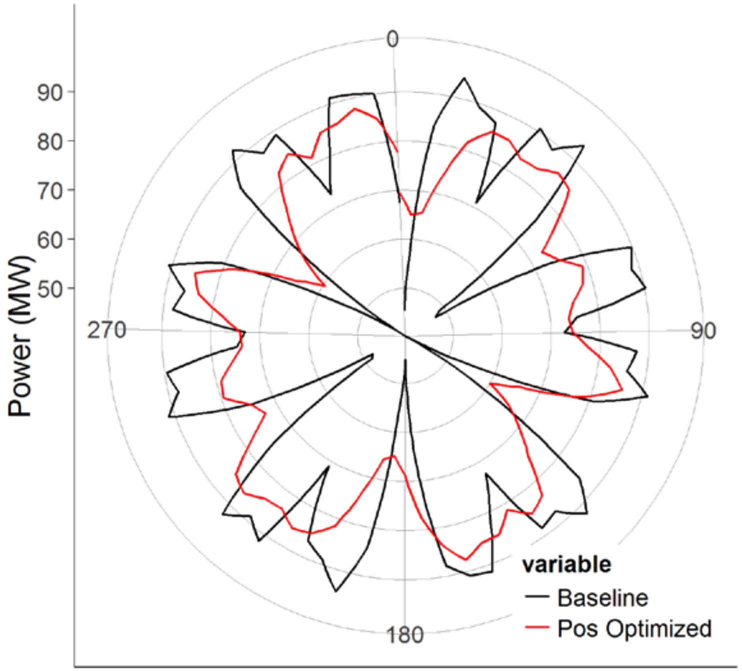
Layout

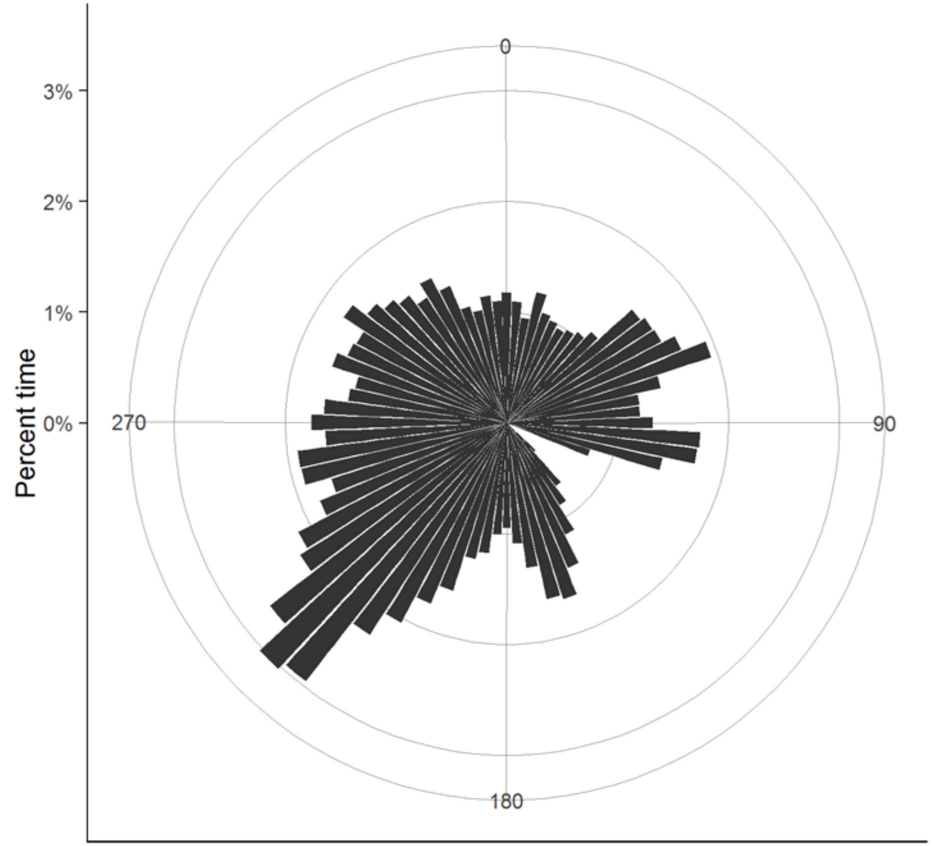


	Baseline	YawOpt
Mean power (MW)	78.86	84.91
Area (km^2)	14.53	14.53
Power density (W/m^2)	5.43	5.84

Layout Optimization

Power Output

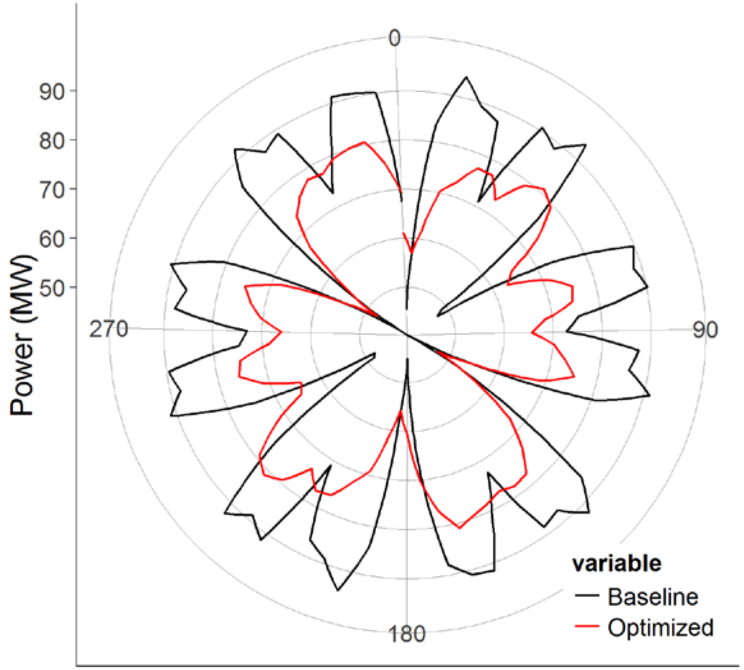




	Baseline	YawOpt	PosOpt
Mean power (MW)	78.86	84.91	78.86
Area (km^2)	14.53	14.53	12.45
Power density (W/m^2)	5.43	5.84	6.33

Combined Optimization

Power Output



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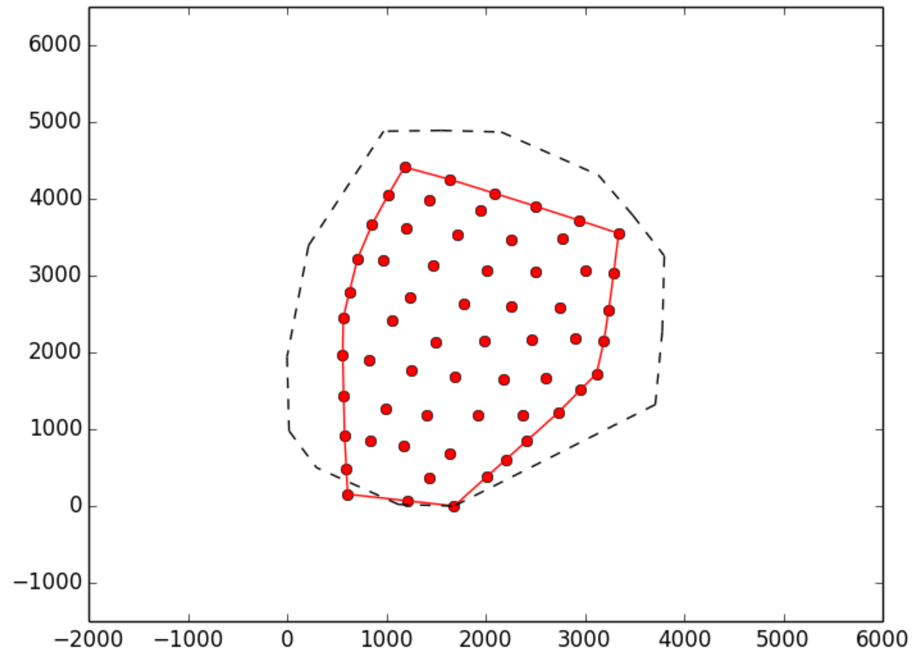

	Baseline	YawOpt	PosOpt	Combined
Mean power (MW)	78.86	84.91	78.86	78.84
Area (km^2)	14.53	14.53	12.45	8.96
Power density (W/m^2)	5.43	5.84	6.33	8.80

Results

- Coupling yaw control and position density provided a 40% increase in power density over layout optimization alone and 50% more than yaw control alone

- Proof-of-concept study demonstrated that the potential of wind plant control can be greatly expanded if included in the design phase

- Full paper includes optimizations for cable length and given a fixed wind plant boundary.

Future Work

- **Current and future work considers:**
  - Impact on loading and inclusion of loading effects in optimization
  - More realistic cost-of-energy optimization function
  - More detailed and realistic constraints
  - Improved optimization for faster convergence.

Thanks for Your Attention!

Photo by Dennis Schroeder, NREL 25915

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