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The American Wake Experiment (AWAKEN)

AIAA SciTech 2020

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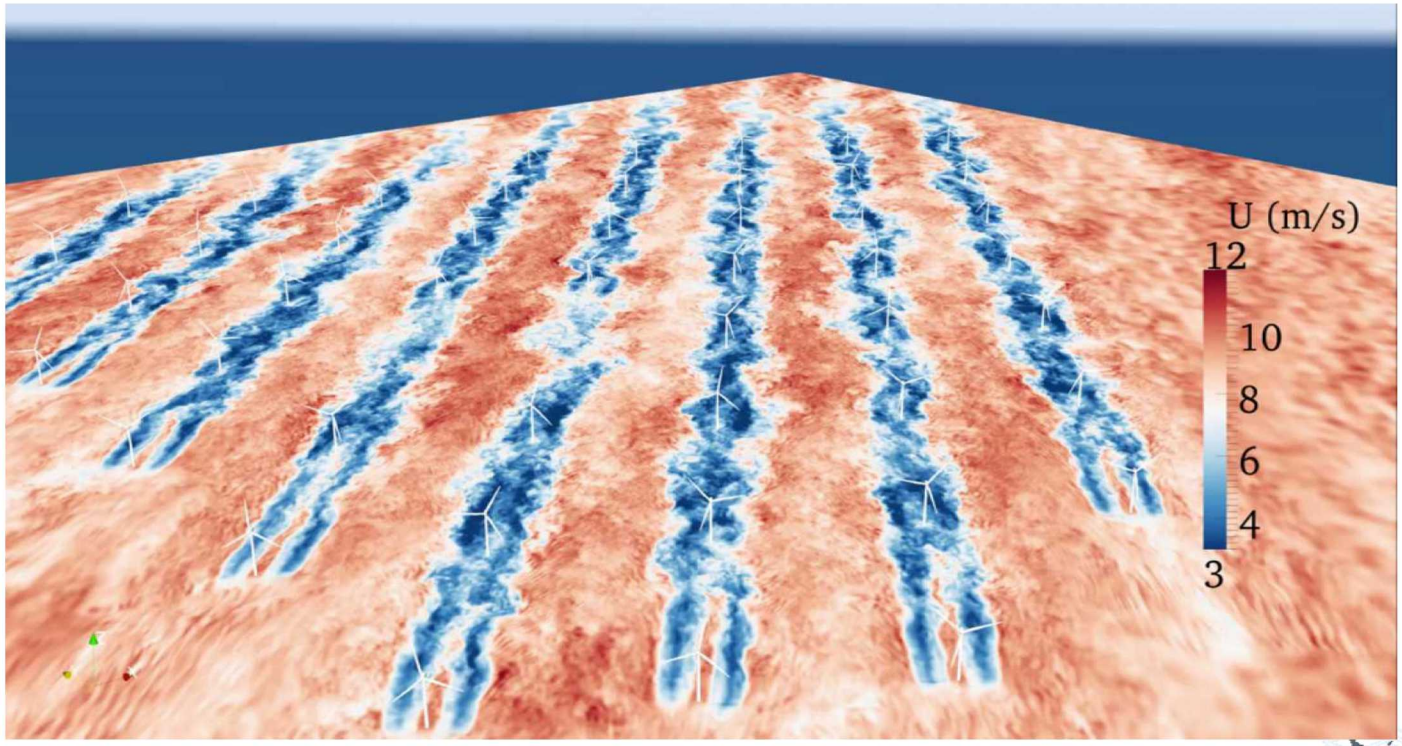
David Maniaci

Tommy Herges

Patrick Moriarty

AWAKEN (American WAKe ExperimeNt)

- What is it?
  - International observational and model validation campaign led by NREL
  - Focused on improved understanding of wind turbine and plant interactions
  - US land-based wind plant in central wind belt
  - Most detailed wind plant observations to date
  - https://openei.org/wiki/AWAKEN



Benefits to the wind industry and research community

- Large scale wind plant experiment to assess credibility of models for wind plant performance metrics
- There is a lack of large scale data sets at the necessary resolution and accuracy to validate wind plant computational models
- Pieces of validation have been done in
  - Wind tunnel
  - Research-subscale
  - Utility turbines, only with a few turbines

- AWAKEN brings the wind plant together to get inner- and intra- plant effects.

Financial Impacts

west

Ørsted

Ørsted presents update on its long-term financial targets

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October 29, 2019 08:05 ET | **Source:** Ørsted A/S

At our Capital Markets Day on 28 November 2018, Ørsted presented a number of long-term financial targets. These targets are based on estimat
offshore auctions, expected long term power prices, interest rates and other factors that are all inherently dynamic and subject to uncertainty. Giv
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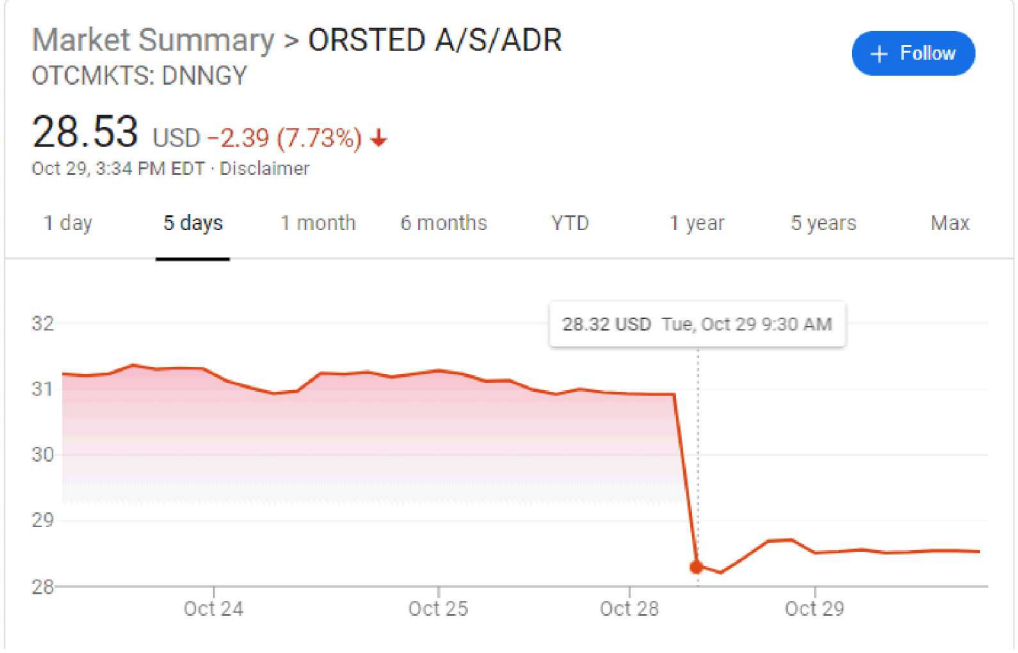

"…our current production forecasts underestimate the negative impact of two effects across our asset portfolio, i.e. the **blockage effect** and the **wake effect**…"

"…we believe that underestimation of blockage and wake effects is likely to be an **industry-wide issue**…"

"…we are convinced that Ørsted's access to **data** and **advanced analytics** will be a driver of our long-term competitive advantage…"

"…We have, among other things, leveraged a first-of-its-kind **advanced radar system** collecting three-dimensional data on the wind flow…"

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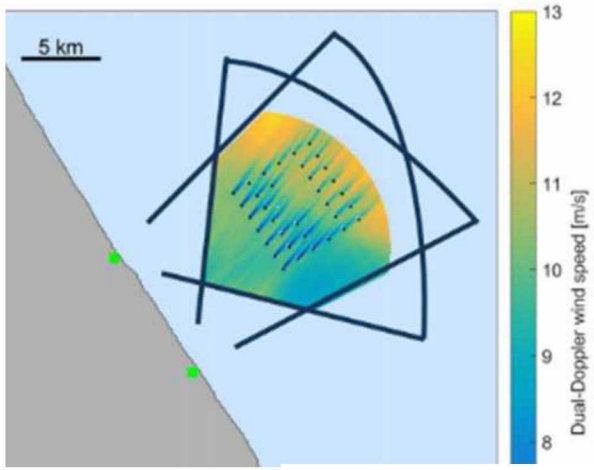
Benefits for owners and requests for access

- Benefits
  - Detailed observation, simulation and analysis of wind plant performance and interplant impacts
  - Work with world's leading wind energy research institutes and state of the art technologies
  - Testing of wind farm control strategies to increase power and reduce loads (optional)
- Requests
  - Farm access
    - Access to land for equipment installation or landowner contacts
    - Power for instrumentation
  - Turbine access for installation of sensors
    - Structural loads and turbine performance
    - Nacelle mounted lidars
    - Access to operational SCADA data

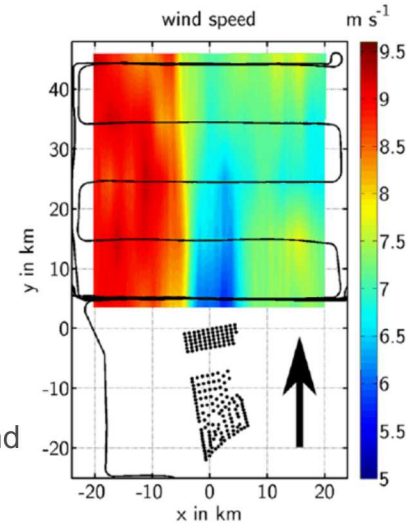
Observational Technology

- Wind plant observations
  - X-band radar systems
  - Manned and unmanned aircraft
- Turbine observations
  - Scanning lidars
  - Drone-based sensors
- Atmospheric observations
  - Flux stations, meteorological towers and remote sensing

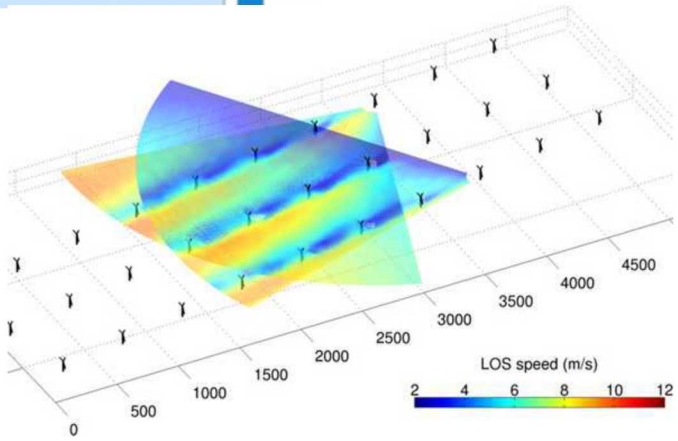


X-band radar of wind plant interactions

DOE ARM Mid-size UAS



Manned aircraft observations of wind plant wakes



Scanning lidar measurements of turbine wakes

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Simulation Technology

- Range of atmospheric and wind plant models
  - From standard industry tools to state-of-the art research tools
  - From mesoscale to blade and component scale
  - Run on Department of Energy High Performance Computing platforms (fastest in world)
- Validation studies and uncertainty quantification
  - Wake models have highest uncertainty in pre-construction energy estimation
  - Rigorous quantification of bias and uncertainty for industry models

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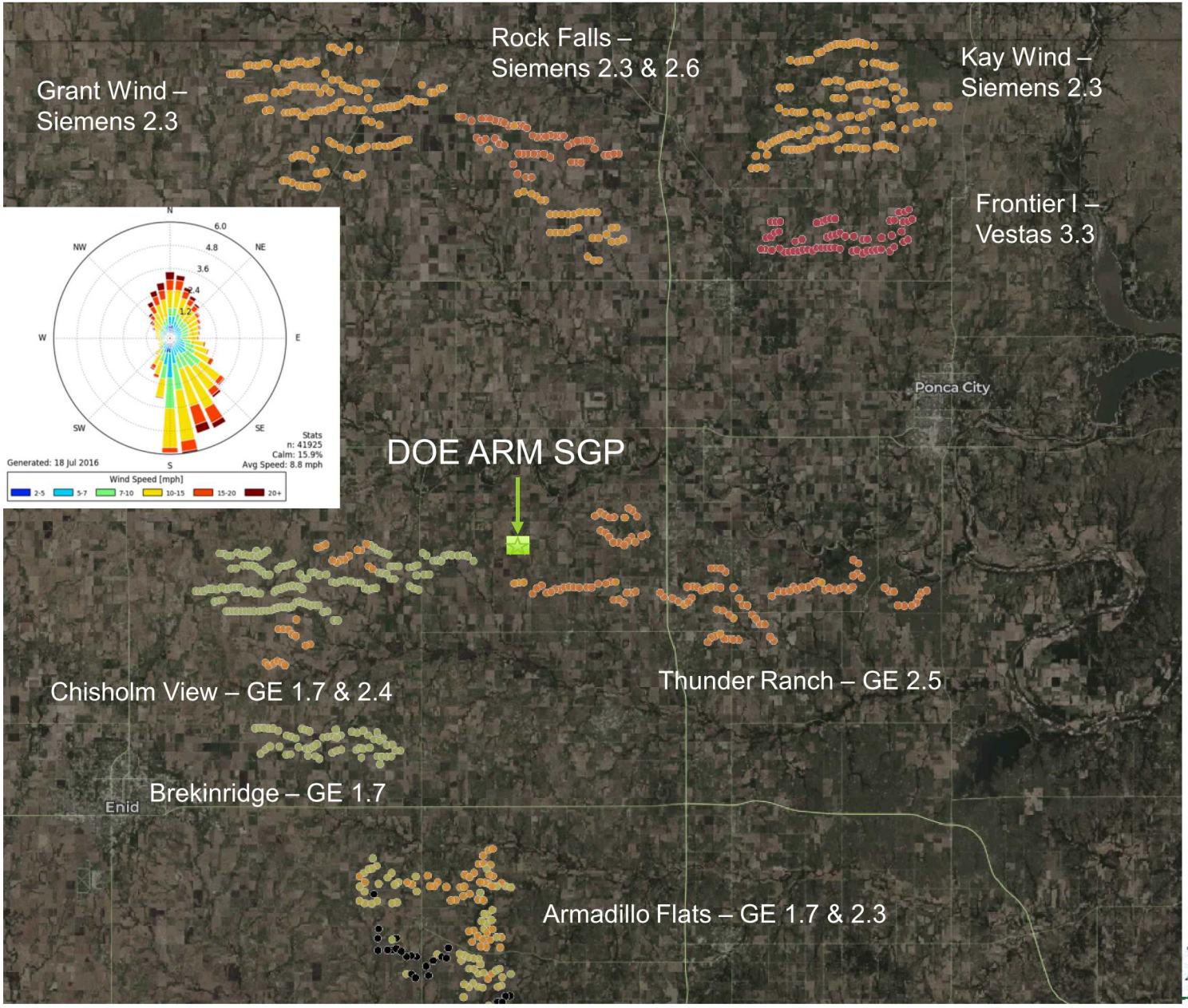
Site Selection



8 farms
5 owners
3 OEMs

V&V/UQ Background and Context

- Transform today's wind plant operating environment through advanced physics-based modeling, analysis, and simulation capabilities

- Approach
  - Development of high fidelity models and physics based engineering models
  - Collection of existing data and generation of new data through an experimental measurement campaign
  - Strategic linking of these efforts through a Validation Focused Program

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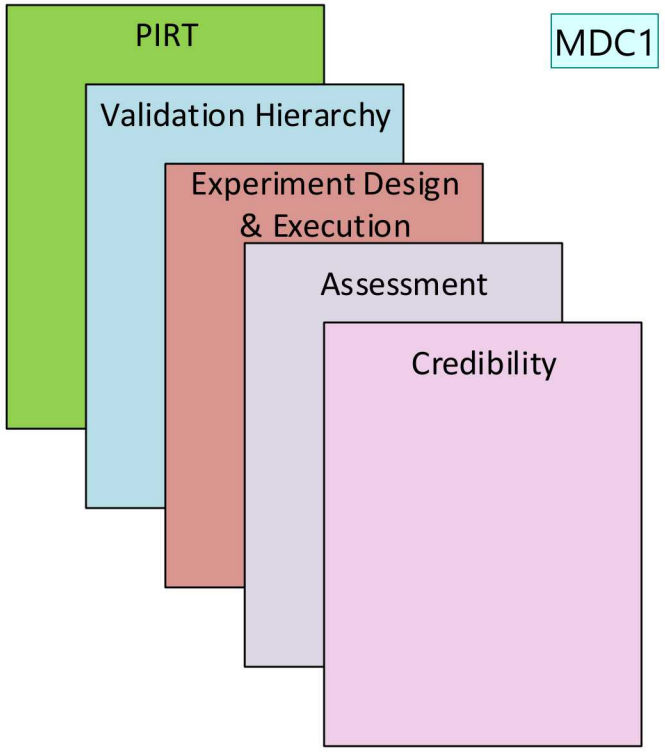
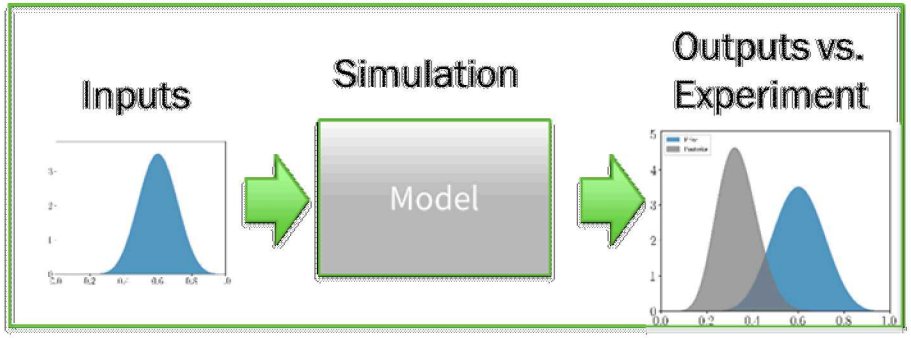
Importance of V&V/UQ

- V&V/UQ are the processes by which we identify important physics and assess the level to which models capture them
- V&V/UQ thus allows us to quantify the uncertainty of a model for a specific application
  - Knowing the uncertainty allows for better planning
  - Reducing the uncertainty reduces risk





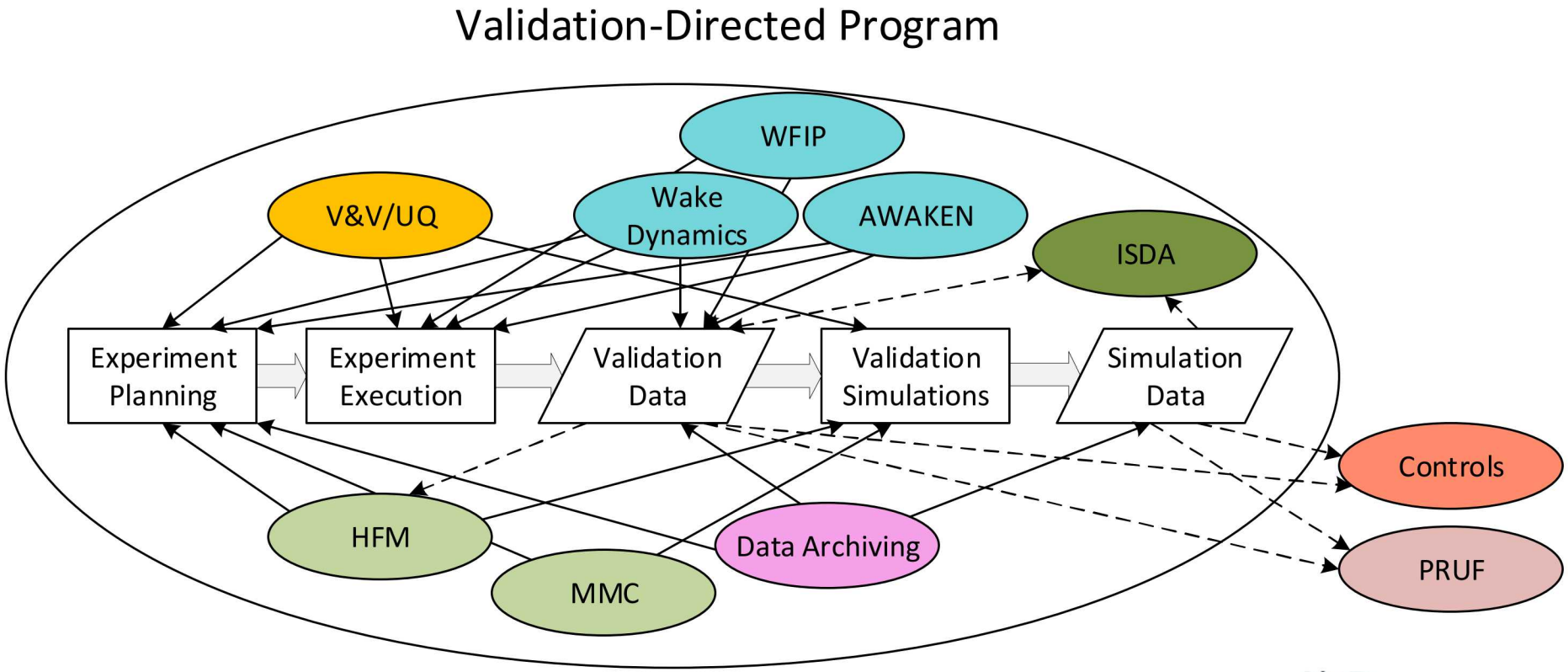
Slide 10

MDC1 Change PIRT to "Physics > PIRT"

Maniaci, David Charles, 11/18/2019

Importance of V&V/UQ

- V&V/UQ plays an integrating role across A2e projects



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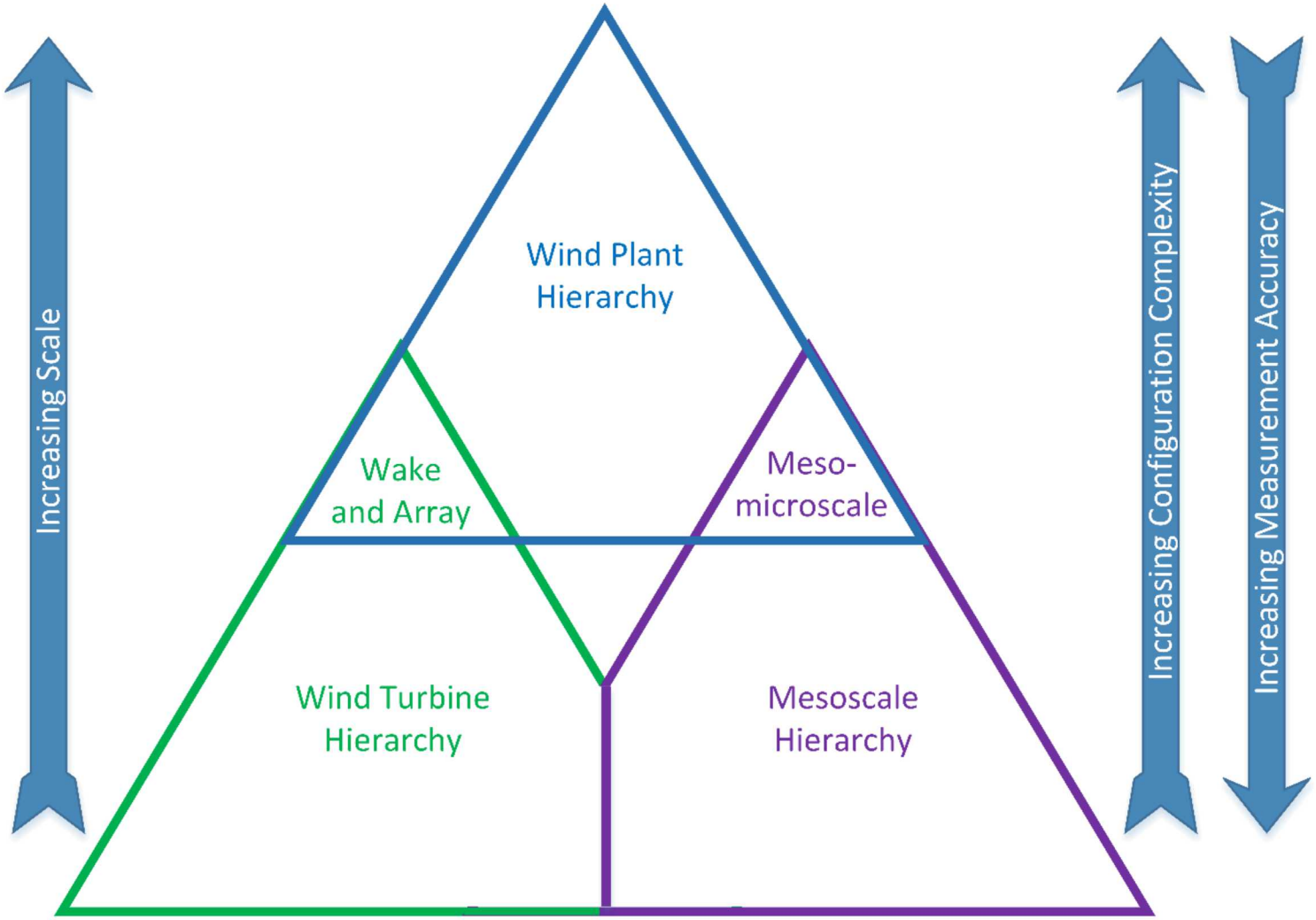
Backbone of Prioritization Process: PIRT

PIRT: Phenomenon Identification Ranking Table

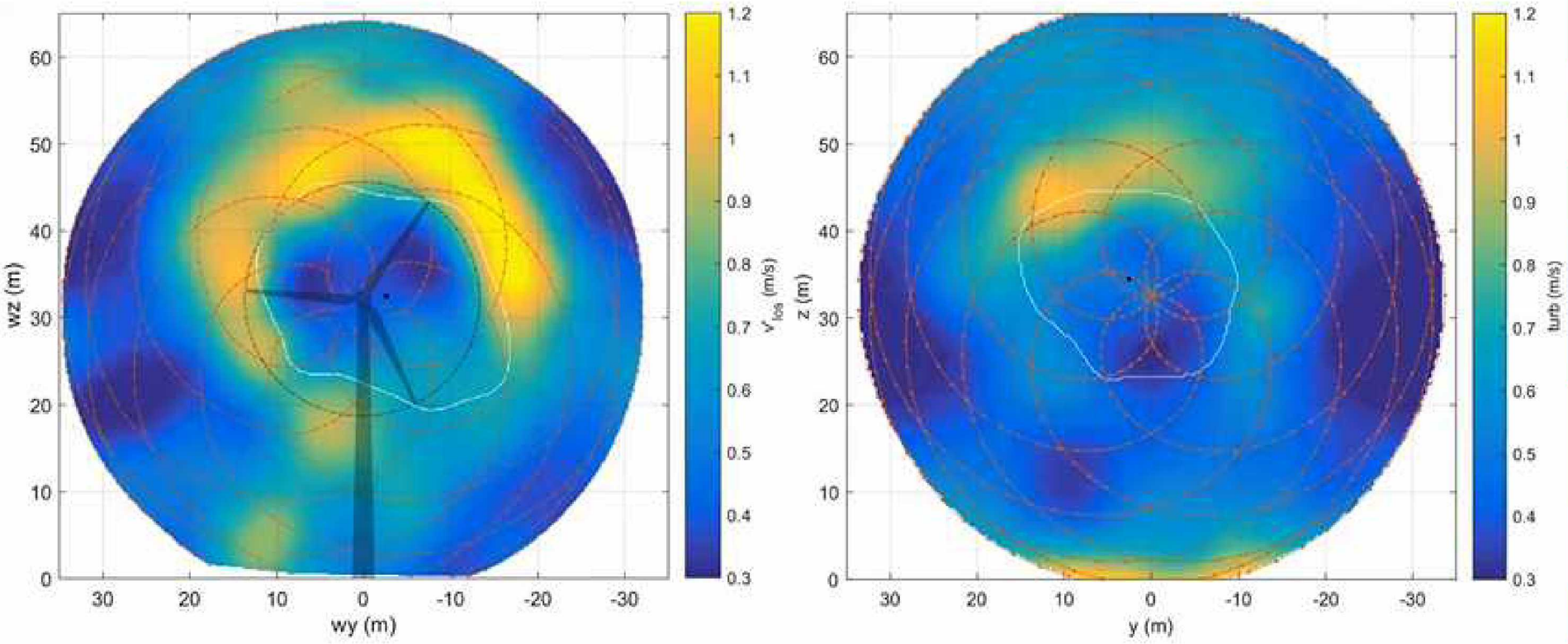
- Consensus based
- Provides gap analysis of ability to model phenomena
  - Physics gaps
  - Numerical gaps
  - Data gaps
  - Validation gaps
- Gap analysis used to prioritize planning, including experimental planning

Phenomenon	Importance at Application Level	Model Adequacy		
		Physics	Code	Val
Turbine scale flow phenomena				
Blade Aero / Wake Generation				
Blade load distribution effects and rotor thrust	H	M	L	L
Tip and root vortex development, and evolution and merging	H	M	L	L
Vortex sheet and rollup (in addition to tip/root vortex)	M	M	M	L
Blade generated turbulence characteristics (energetic scales)	H	L	L	L
Root flow acceleration effect ('hub jet')	Unknown	M	L	L
Boundary layer state on turbine performance (roughness, soiling, bugs, erosion)	H	L	L	L
Boundary layer state (Re)	L	M	L	L
BL details near TE and LE	H	M	L	L
Rotational augmentation	H	L	L	L
Dynamic stall	H	L	L	L
Unsteady inflow effect (turb. intensity, spectra, coherence; veer, shear)	H	L	L	L
Blade flow control	M	L	L	L
Tower/rotor/nacelle wake interactions	H	M	L	L
Icing	L	L	L	L



Experimental Uncertainty Assessment and Propagation

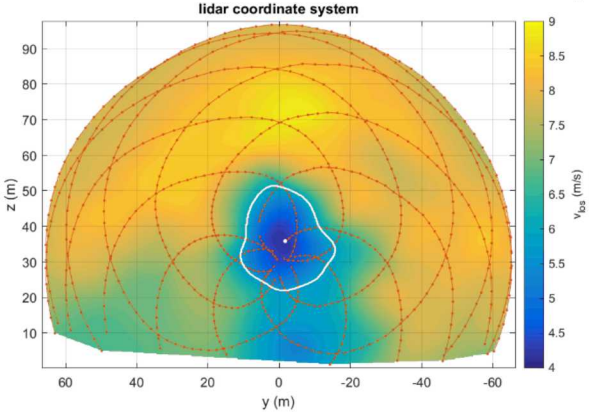
Wake comparison, Measured and Simulated Lidar



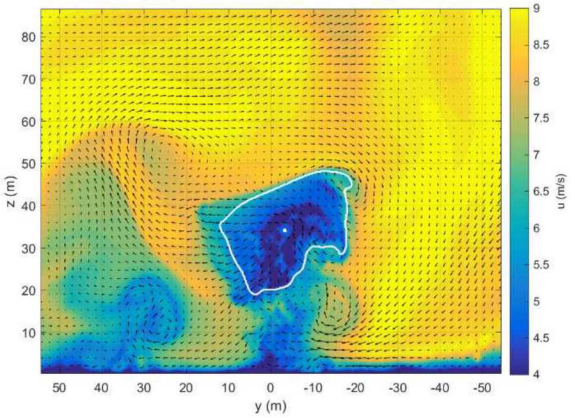
- Current work is focused on the quantification of the fundamental uncertainty of lidar measurements and how it propagates to wind plant metrics.

Nalu-Wind Wake Assessment Metrics

- Comparisons between neutral atmospheric boundary layer inflow experimental data were compared with Nalu-Wind simulations, including power, loads, and wake data.



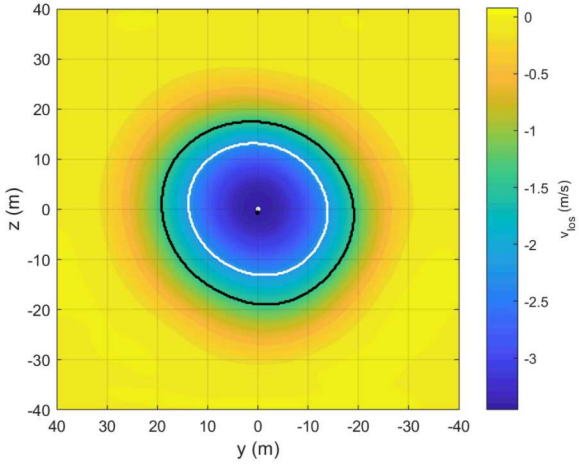
Sample of the wake date from the measured Spinnerlidar at the SWiFT facility.



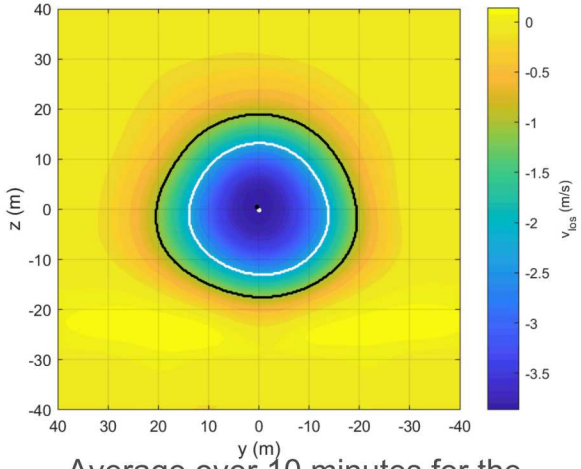
Nalu-Wind Simulated wake data 5D downwind.

	Simulation	Experiment
OOP Blade Bending (kN m)	37.0 ± 6.0	37.1 ± 6.2
Rel. Flapwise DEM (sim./exp.)	1.06	1.00
Generator Power (kW)	88.4 ± 17.3	81.2 ± 19.3

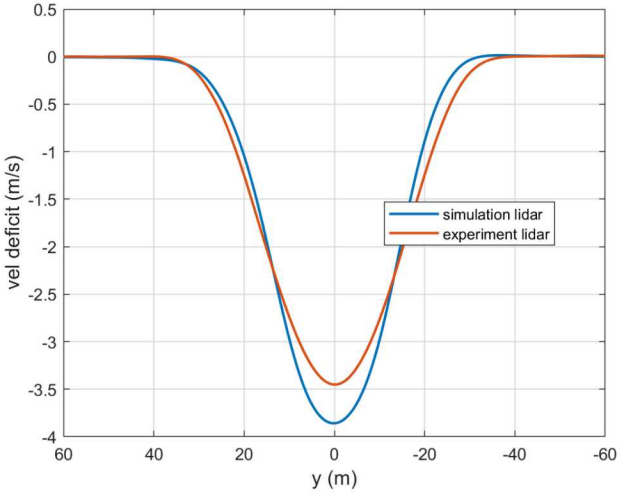
Wind turbine power and loads metrics for wake dynamics.



Average over 10 minutes of the wake data from the measured Spinnerlidar.



Average over 10 minutes for the simulated wake data 5D downwind, sampled to match the experimental lidar data.



Comparison of wake velocity deficit for the experiment and the Nalu-Wind simulated lidar data.

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Thank you

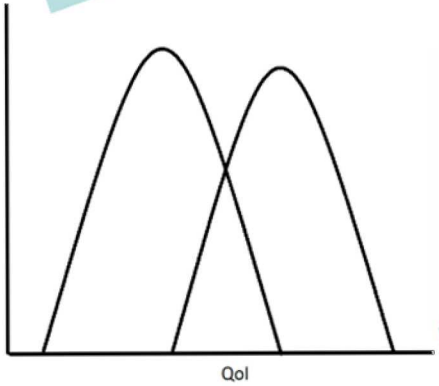
Virtuous Cycle

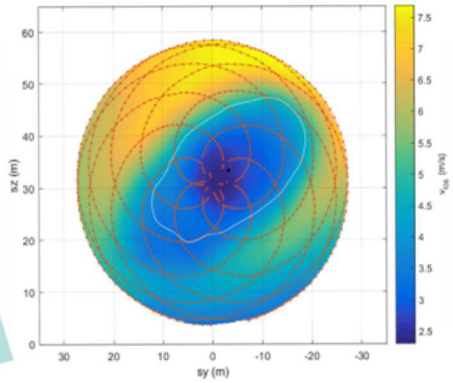
Validation

Model Development

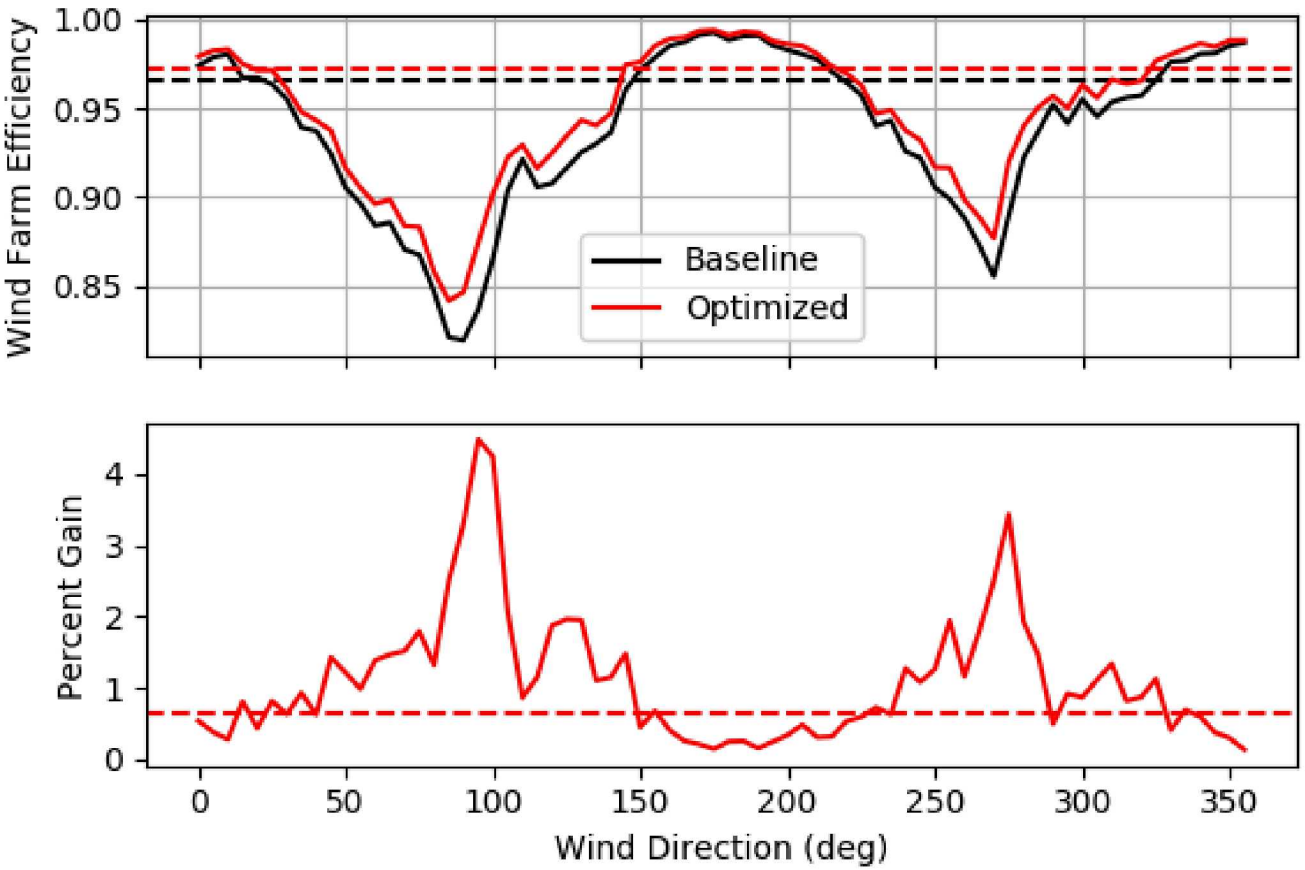
Experimentation

Uncertainty Quantification





Wind farm control benefit



AEP Gain = 0.56%