

Full-Scale Field Test of Wake Steering



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Goal of the Talk

- **Field Test using scanning LiDAR**
 - Observe wake deflection under various yaw settings
 - Compare with control-oriented model predictions



Outline

- **Wind Farm Controls**
- **Control-Oriented Model – FLORIS**
- **Field Experiment Setup and Procedure**
- **Results and Model Validation**
- **Conclusions**

Wind Farm Control

- **Wind Farm Performance**
 - Maximize wind farm power
 - Mitigate loads
- **Understand aerodynamic interactions in a wind farm**



Horns Rev 1 (Photographer: Christian Steiness)

Control Objective

- Example: Maximize power

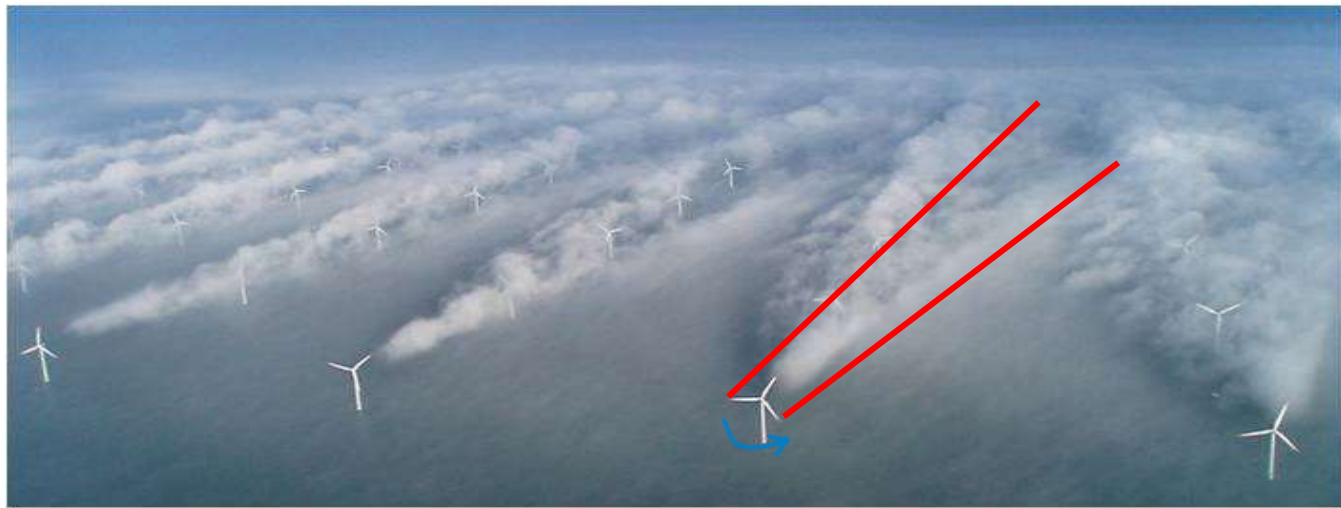
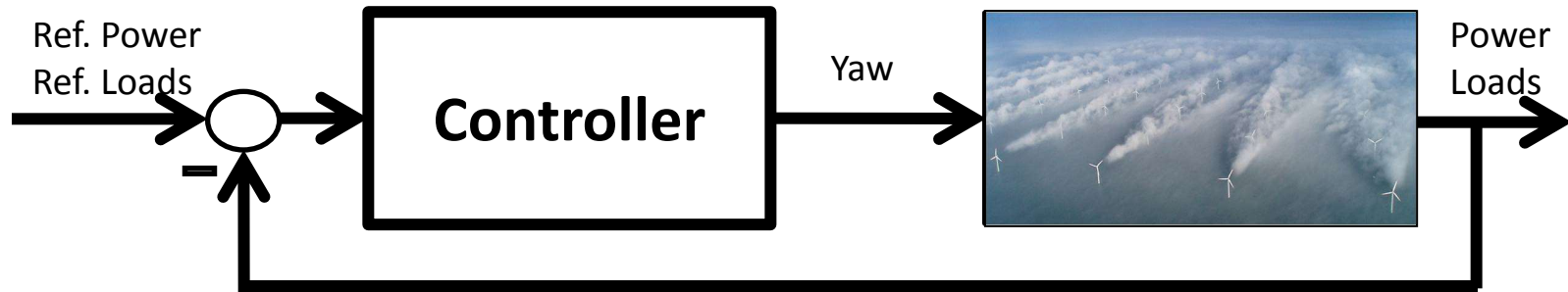


Horns Rev 1 (Photographer: Christian Steiness)

Fleming, et. al. "Evaluating techniques for redirecting turbine wakes using SOWFA." Renewable Energy. 2014

Control Objective

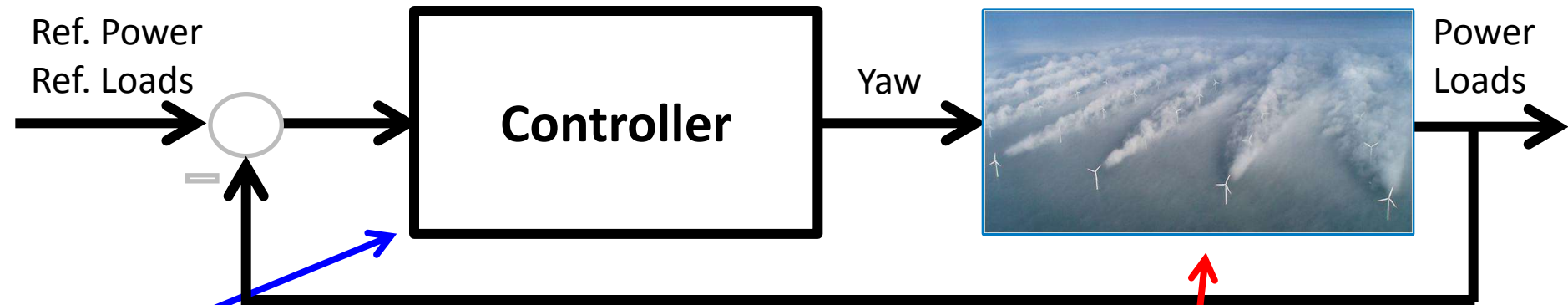
- Example: Maximize power



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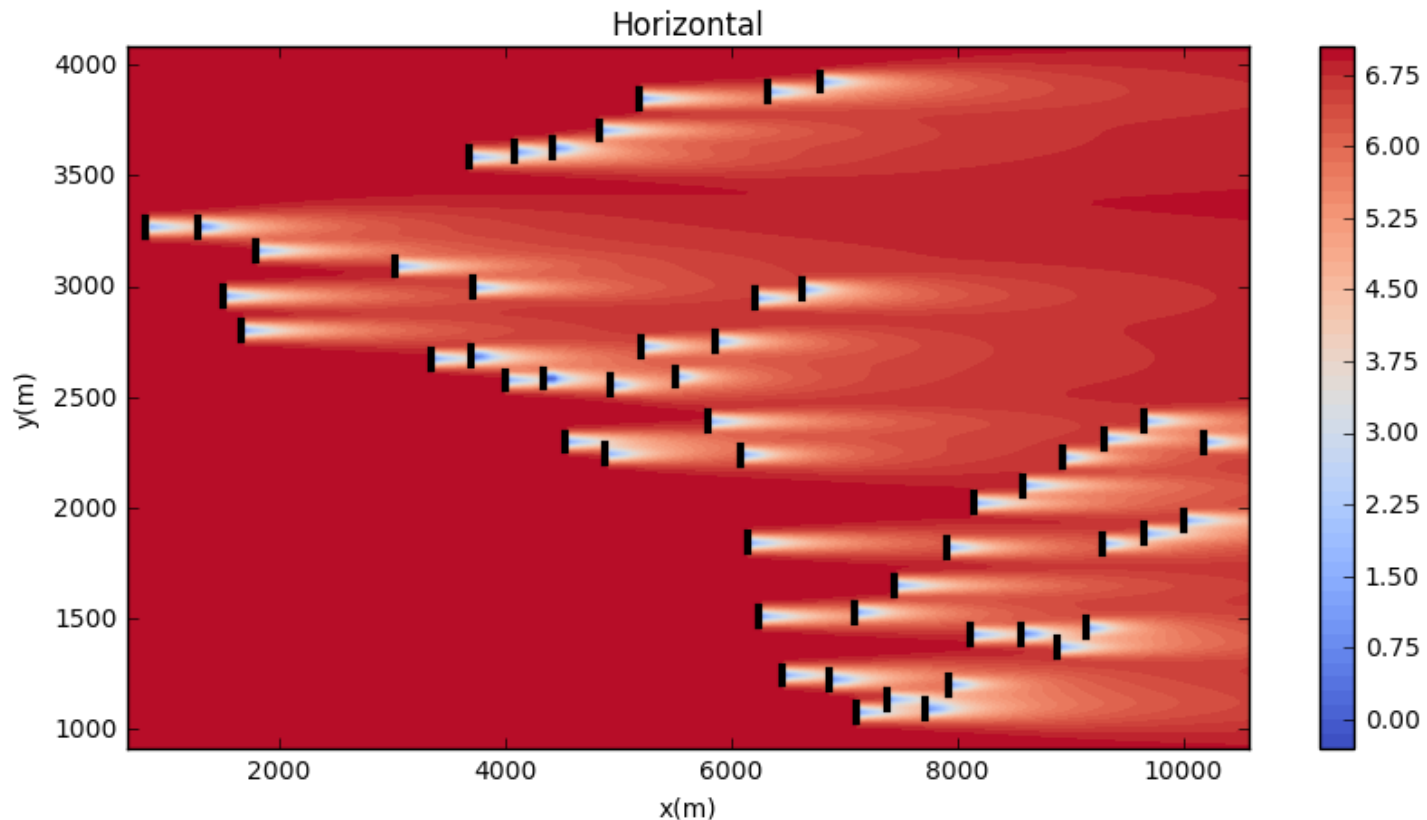
Modeling and Control Problem



- **Two issues that need to be resolved**
 - Develop a model of the system for control design
 - Controller design

FLORIS Wake Model

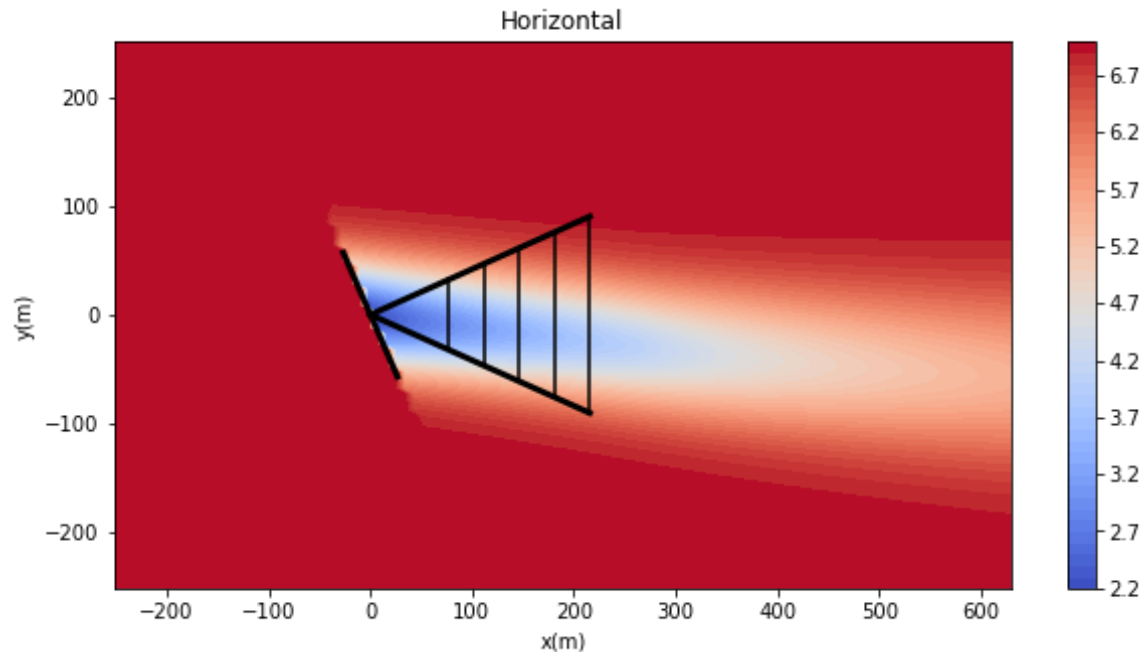
- FLOW Redirection and Induction in Steady-State
- Developed by NREL and TU Delft
- Predicts the average steady-state behavior of wakes



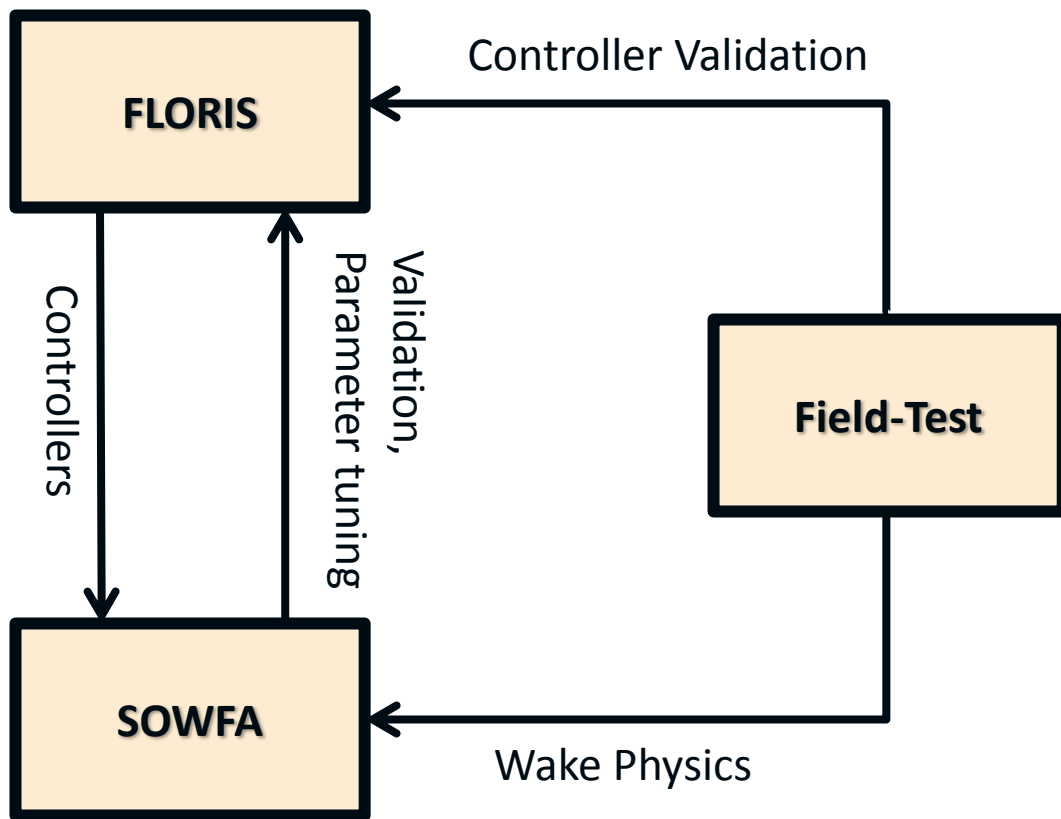
FLORIS Wake Model

- Improvements to FLORIS: Porte-Agel et. al. 2016/17
 - Self-similarity theory: Gaussian Wakes
 - Atmospheric stability based on TI, shear, and veer
- Accounts for changes in yaw and pitch control

- FLORIS is tuned to match simulation results
- Later compared to field-test data

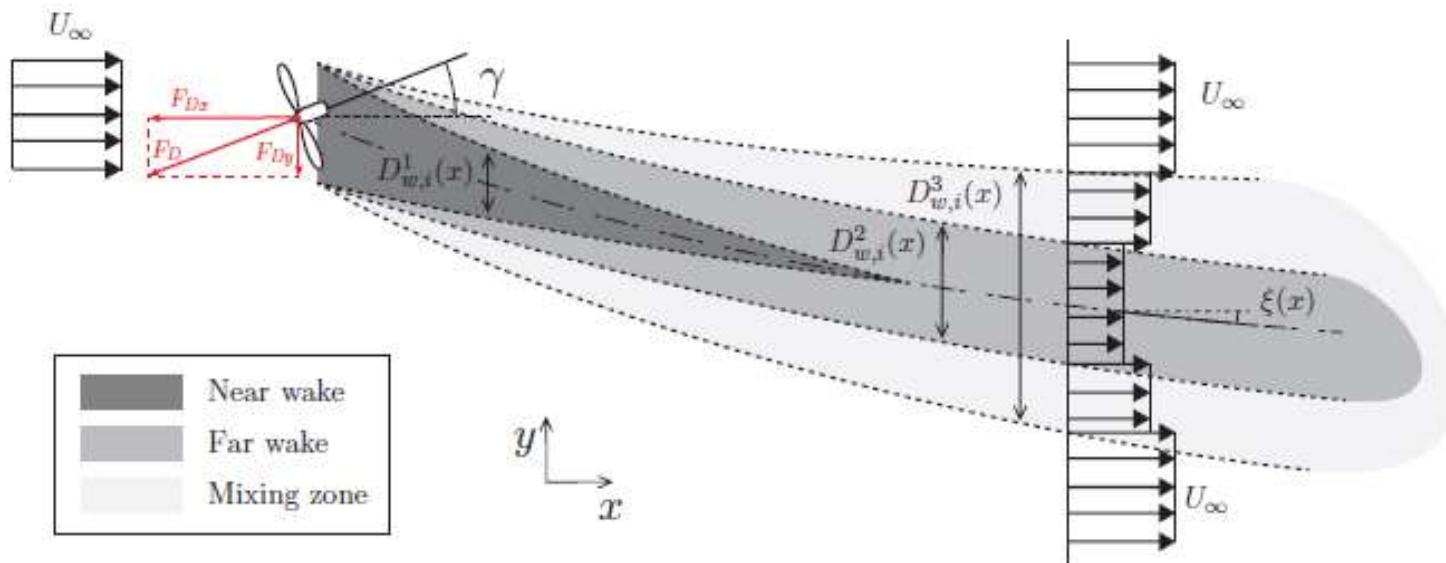


Wind Farm Controls Development



Field Test Campaign Objectives

- Operate the turbine in yaw while monitoring wakes
- Use the collected data to inspect the key phenomena governing the success/failure of wake steering from a controls perspective:
 - Rate of loss of power due to yaw misalignment
 - Recovery rate of wake, with and without yawing
 - Relationship of yaw misalignment and deflection



Field Experiment Conducted at NWTC



Field Experiment – Utility-Scale Turbine

- **GE 1.5MW SLE** – located at NWTC

University of
Stuttgart
Scanning LiDAR

- Rated Power = 1.5 MW
- Hub Height = 80 m
- Diameter = 77 m
- Rated Wind Speed = 14 m/s



LiDAR Information

- Developed in 2008 for nacelle measurement campaign
- Windcube V1 and a scanner unit developed at Stuttgart
- 2 DOF mirror for redirecting the beam to any position

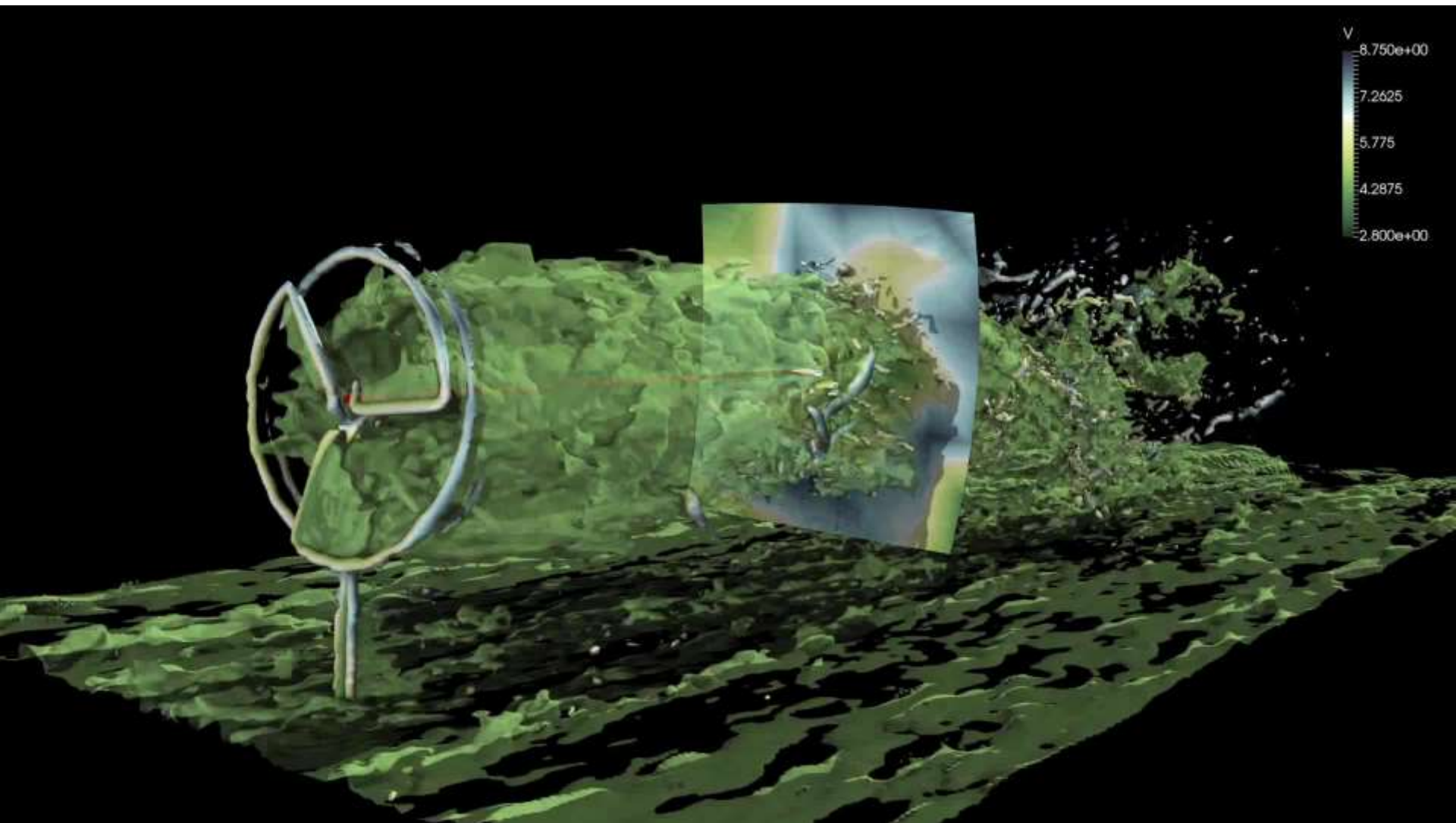


LiDAR Information

- Modified software allows:
 - 49 measurement positions (at 1 second timesteps)
 - 5 scan distances (1D to 2.8D for this experiment)

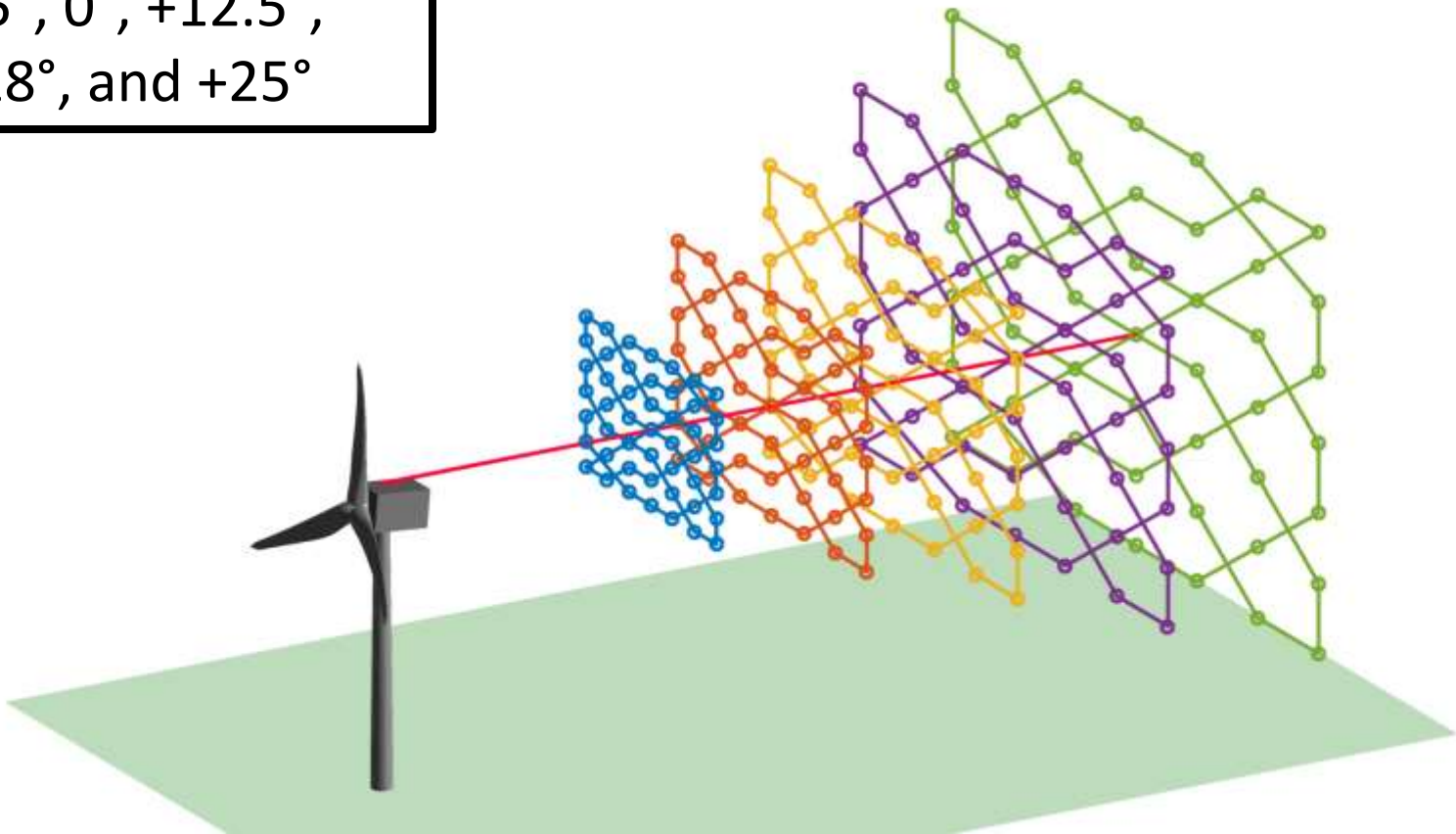


LiDAR Setup – Visualization with SOWFA



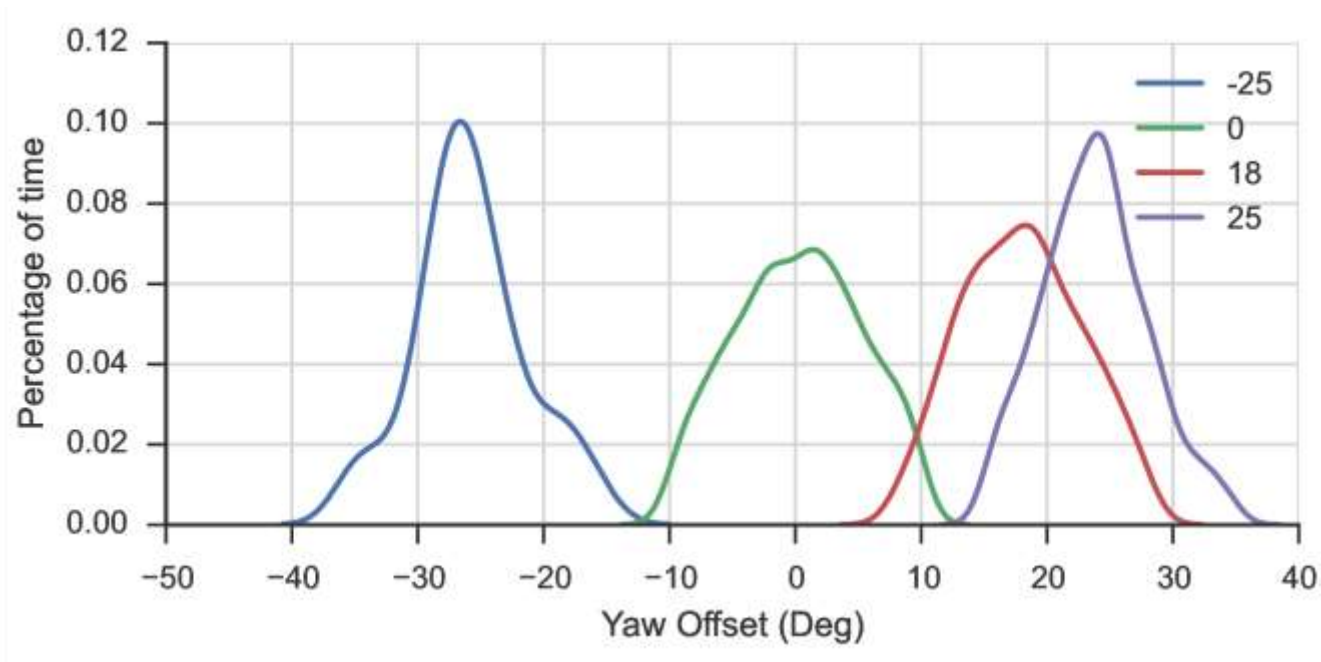
LiDAR Scanning Procedure

Yaw offsets set to
 -25° , 0° , $+12.5^\circ$,
 $+18^\circ$, and $+25^\circ$



Yaw Offsets for the Field Experiment

- Implement outer control system to track yaw offsets
 - Yaw Offsets: -25° , 0° , $+12.5^\circ$, $+18^\circ$, and $+25^\circ$
- 1 hour at baseline (0°) and 1 hour at a yaw offset
- LiDAR rotated and directed downwind while yawed

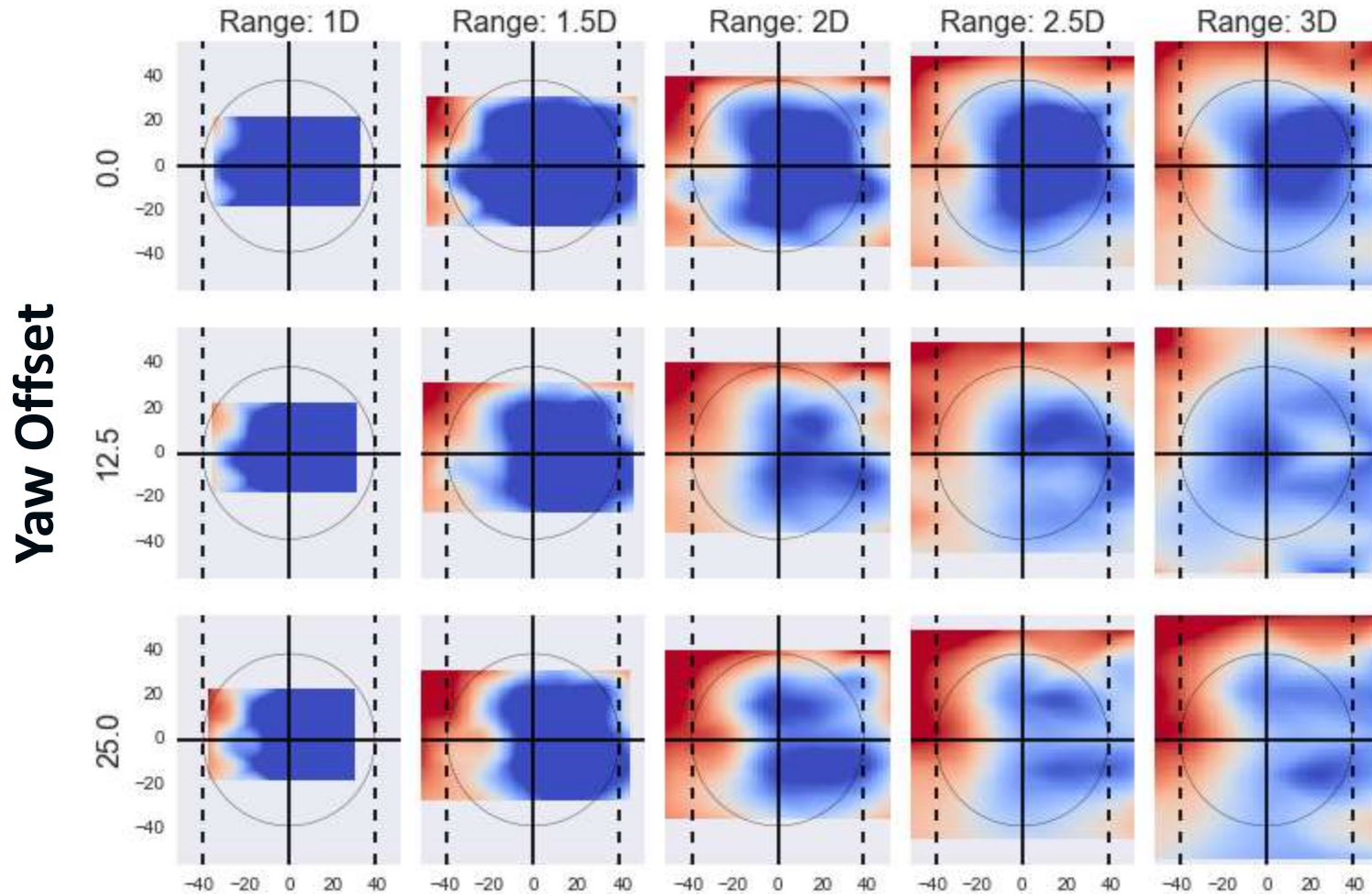


Data Processing in Field Experiment

- Recorded LiDAR measurements are processed to filter out implausible data
- Filter out data with bad carrier-to-noise ratio
- Data reduced based on:
 - Met tower upwind of turbine
 - Turbine power < 100 kW
- 15k scans completed
- 1.5k scans used in analysis



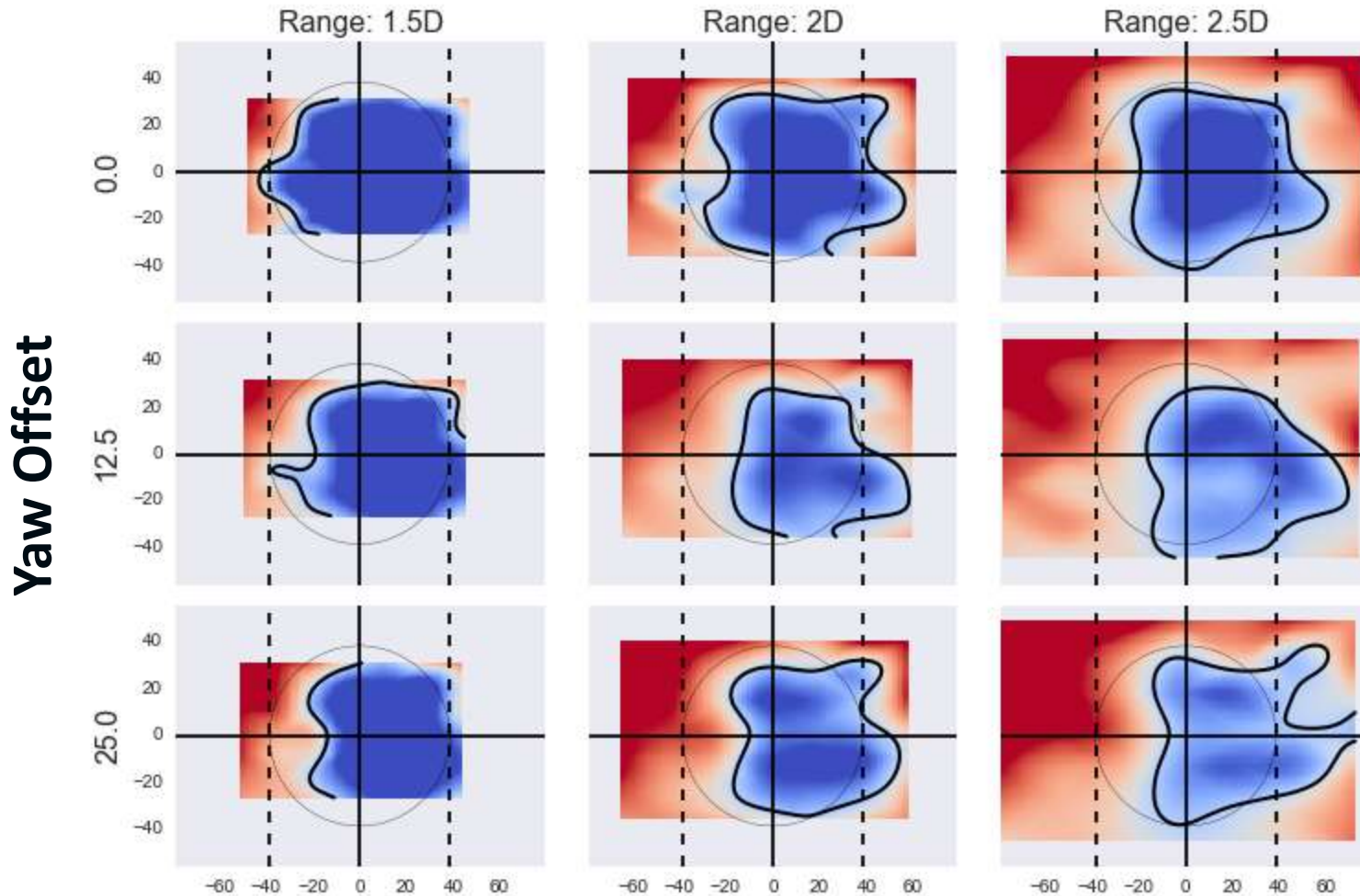
Averaged Lidar Scans



Slices with contours

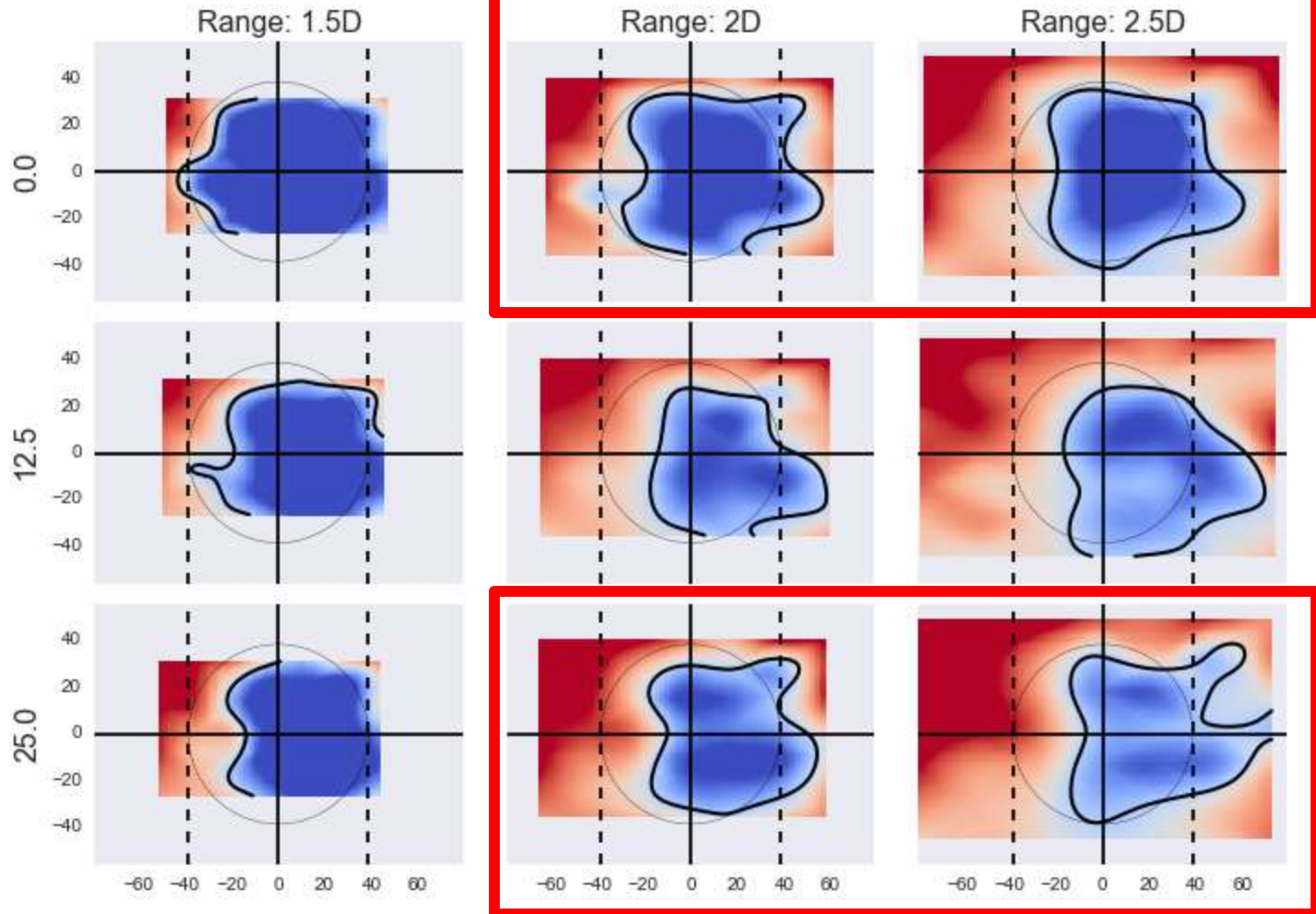
SAMWICH BOX

Simulation and Measurement Wake Identification and CHaracterization toolBOX



Slices with contours

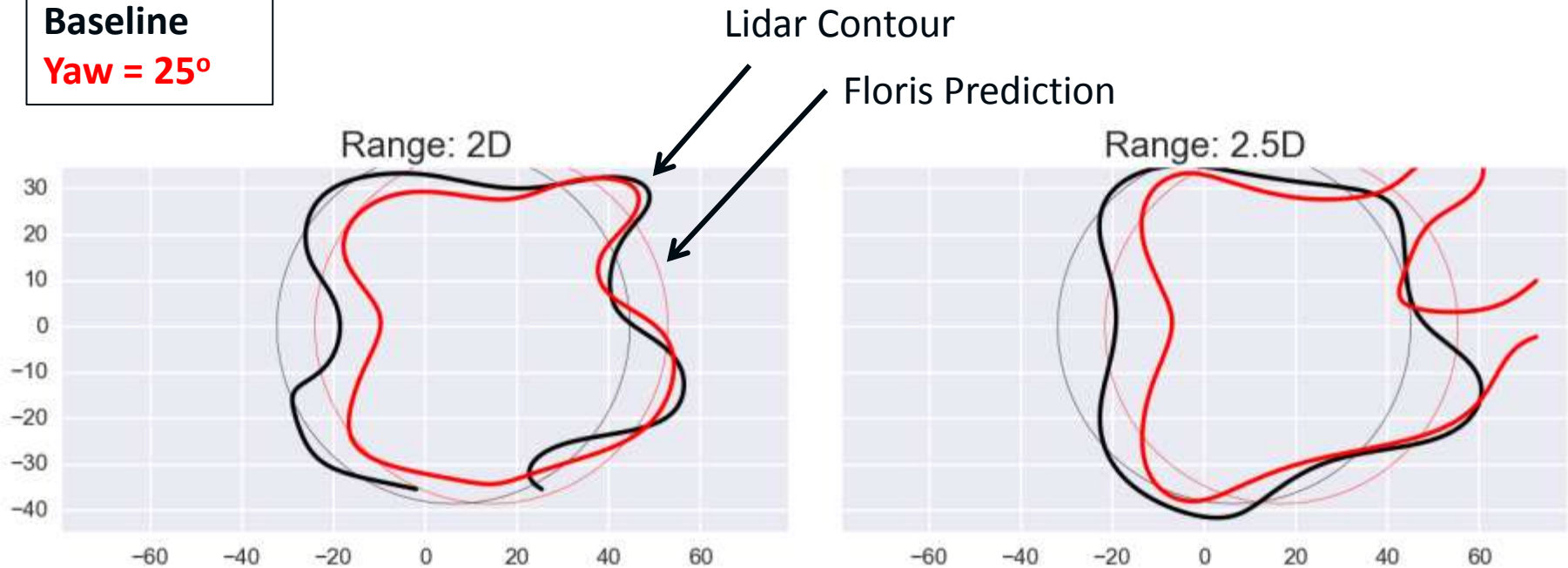
Yaw Offset



Comparison of contours with FLORIS prediction

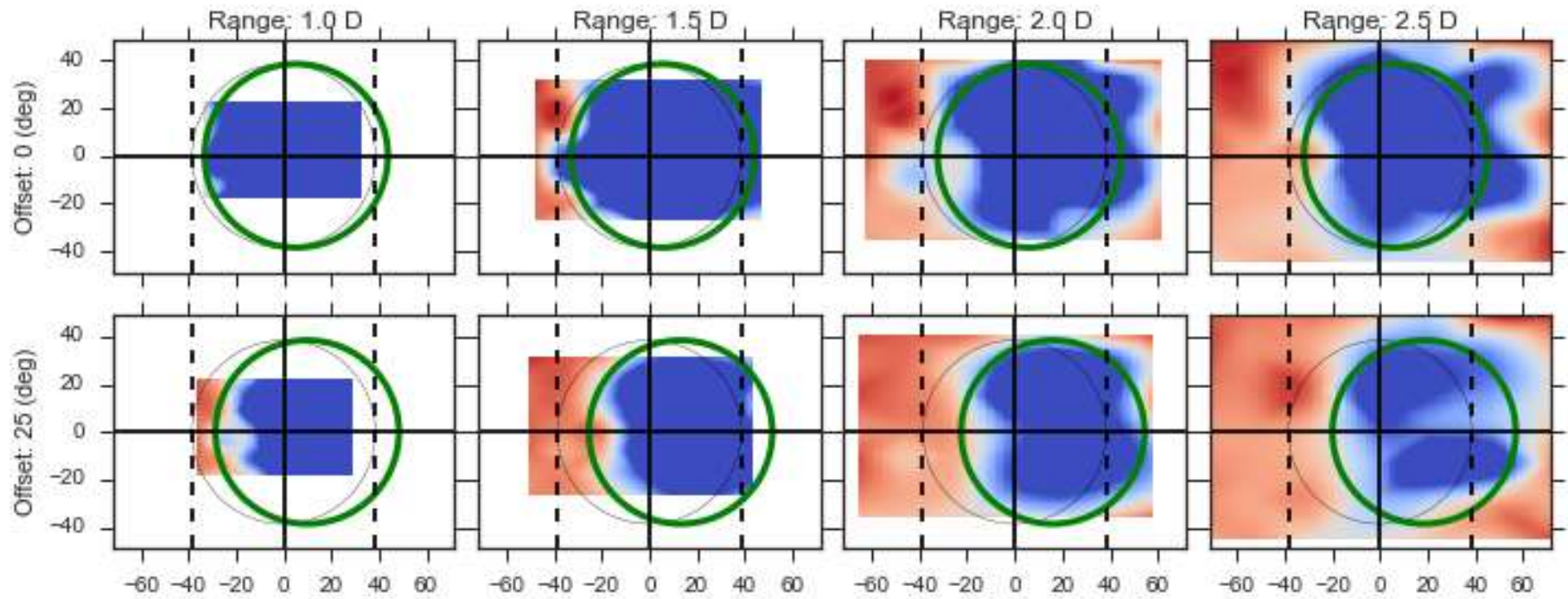
Baseline

Yaw = 25°



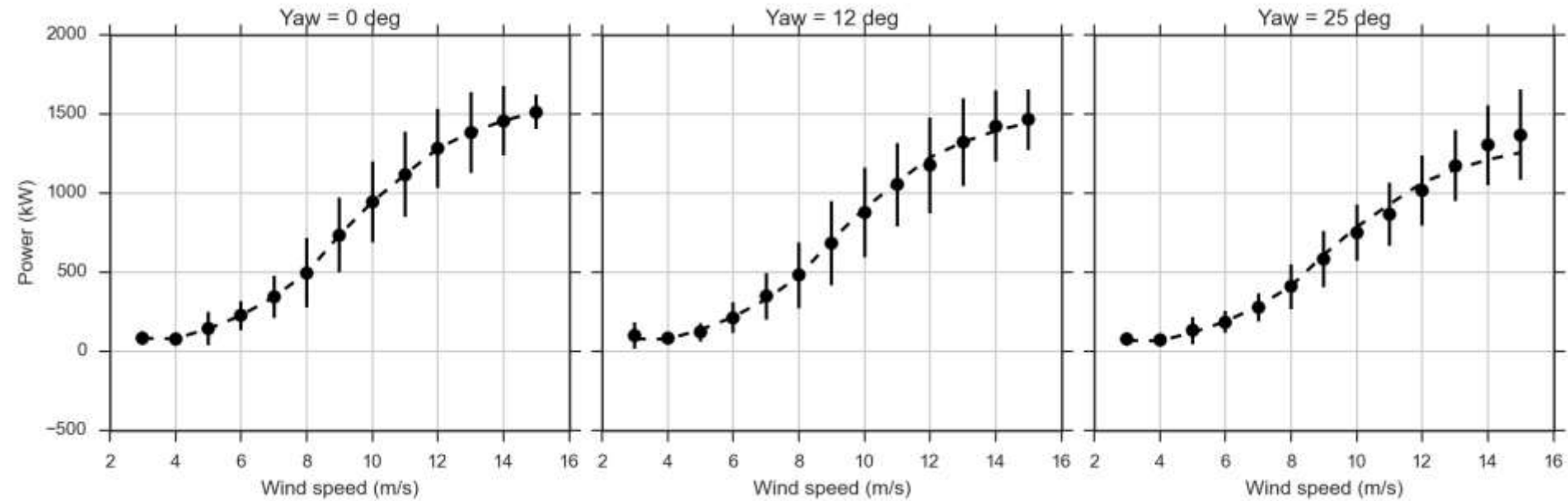
For these ranges, FLORIS (tuned to SOWFA) predicts an offset of in the range of 10m, which is in line with the observations of the lidar scans

Model Validation – Wake Deflection



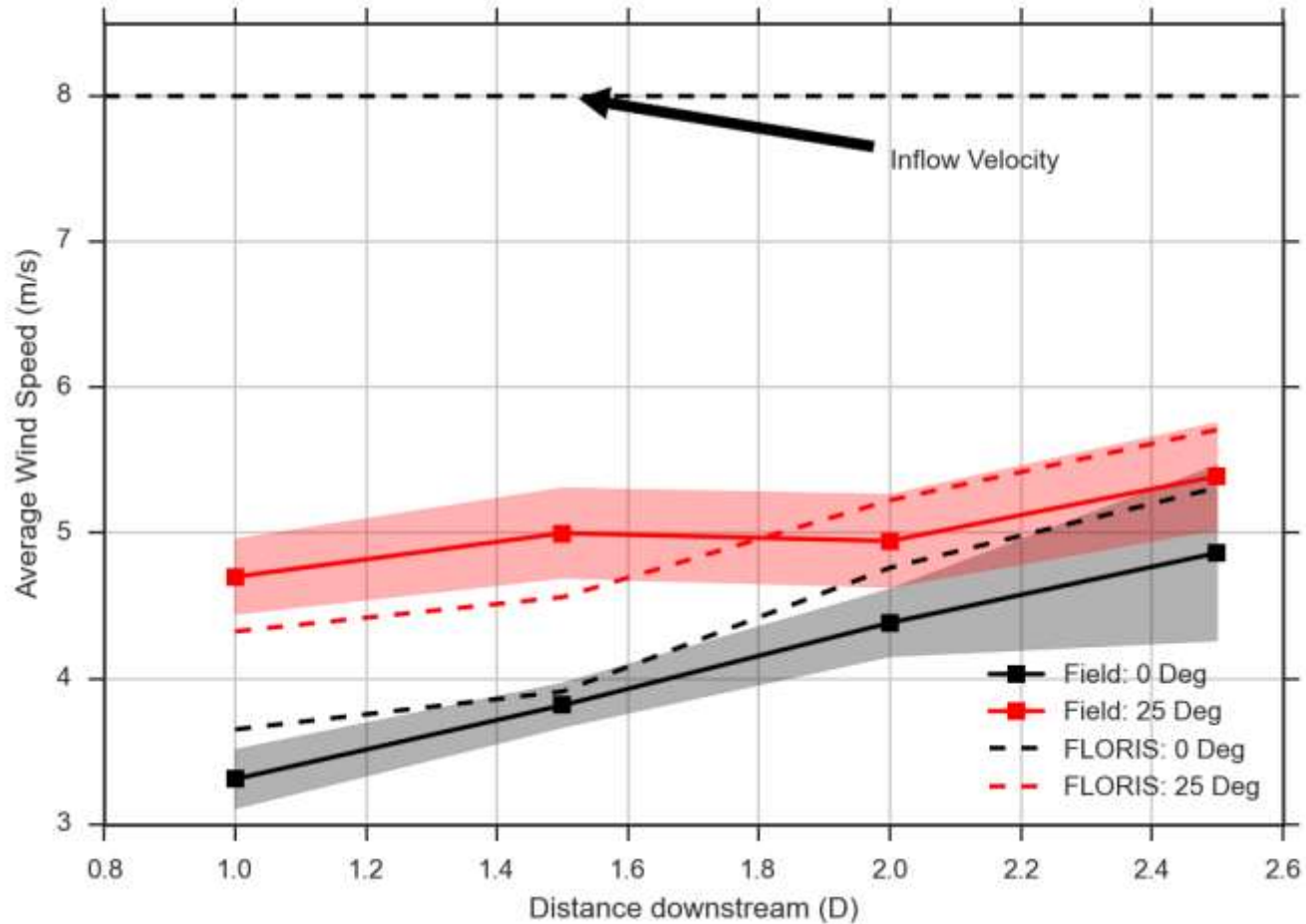
- FLORIS can predict amount of wake deflection

Model Validation – Power Curve



- Good agreement noted here between the rate of power predicted a priori predictions

Model Validation – Velocity Deficit



Conclusions and Future Work

- **Field Test using scanning LiDAR**
 - Observe wake deflection under various yaw settings
 - Compare with control-oriented model predictions
- **LiDAR scans showed good agreement with FLORIS**
- **Next steps:**
 - Analyze effects of atmospheric stability
 - Test controller designed with FLORIS in the field



Thank you.