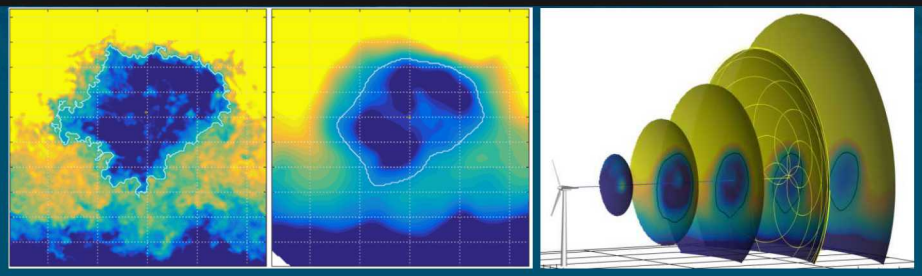
SAND2018-4017PE

SWiFT Wake Steering Experiment Data Overview



Tommy Herges and David Maniaci

Wind Energy Technologies Department

Sandia National Laboratories

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

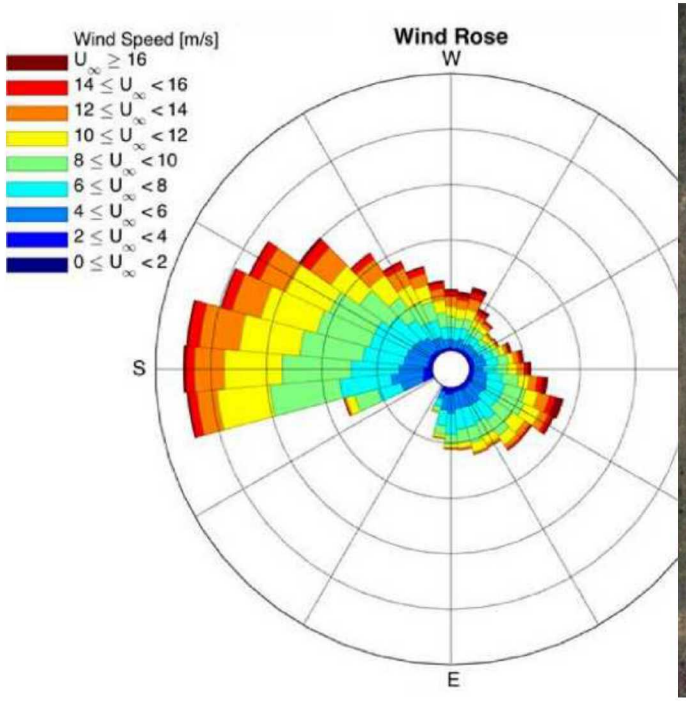
SWiFT Facility Overview

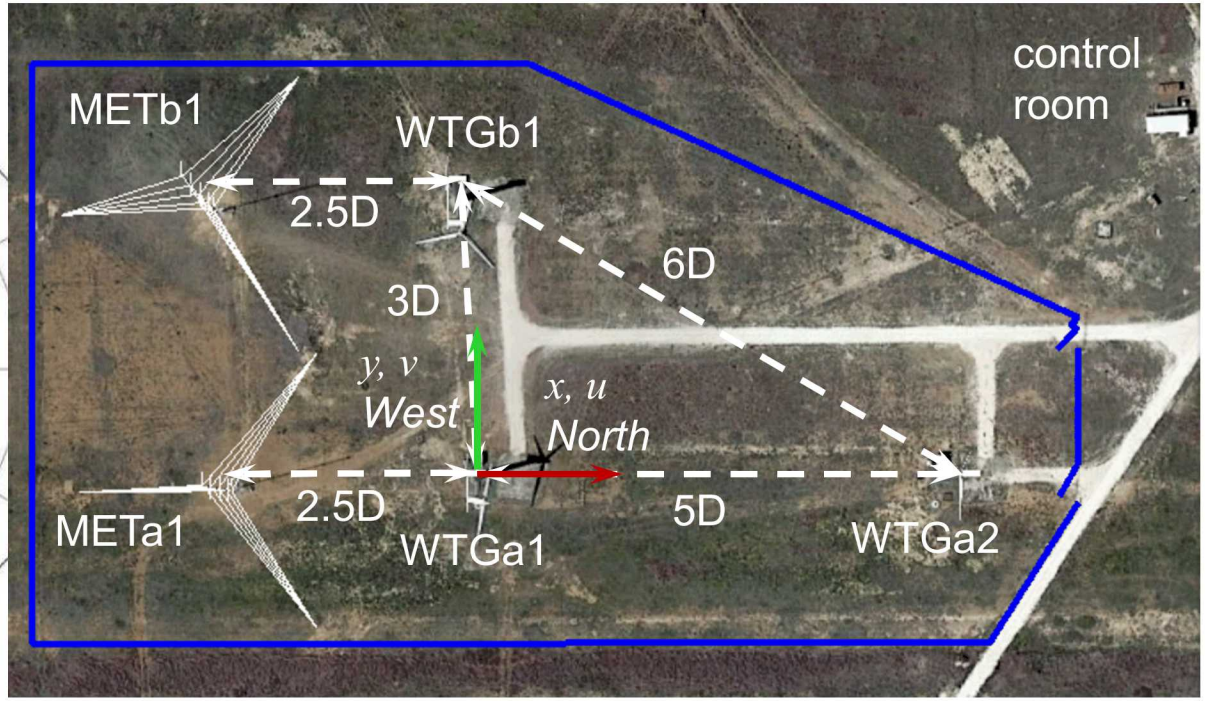
SWiFT facility created to:

- Measure wind plant flows and turbine-turbine interactions
- Perform prototype testing of innovative rotor technology

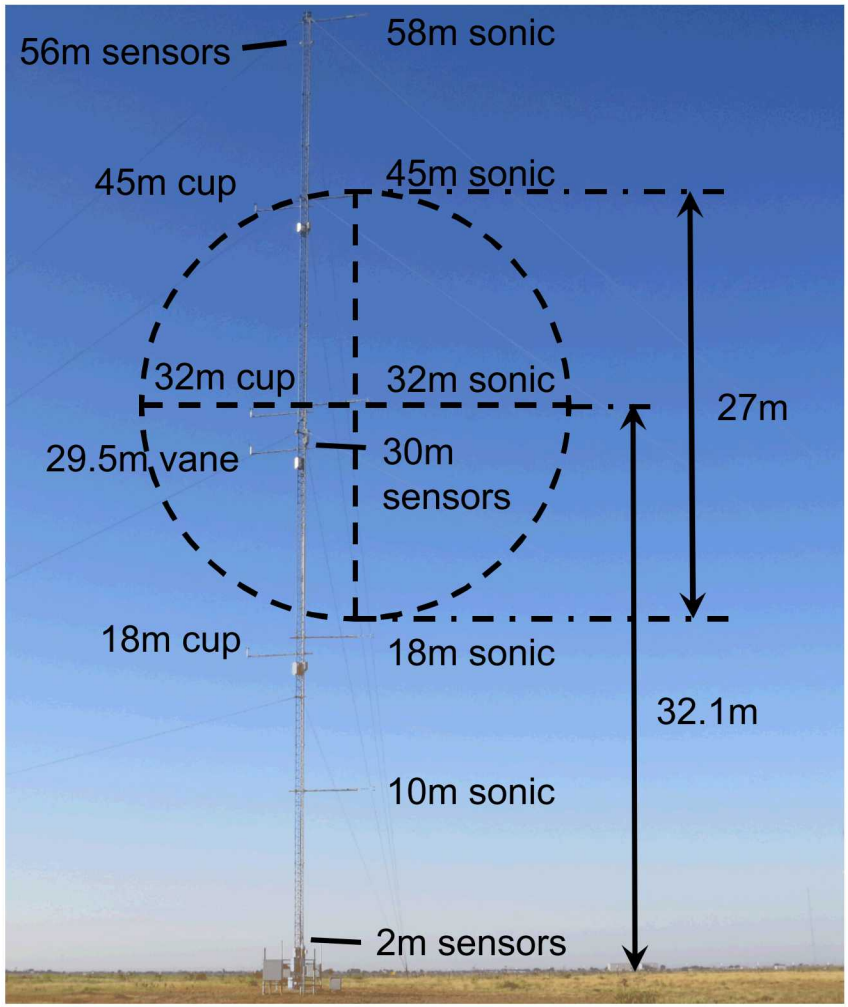
Wake steering experiment sought to quantify wake deflection vs. yaw offset and the corresponding effects on a two-turbine system

- Characterize wake shape, velocity deficit, turbulence, and dynamics under various conditions





SWiFT Site Instrumentation



Measurements:

All sensor channels GPS timestamped

Inflow: 59m MET Tower (5 sonics)

Turbines

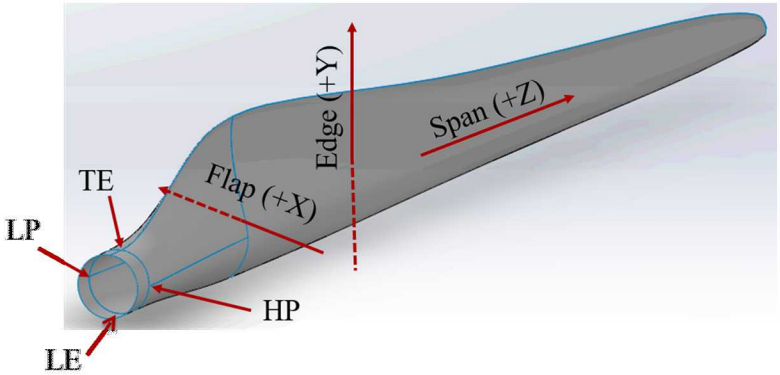
- WTGa1, upstream turbine highly instrumented, 1 blade root strain measured 4/19/17 – 7/14/17
- WTGa2, waked turbine highly instrumented, 1 blade root strain measured 7/11/17 – 7/13/17

Wake Flow Diagnostic:

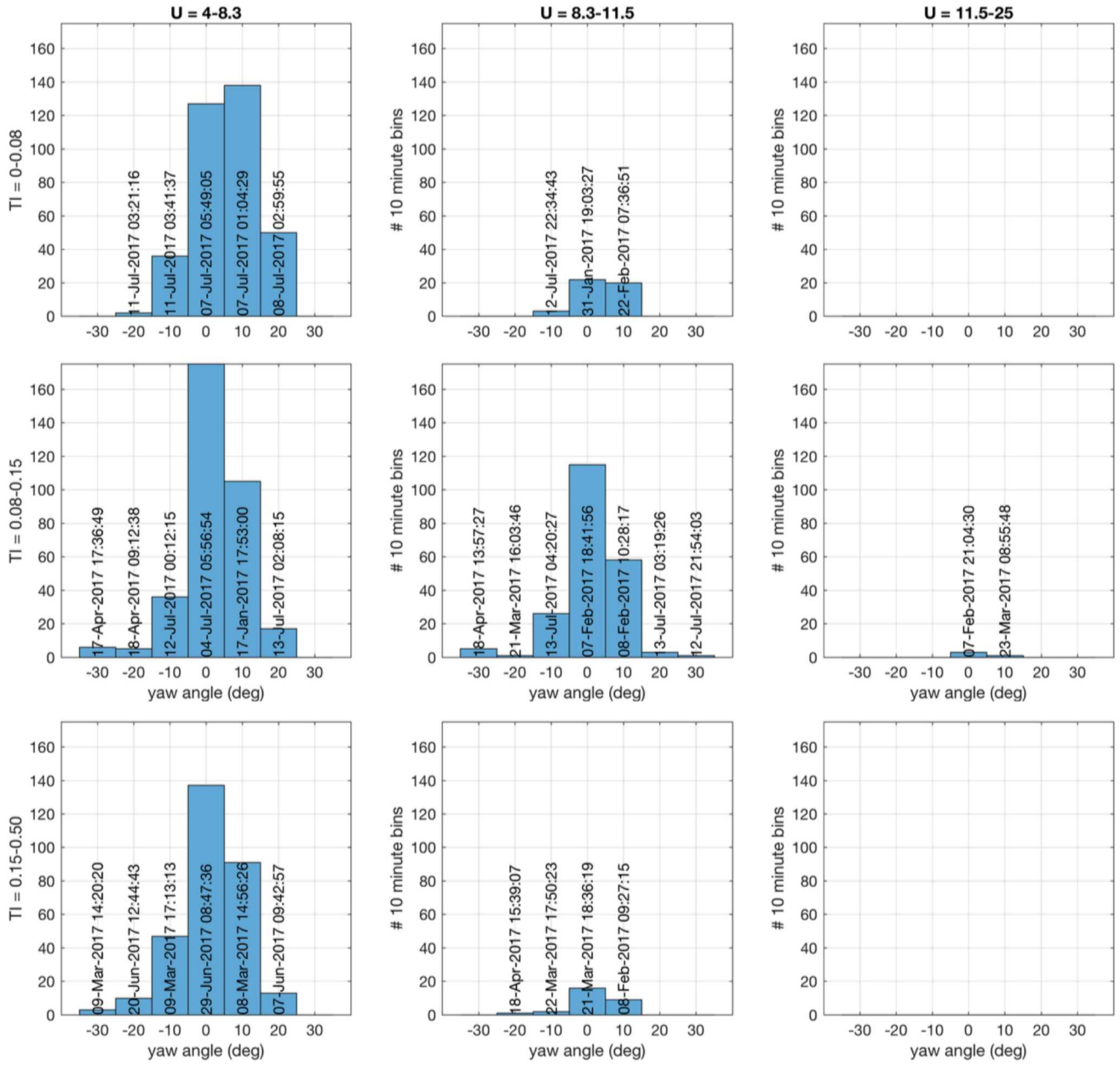
- DTU SpinnerLidar

Data collected:

- 12/15/16 – 7/14/17



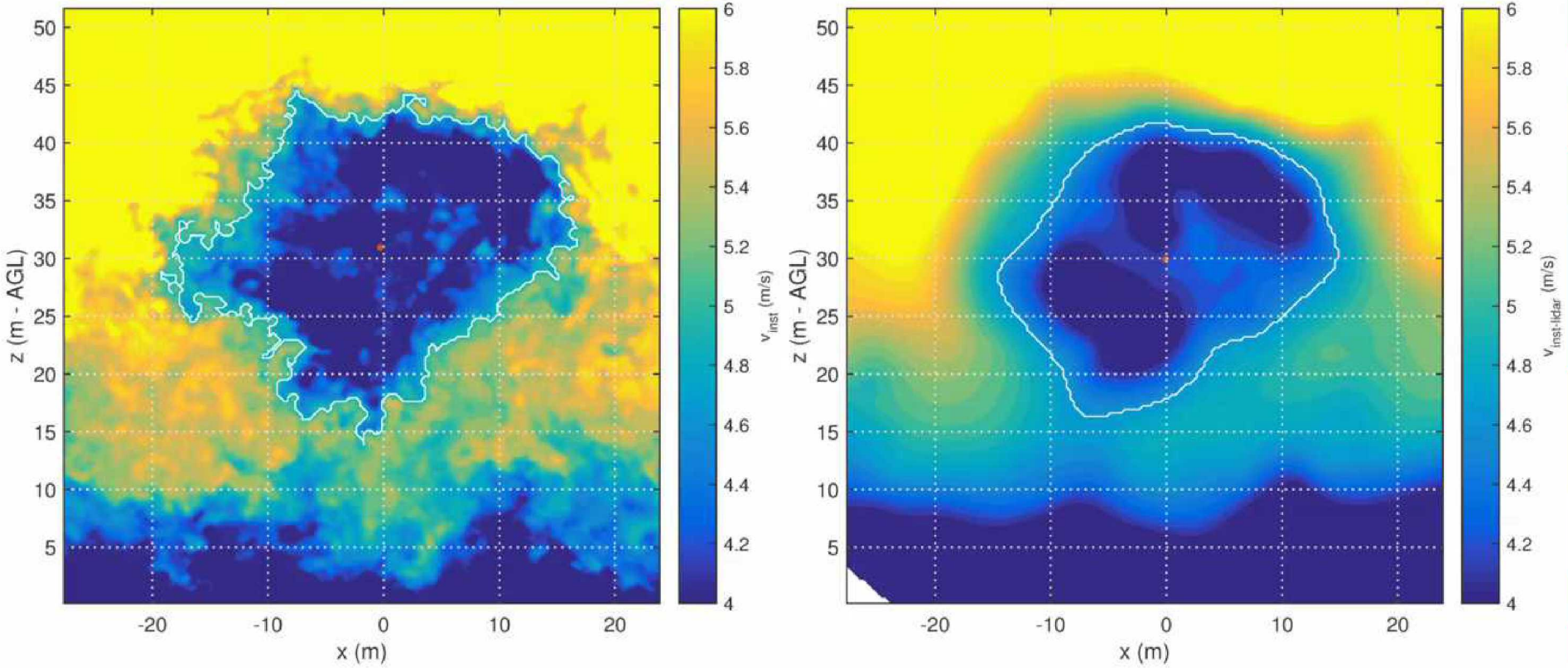
WTGa1: Inflow Statistics



WTGa1: Lidar Simulation and Selection

SOWFA Simulated Velocity

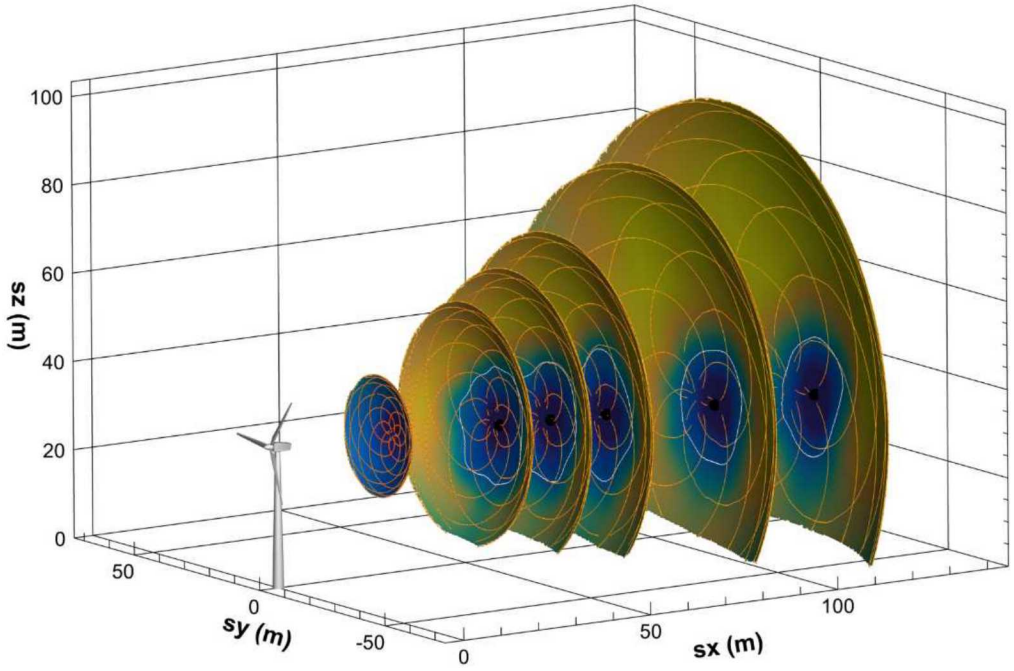
Simulated Lidar Measurements

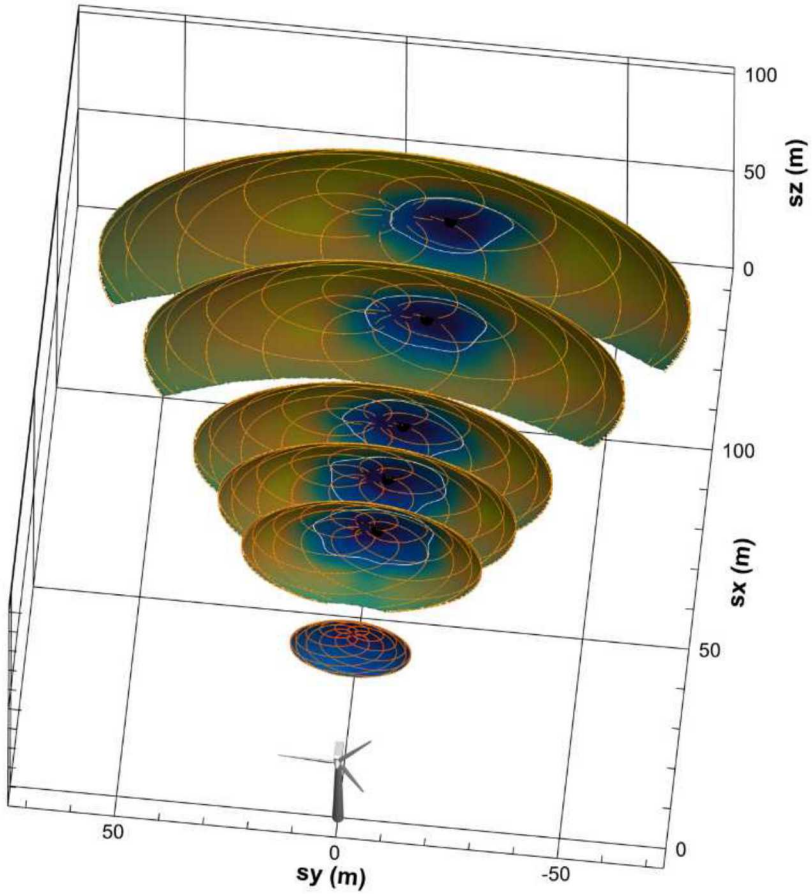


Comparison of identical time steps in order to show effect of SpinnerLidar on measurements and how that impacts wake position determination

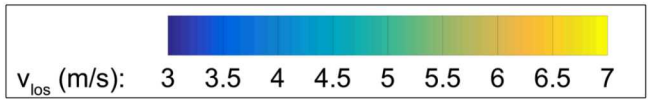
Measurements at 3D downstream of turbine

WTGa1: Measuring impact of inflow - Stable



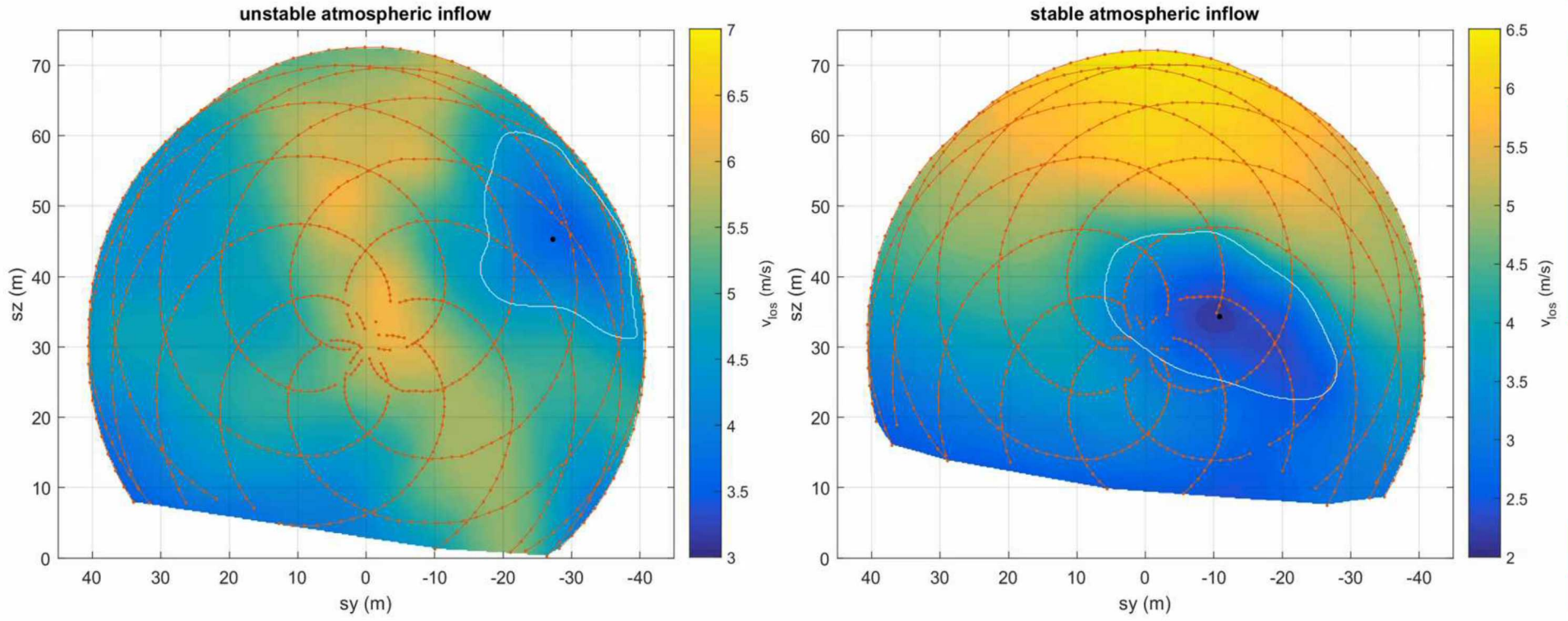


- Bulk Richardson = 1.7
- z/L = 3.4
- α = 0.19
- wind speed = 6.8 m/s
- TI = 0.05
- veer = 0.1°
- yaw offset = 4.0°
- yaw heading = 236.7 degN



WTGa1: Wake Tracking vs Inflow

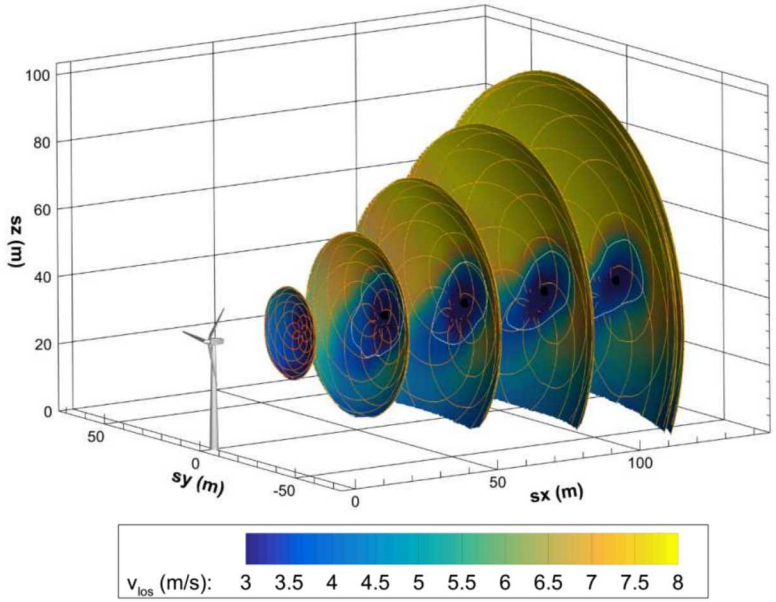
Lidar data viewed 3D (81 m) downstream looking downwind

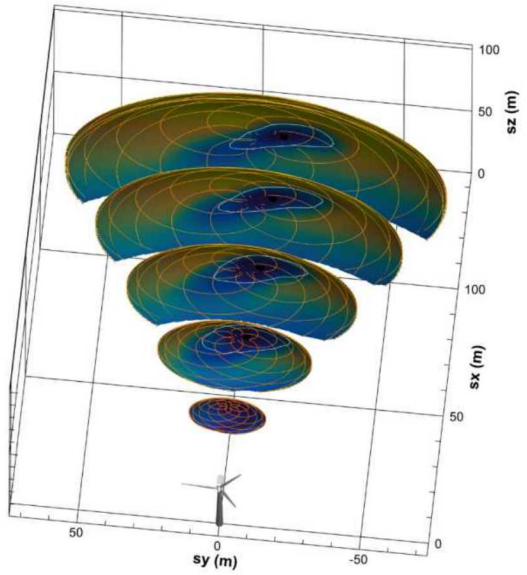


WTGa1: Measuring impact of inflow

Stable ABL Positive Veer

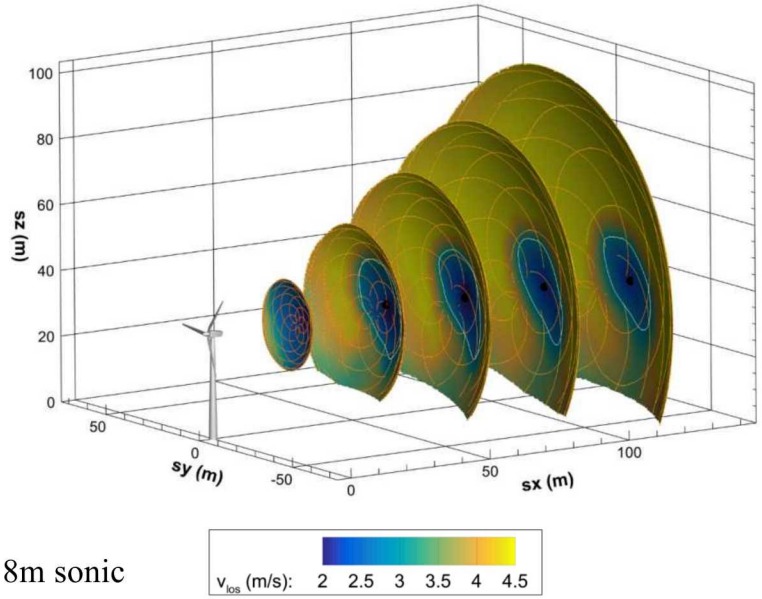
Bulk Rich = 0.7
z/L = 2.3
α = 0.37
TI = 0.04
veer = 14.6°
yaw offset = -0.12°

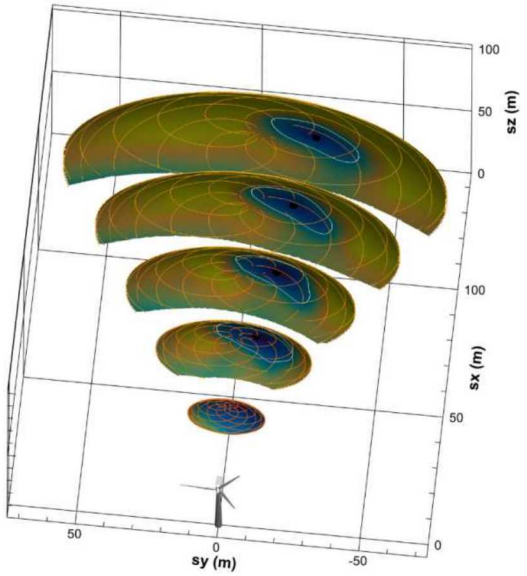




Stable ABL Negative Veer

z/L = 0.9
α = 0.15
TI = 0.08
veer = -5.0°
yaw offset = 10.9°

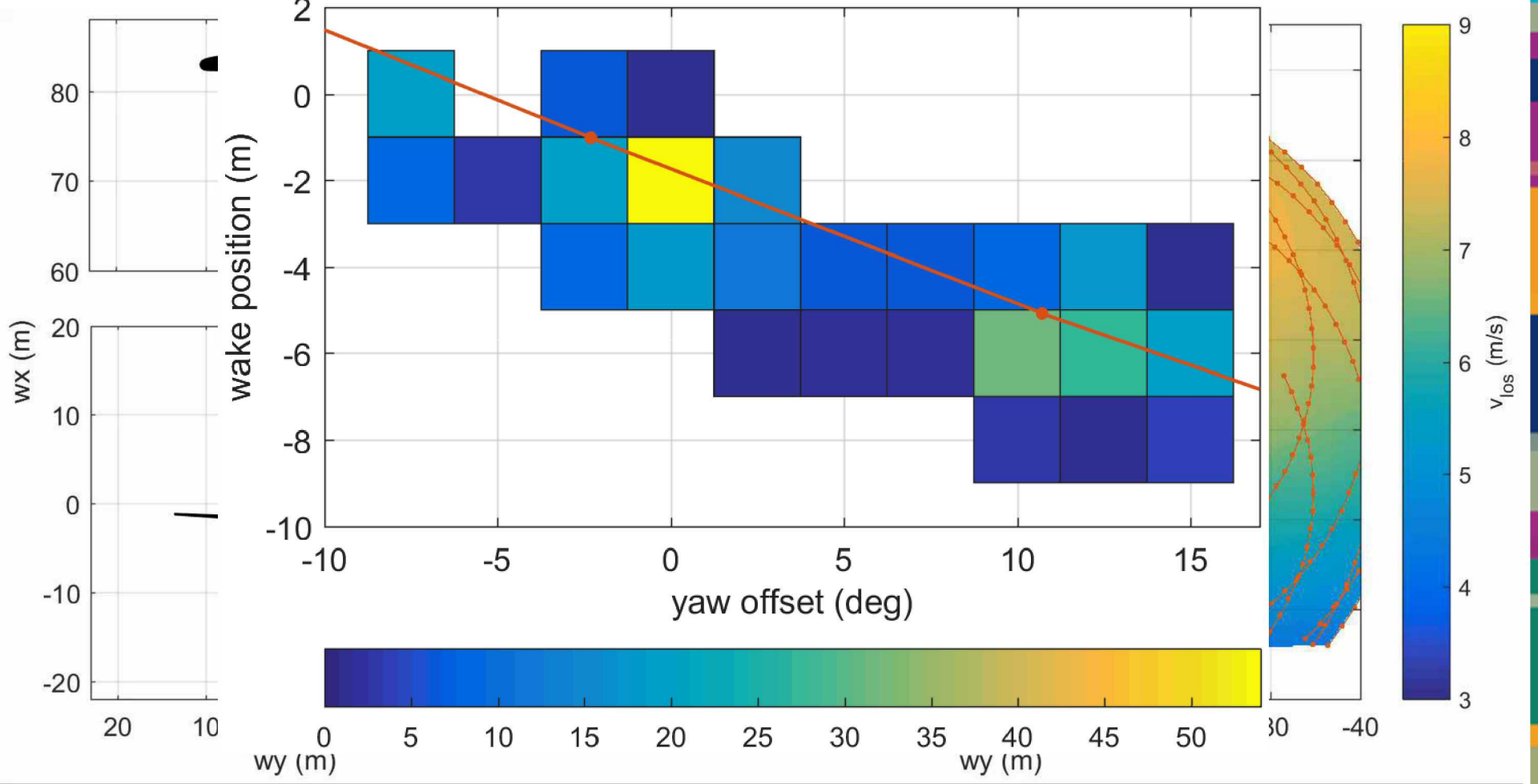




$$veer = \theta_{45\text{m sonic}} - \theta_{18\text{m sonic}}$$

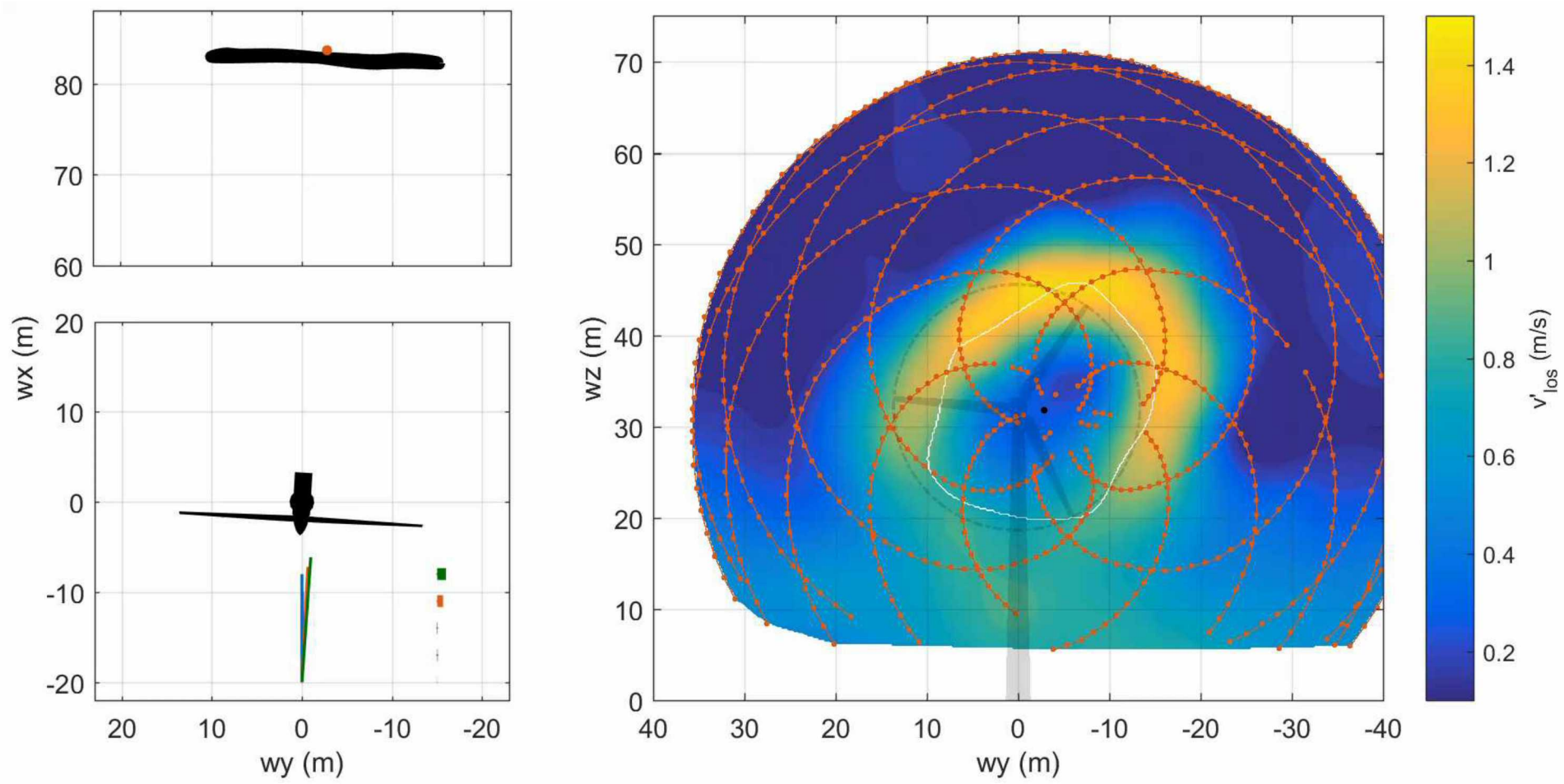
WTGa1: Measuring impact of turbine state

- Bulk Richardson = 0.7
- z/L = 3.1
- α = 0.3
- wind speed = 7.5 m/s
- TI = 0.08
- veer = 4.4°
- yaw offset = -7.5° to 15°
- Yaw heading = 159.5 degN



WTGa1: Measuring impact of turbine state

- Bulk Richardson = 0.7
- z/L = 3.1
- α = 0.3
- wind speed = 7.5 m/s
- TI = 0.08
- veer = 4.4°
- yaw offset = -7.5° to 15°
- Yaw heading = 159.5 degN

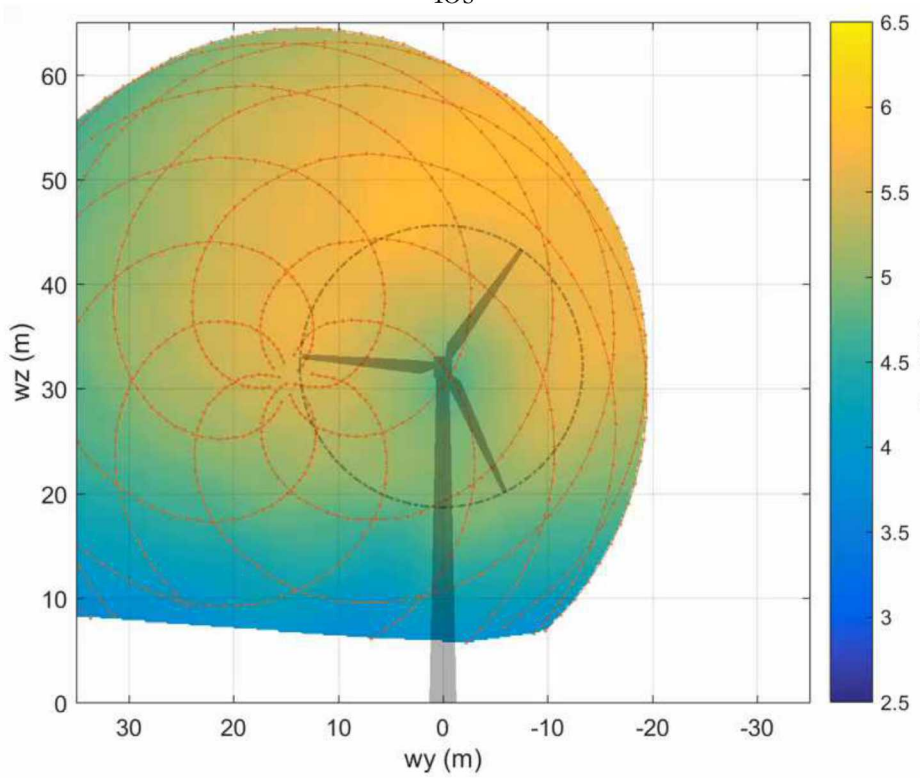


WTGa1: Stable BL Video at 2.5D

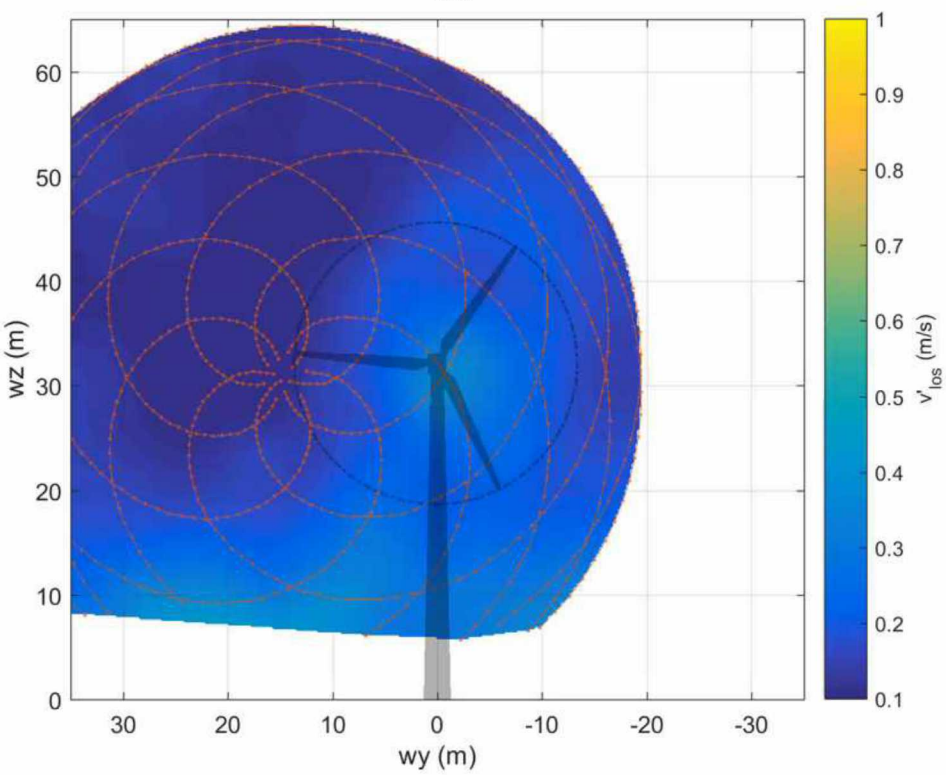
Obukhov length $z/L = 2.3$
$\alpha = 0.25$
wind speed = 5.7 m/s
TI = 0.04
veer = 5.7°
yaw offset = 7.43°
yaw heading = 145.6 degN

Note that you can see turbulence coming off the nacelle and tower before the turbine turns on and the wake forms

v_{los}



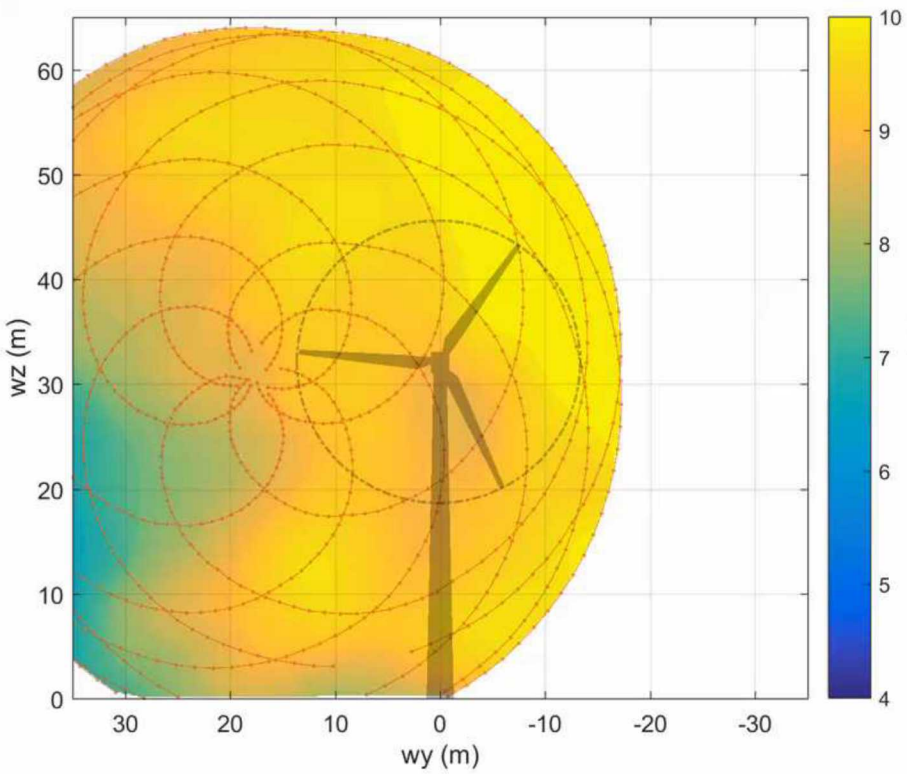
v'_{los}



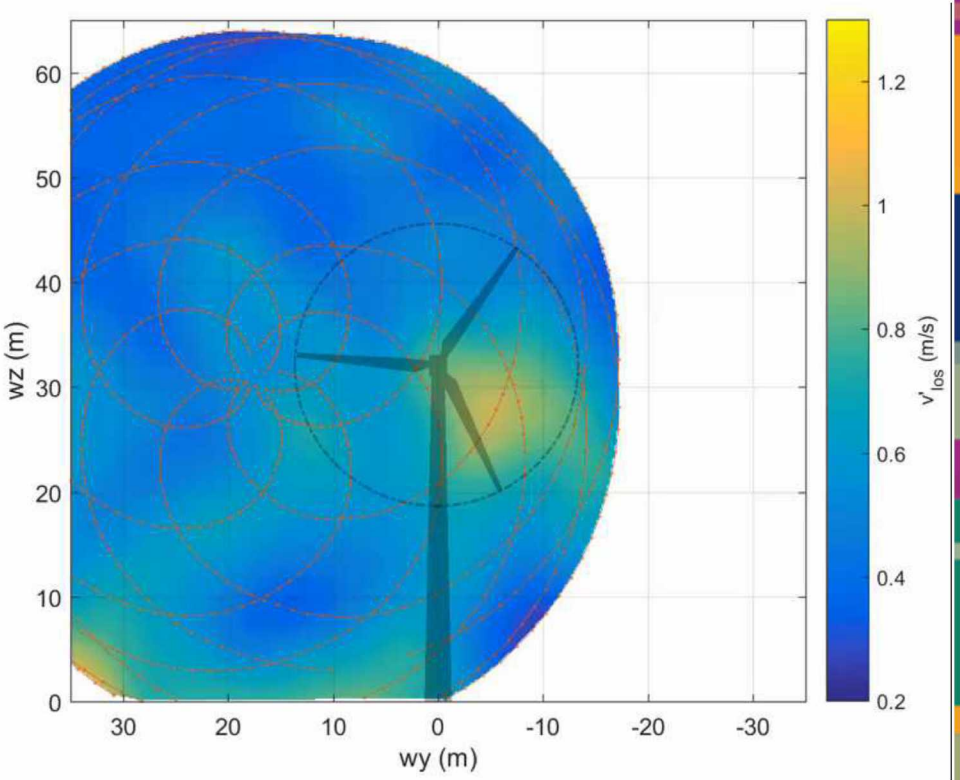
WTGa1: Neutral BL Video at 2.5D

Obukhov length $z/L = 0.0$
$\alpha = 0.12$
wind speed = 9.0 m/s
TI = 0.14
veer = 0.26°
yaw offset = 5.27°
yaw heading = 198.3 degN

v_{los}

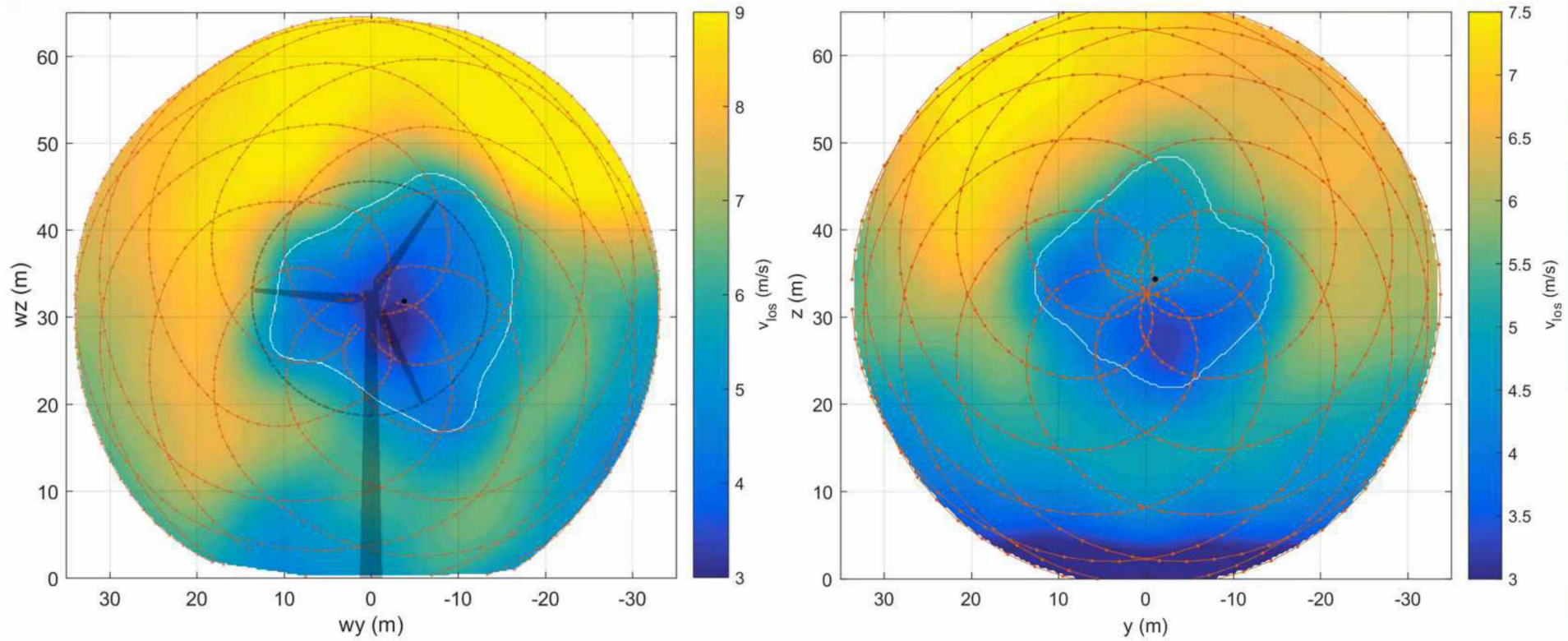


v'_{los}



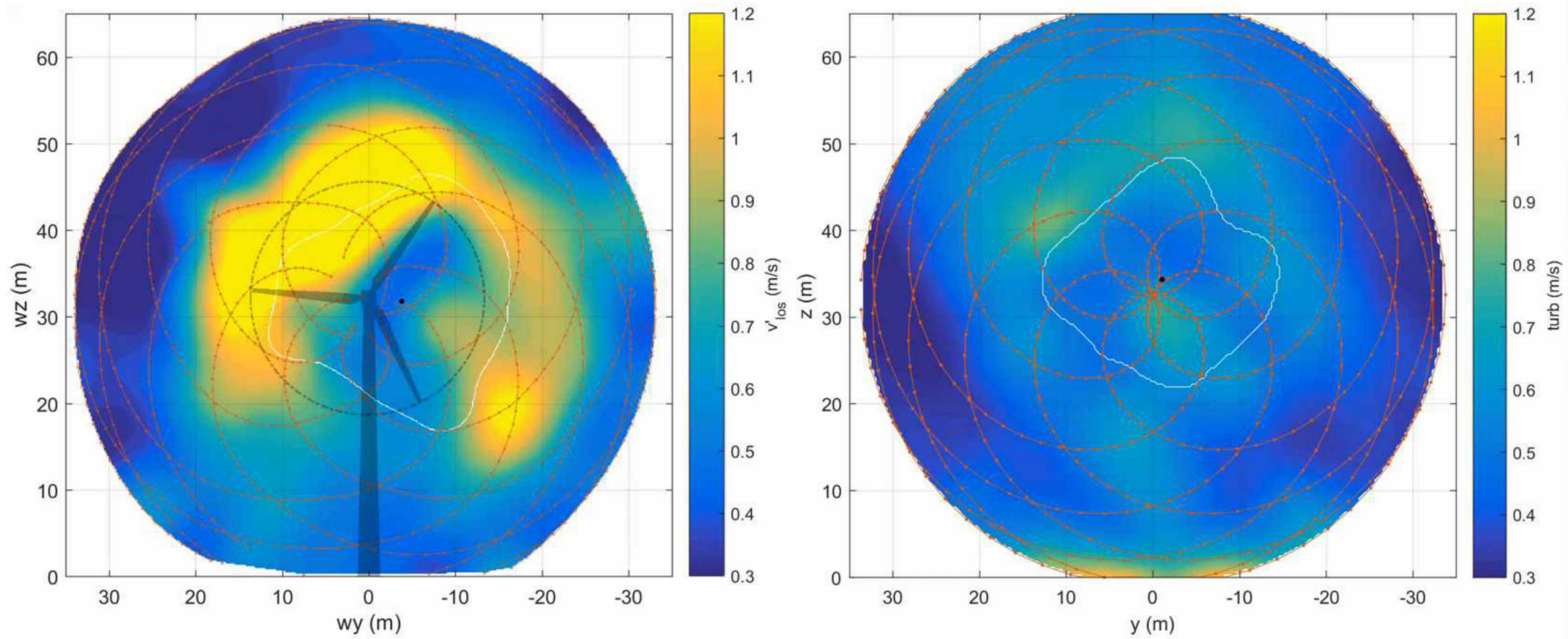
WTGa1: Initial Model Assessment

Measured and Simulated v_{los}

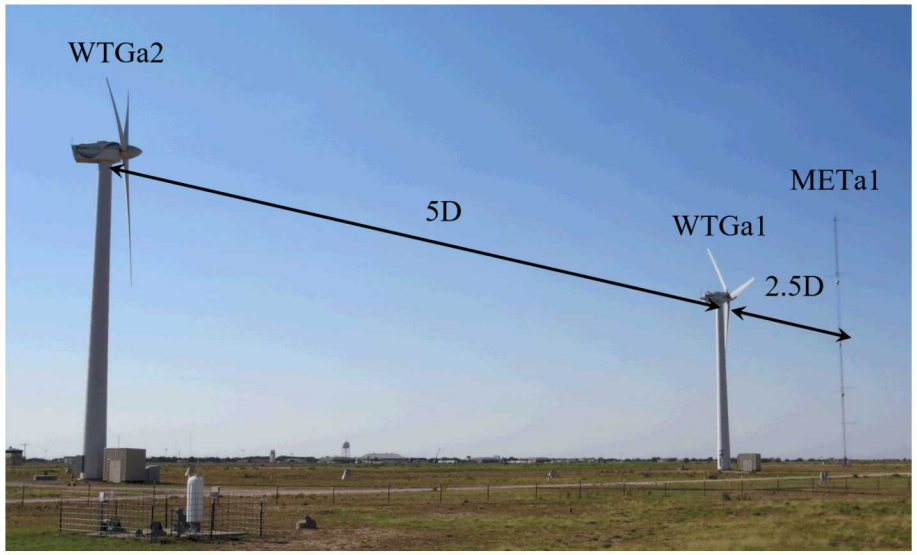


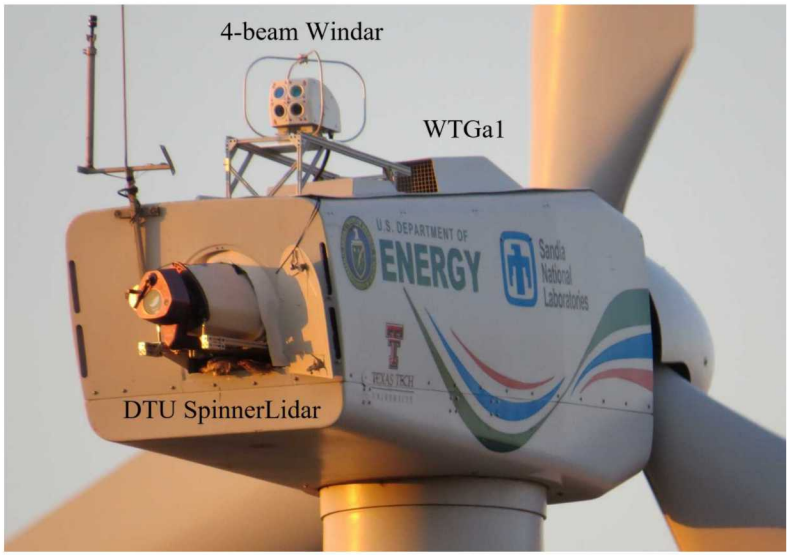
WTGa1: Initial Model Assessment

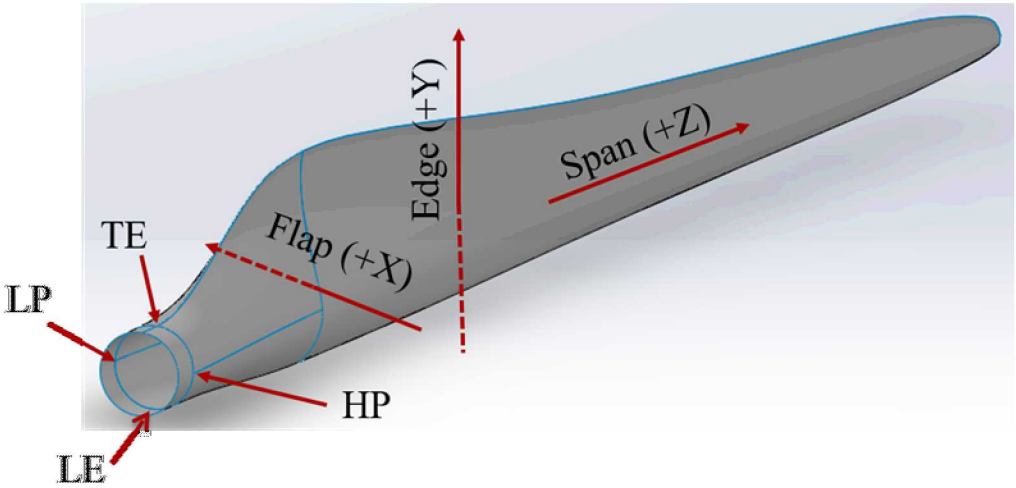
Measured and Simulated v'_{los}



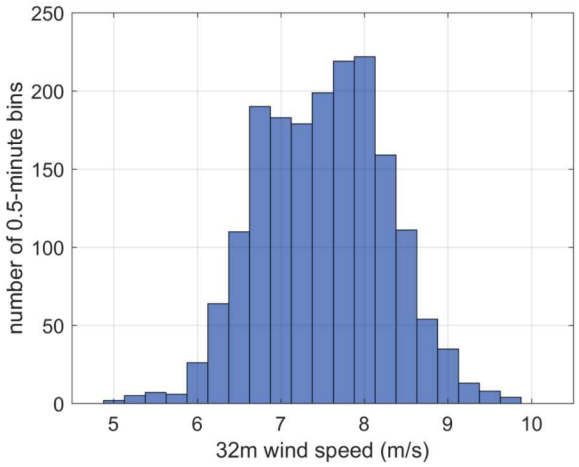
WTGa2: Waked Turbine Setup

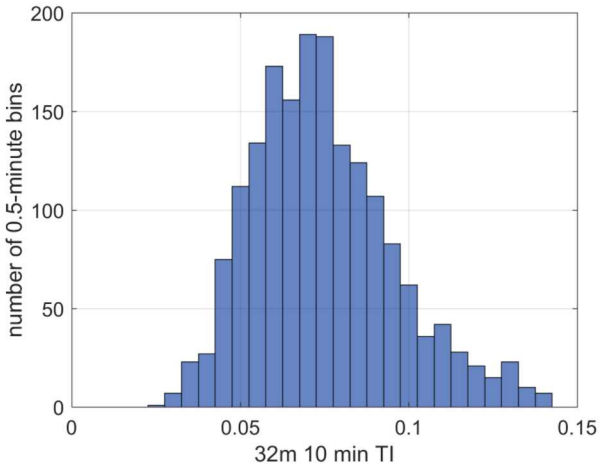


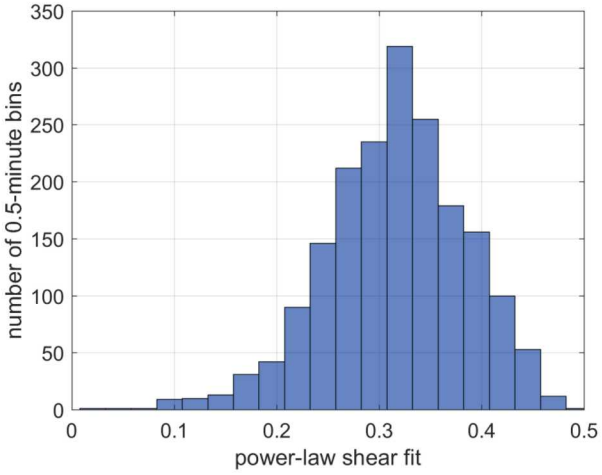




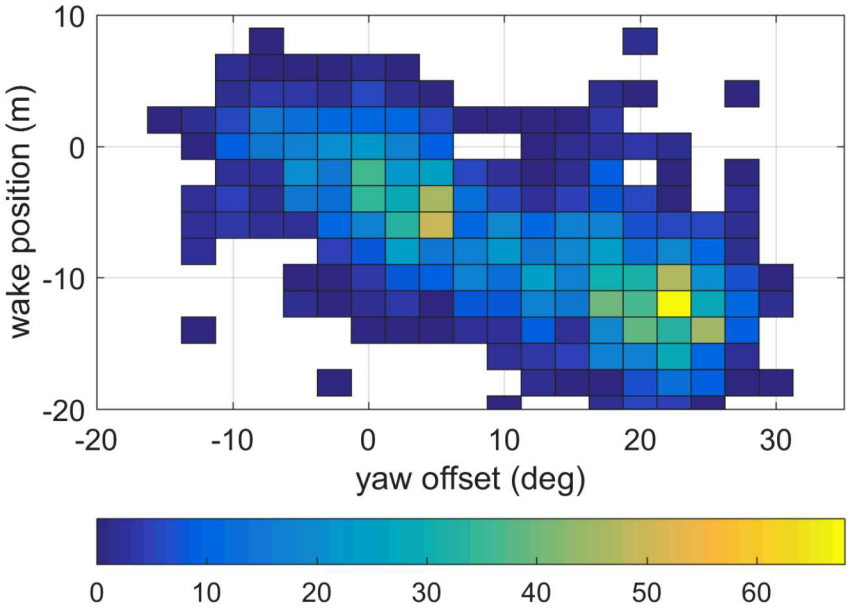
WTGa2: Waked Turbine Inflow Conditions



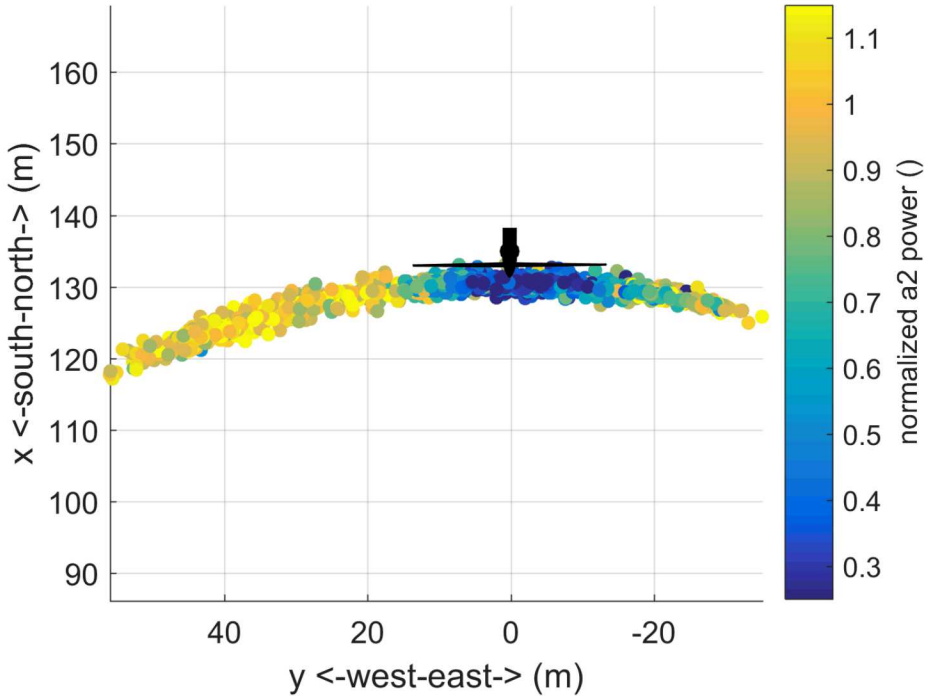


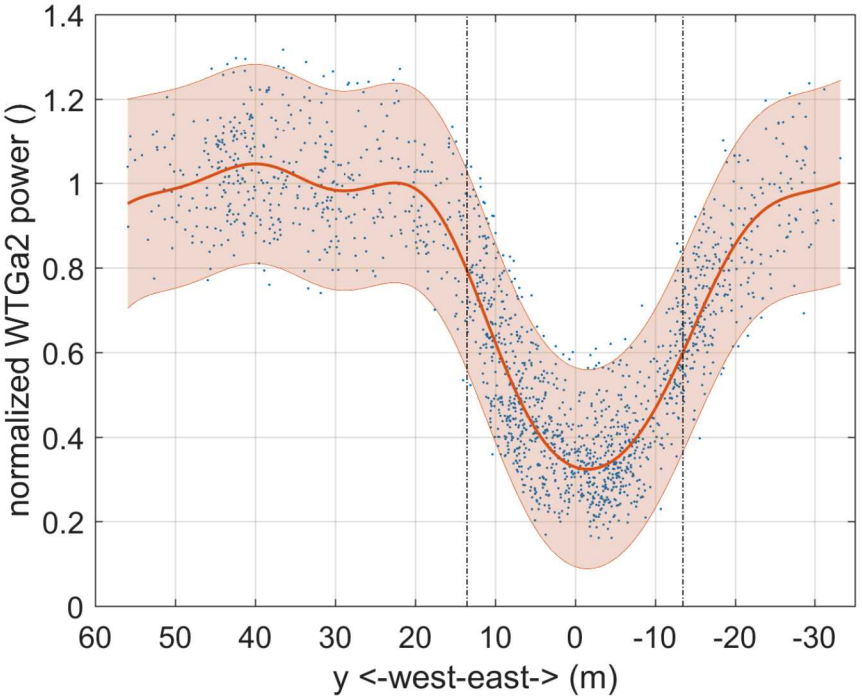


WTGa1 wake deflection vs. yaw offset during waked turbine period

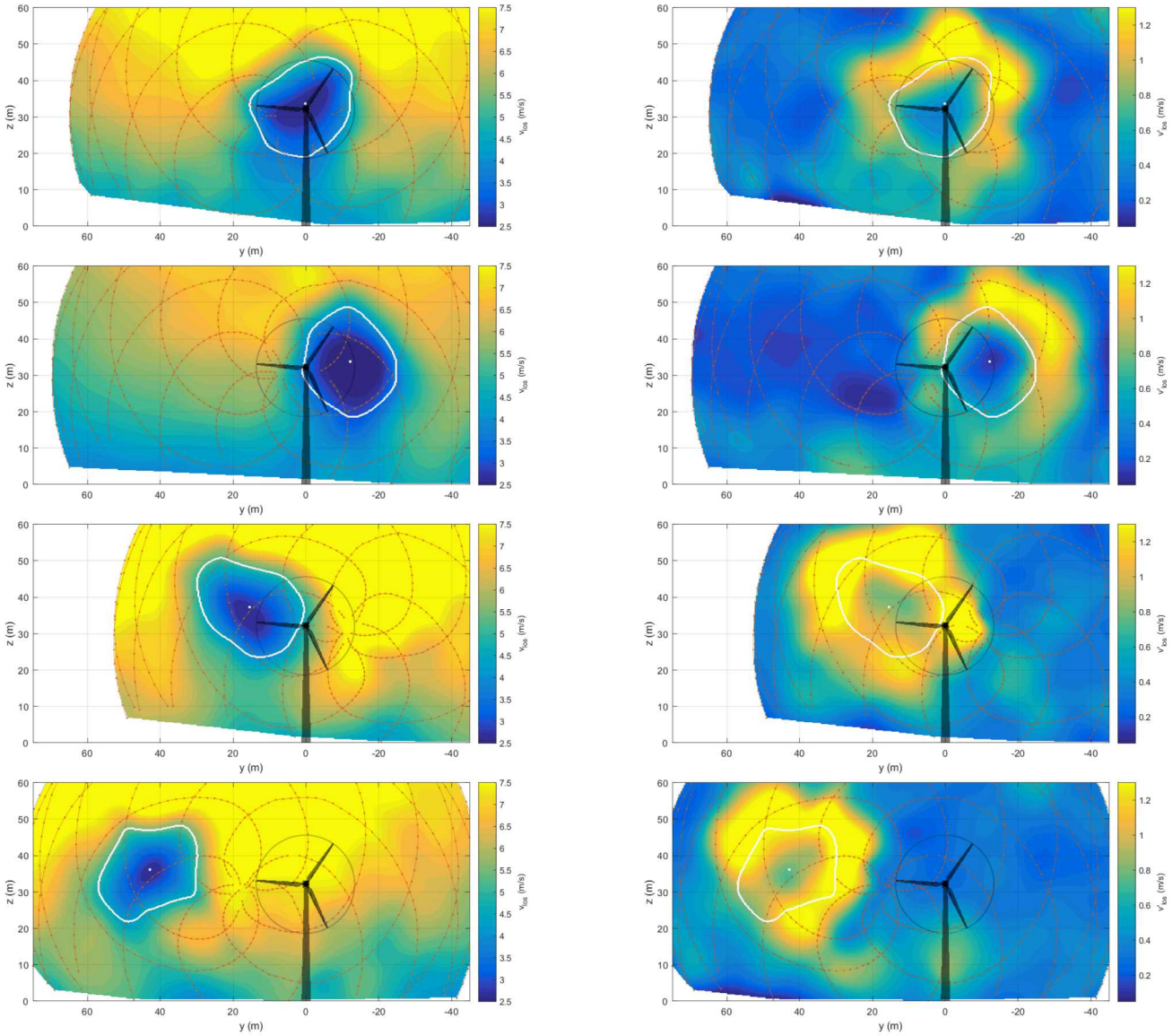


WTGa2: Measurement Arc and Power Output



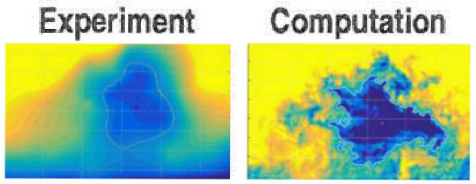


WTGa2: Wake Positions

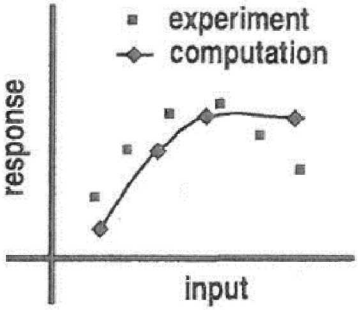


Uncertainty Quantification

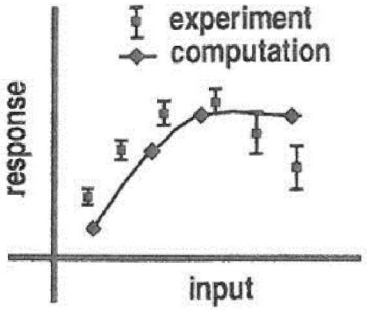
Levels of Precision



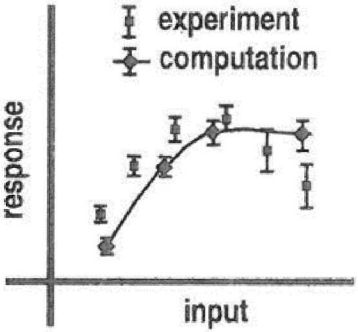
(a) Viewgraph Norm



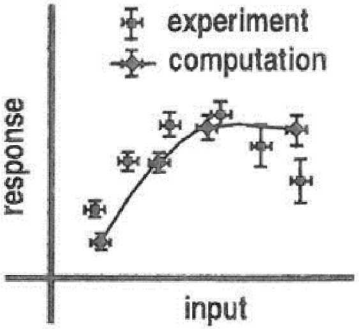
(b) Deterministic Simulation



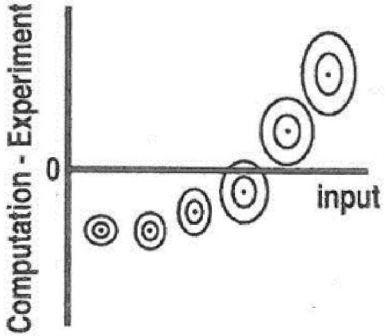
(c) Including Experimental Uncertainty



(d) Including Numerical Error



(e) Nondeterministic Simulation



(f) Statistical Mismatch

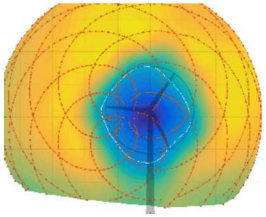
Modified from Oberkamf and Roy, 2012

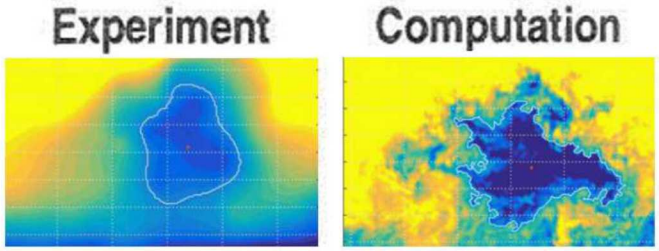
SWiFT UQ

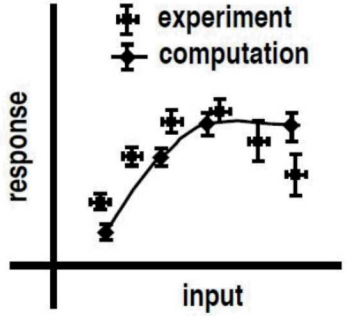
Objective: Conduct Uncertainty Quantification on experimental data from SWiFT data sets for inflow, turbine, and wake quantities of interest.

Outcome: A quantitative assessment of experimental uncertainty and model prediction uncertainty using probabilistic methods for turbine and wake quantities of interest.

SWiFT

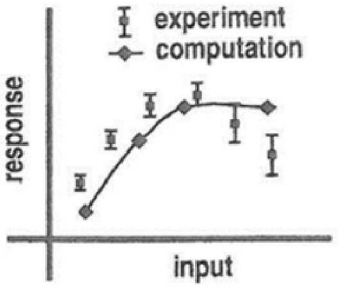






SWiFT Site Experimental Uncertainty Quantification

- Inflow Measurements
  - α
  - ρ
  - p
  - RH
  - T
  - TI (sonic)
  - U_∞ (sonic)
  - U (sonic)
  - V (sonic)
  - U_∞ (cup)
  - U_∞ (nacelle)
  - Vr (sonic)
  - WD (sonic)
  - WD (vane)
- Turbine Measurements
  - Aerodynamic power
  - Rotor speed
  - Aerodynamic torque
  - Rotor thrust
  - Individual blade root loads (instantaneous)
  - Individual blade loading profile (instantaneous)
  - Nacelle measured wind direction
  - Nacelle measured wind speed
  - Yaw heading
  - Yaw misalignment
  - Blade pitch
  - Rotor azimuth
  - Nacelle acceleration
- Wake Measurements
  - DTU Spinner Lidar
  - Wake identification and tracking
  - Turbulence estimators



SWiFT Site Experimental Uncertainty Quantification

Measurand	units	u	u/mean (%)	mean
α	—	1.88×10^{-3}	0.89	0.21
ρ	kg/m^3	7.9×10^{-4}	0.0731	1.08
p	Pa	1.53	1.71×10^{-3}	89500
RH	%	2.01	4.49	46.8
T	K	0.212	0.0733	289
TI (sonic)	—	1.23×10^{-3}	1.02	0.12
U_∞ (sonic)	m/s	0.0439	0.207	6.82
U (sonic)	m/s	0.01	0.207	4.82
V (sonic)	m/s	0.01	0.207	4.82
U_∞ (cup)	m/s	0.20	2.93	6.82
U_∞ (nacelle)	m/s	0.50	7.33	6.82
Vr (sonic)	°	1.73	86	2.0
WD (sonic)	°	1.22	0.69	176
WD (vane)	°	1.20	0.68	176

Data Archive and Portal Plan

Goal to have data on DAP by end of Q3 2018

Uploaded data will provide 10-min bin data for sorting

Data loaded chronologically

Sample of data will be purposefully withheld for benchmark

Welcome any suggestions on formatting and distribution