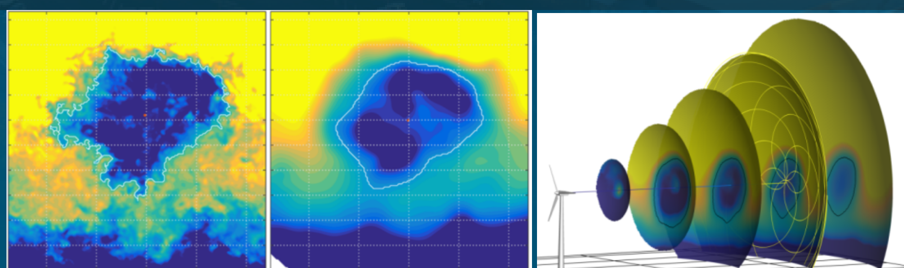
SAND2019-5586C

Sandia National Laboratories

Robust Lidar Data Processing and Quality Control Methods Developed for the SWiFT Wake Steering Experiment



PRESENTED BY

Tommy Herges and Patrick Keyantuo

Wake Conference 2019: 2019-05-22

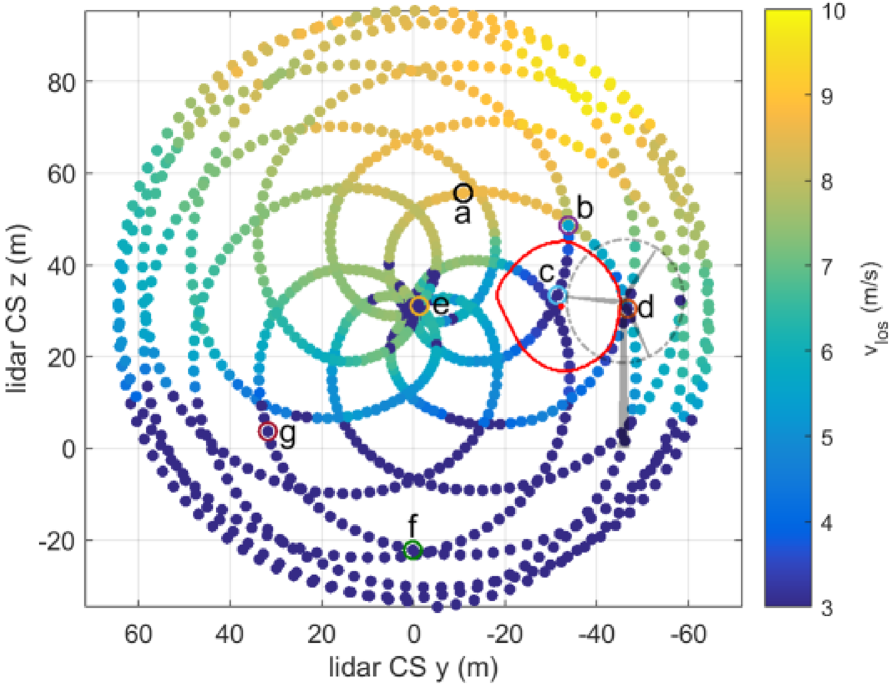
SAND2019-#### C

Funded by DOE Wind Energy Technologies Office

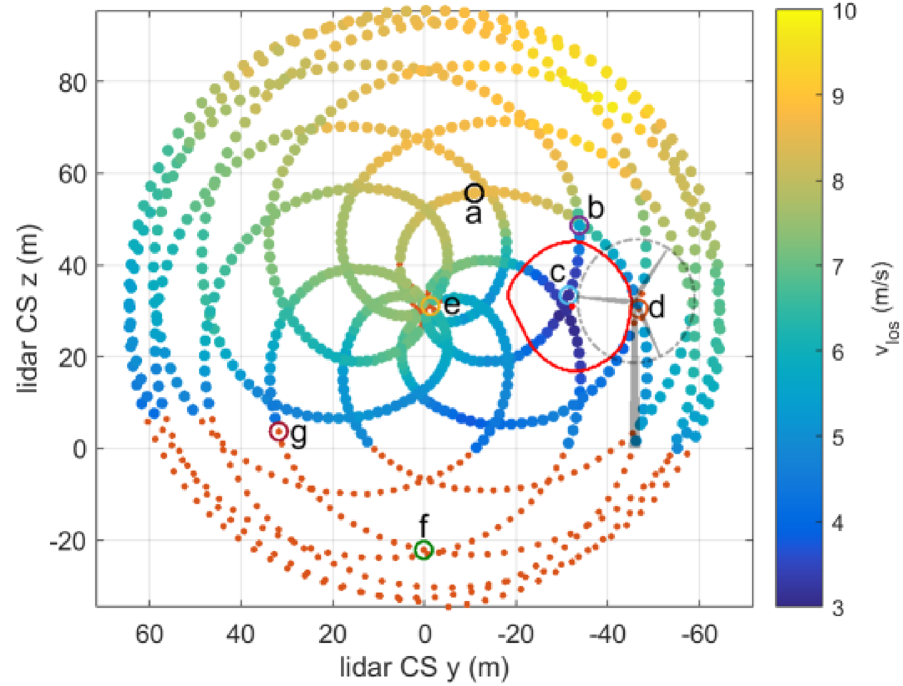
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Importance of QA/QC

Original



Final QA/QC

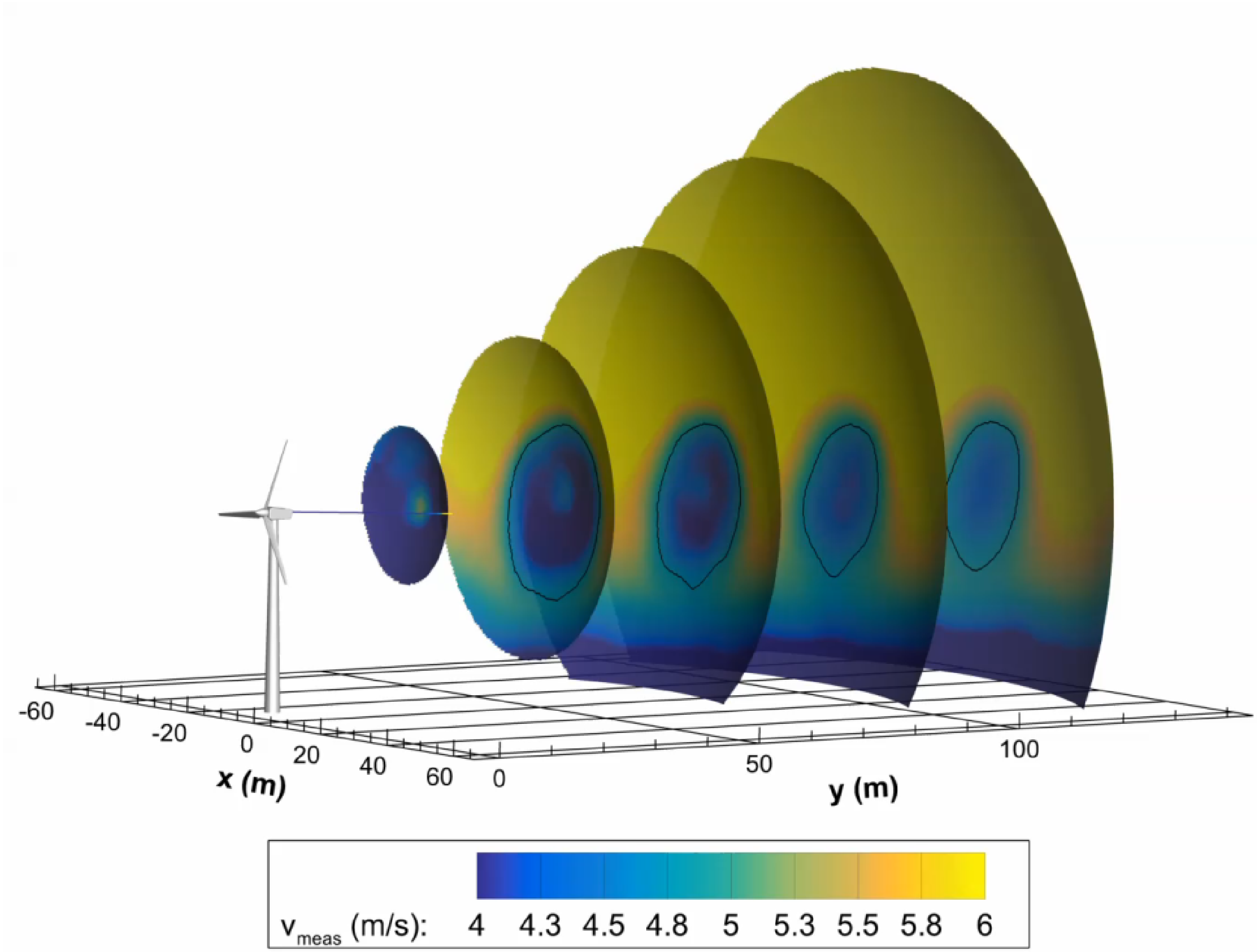


- Invalid measurements could negatively effect:
  - Control decisions
  - Confuse physical phenomena
- Wake is difficult more difficult to discern near hard target returns
- Measurements in the edge of the wake are often removed with traditional QA/QC methods

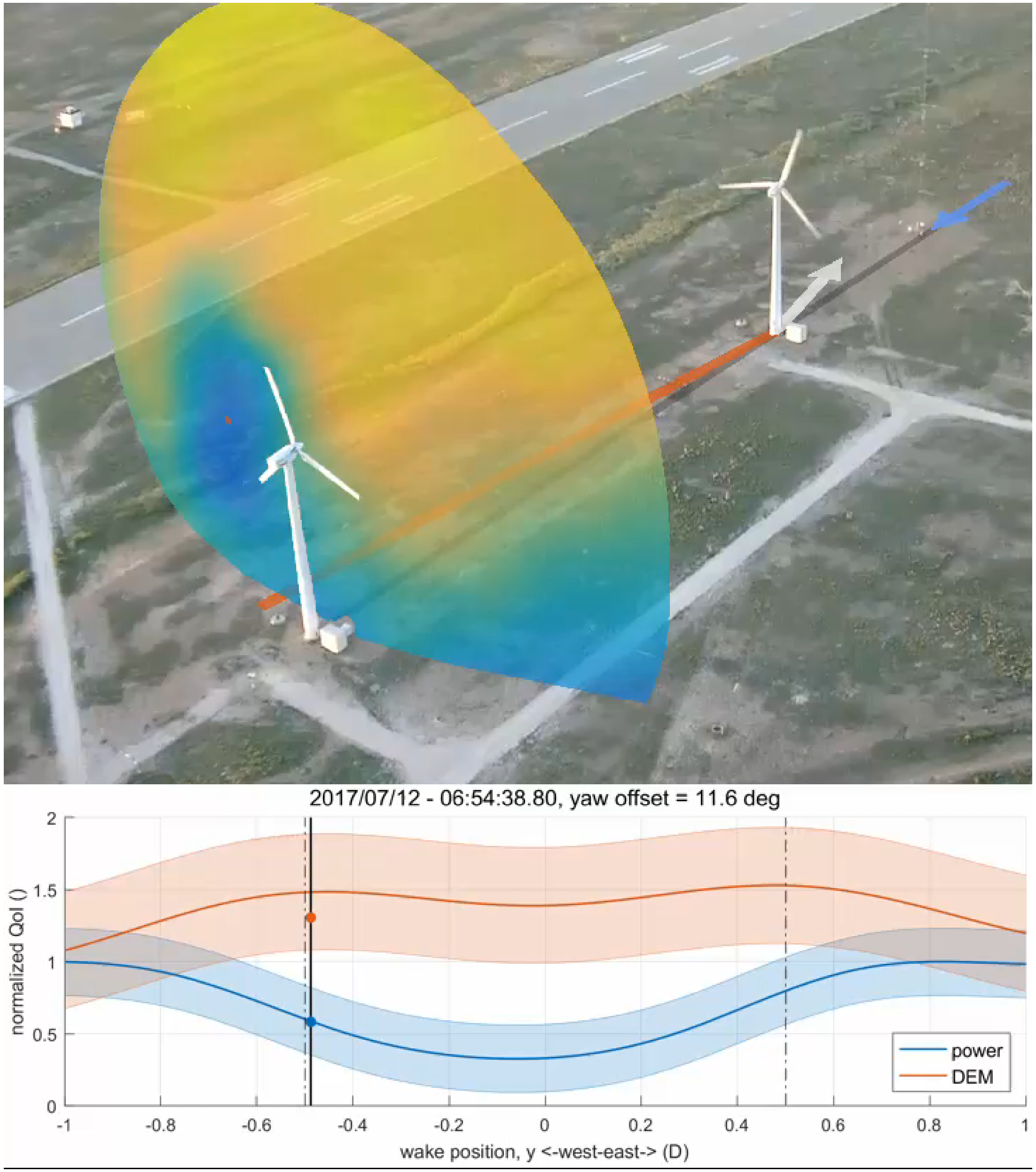
Introduction

- DOE WETO undertaking large verification and validation effort of high-fidelity models to improve modeling of wind turbine wakes
- High-quality measurements of wind turbine wakes required for validation
- DOE SNL/SWiFT facility is a unique open wind plant test site for studying wind turbine wakes and turbine-turbine interactions
- DTU SpinnerLidar capable of capturing wake at high spatial and temporal resolutions
- Description of processing method developed for the DTU SpinnerLidar data acquired during the Wake Steering Experiment at the SWiFT facility
- Including quality assurance and quality control (QA/QC) methods for release of the data on the DOE Atmosphere to Electrons (A2e) Data Archive Portal (DAP)
- QA/QC approach uses feature identification of common measurement errors within the Doppler power spectra "image" and two dimensional spatial implementation of traditional outlier detection methods
- New methods allow more accurate line-of-sight velocity measurements

DTU SpinnerLidar Scan Pattern



DTU SpinnerLidar at SWiFT Facility



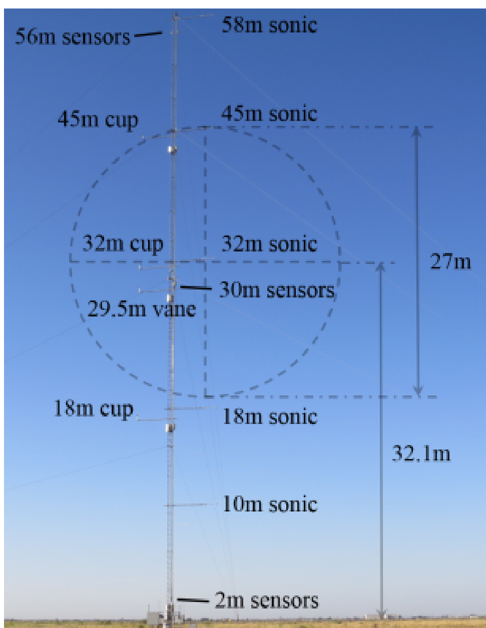
SWiFT Facility Overview

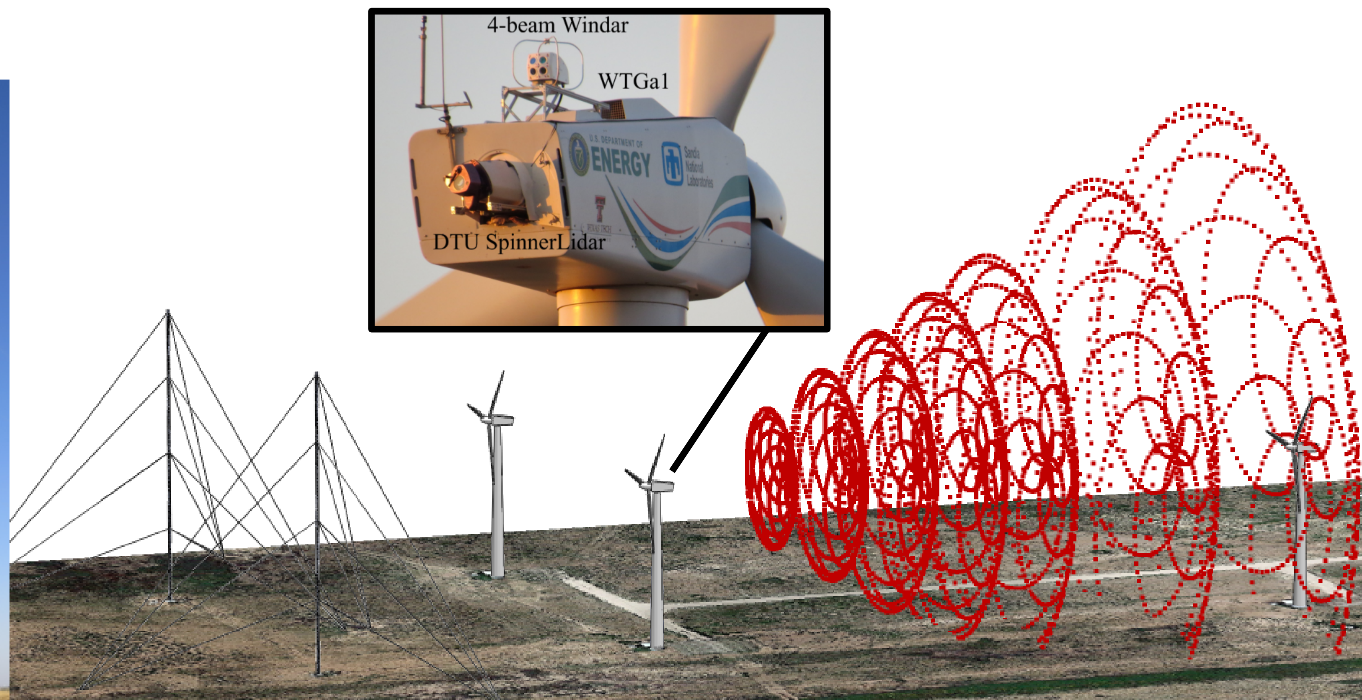
SWiFT facility created to:

- 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

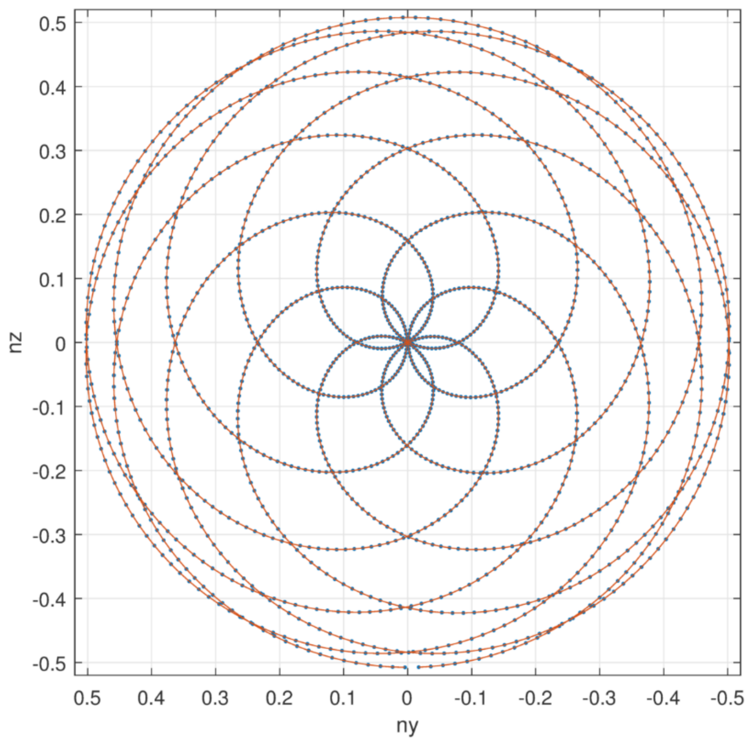
- Characterize wake shape, velocity deficit, turbulence, and dynamics under various conditions

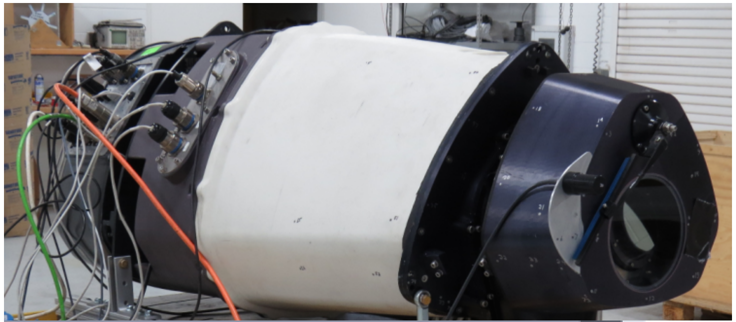


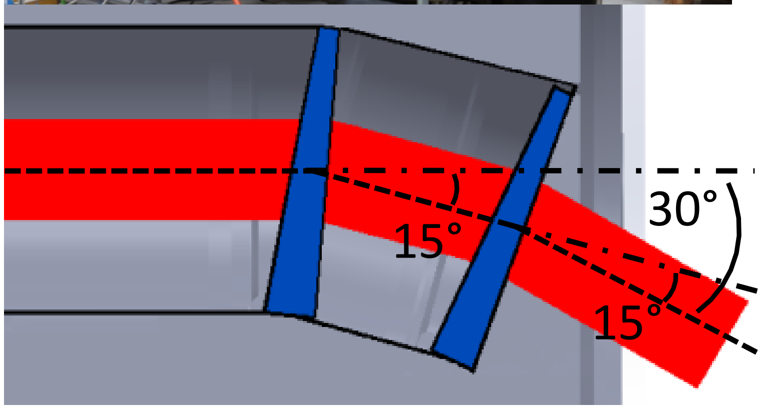


How SpinnerLidar Samples Flowfield

- DTU SpinnerLidar scan pattern
  - 984 points in 2 seconds
  - Continuously acquiring data over that time
  - Each point is an average of velocity spectra along arc between points
  - Fixed scan pattern due to fixed gear ratio of spinning prisms
  - Number of points per scan and duration of scan can be adjusted

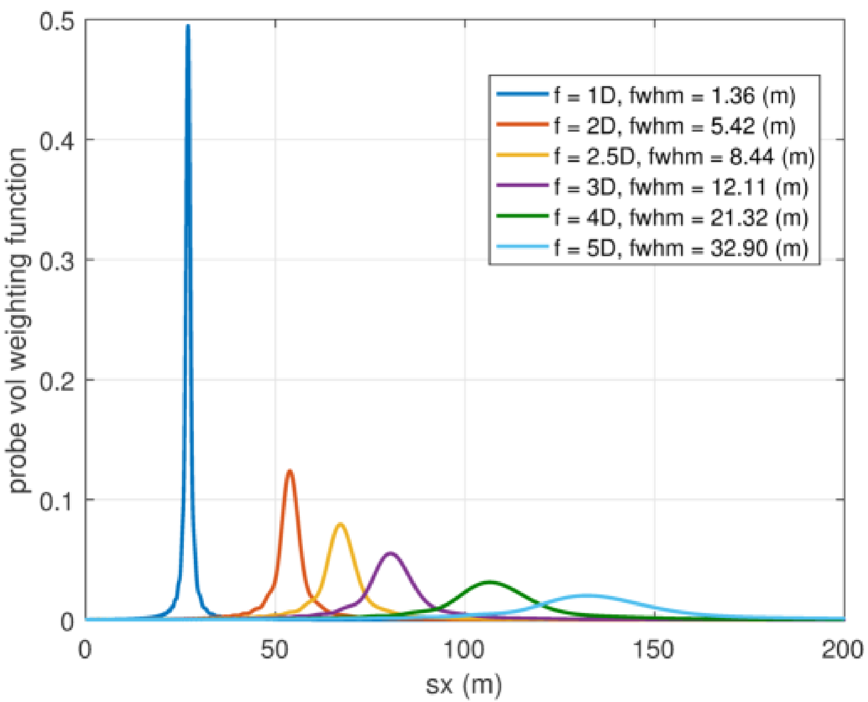


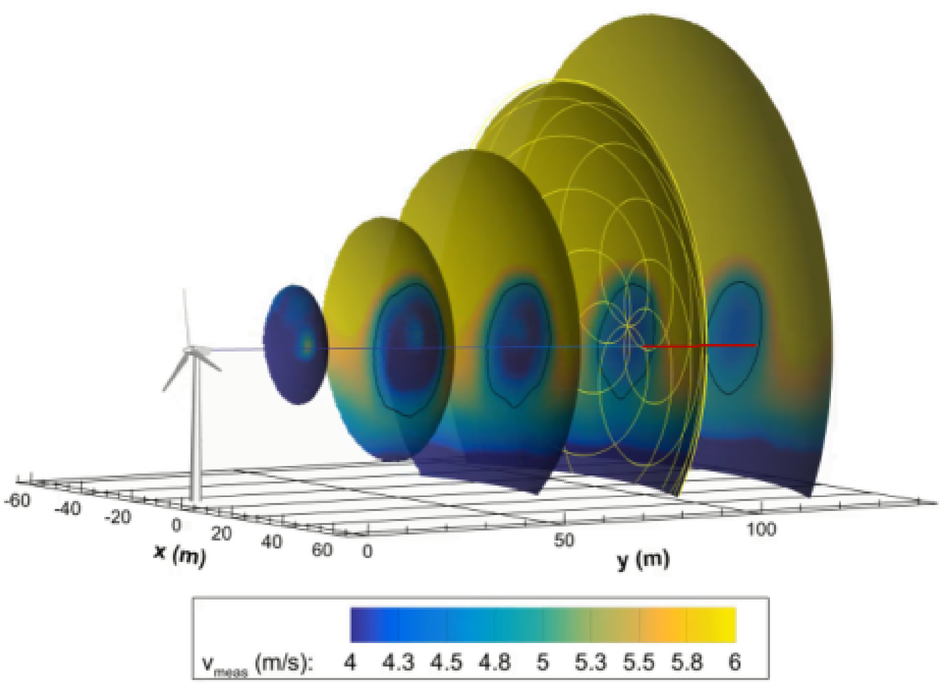




How SpinnerLidar Samples Flowfield

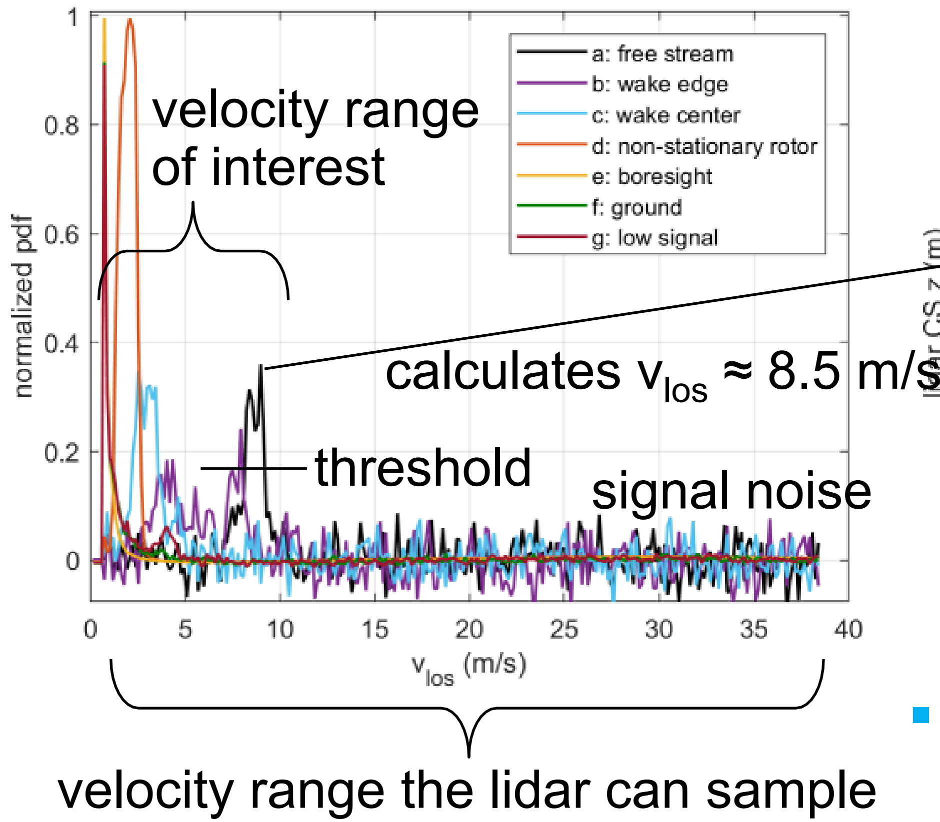
- Probe volume weighting function
  - Line-of-sight velocities along beam vector sampled with weighting function
  - Weighting function dependent on focus distance

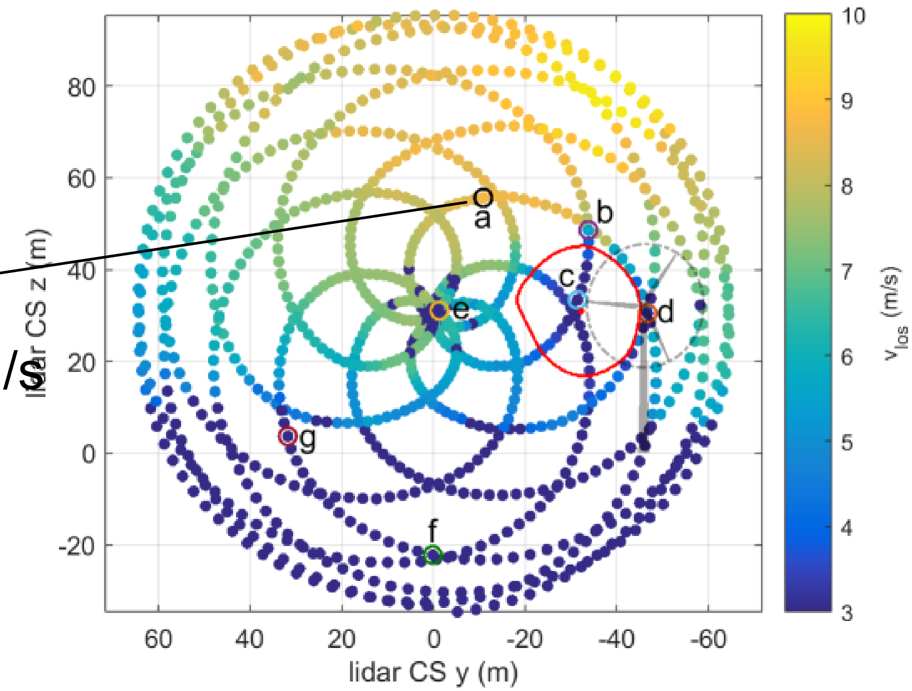




How SpinnerLidar Samples Flowfield

- Normalized Doppler power spectra
  - Most processing methods calculate the centroid or geometric median from the normalized pdf above a threshold of 5σ

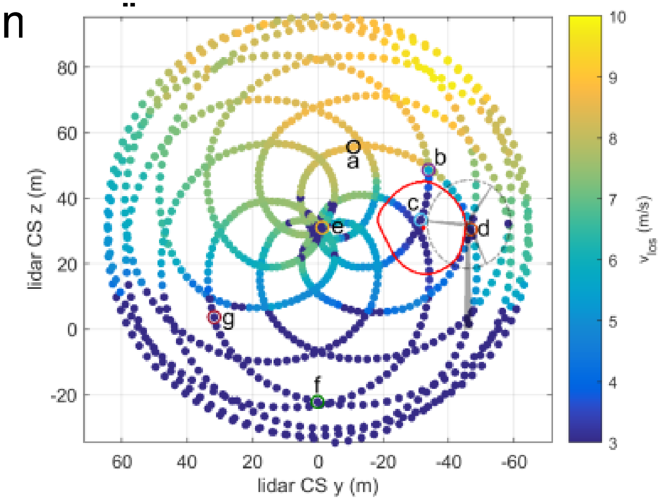


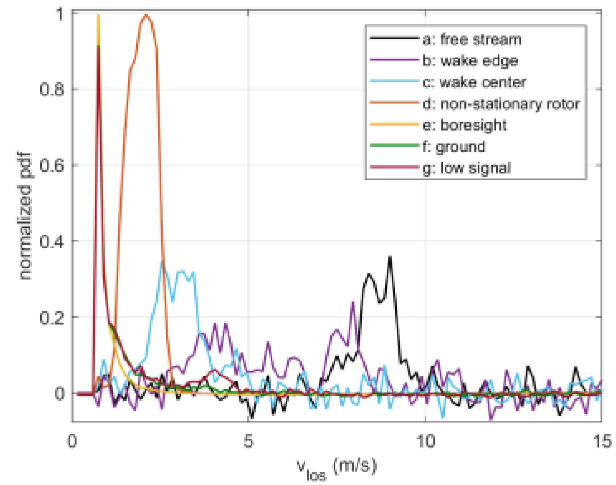


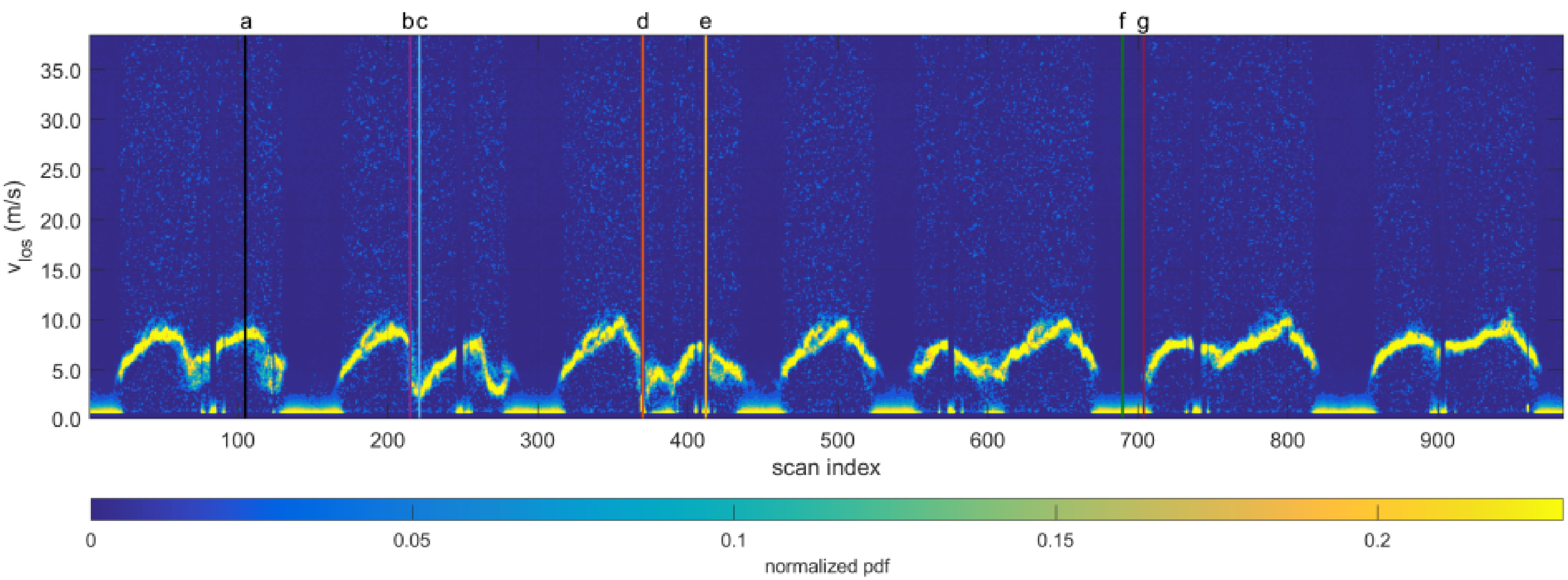
- Signal noise
  - Primarily due to shot noise from weak laser signal return
  - Averaging over longer time periods would reduce noise

How SpinnerLidar Samples Flowfield

- Doppler power spectra
  - Each scan has 984 pdf's of power spectra resulting in a Doppler spectra "in

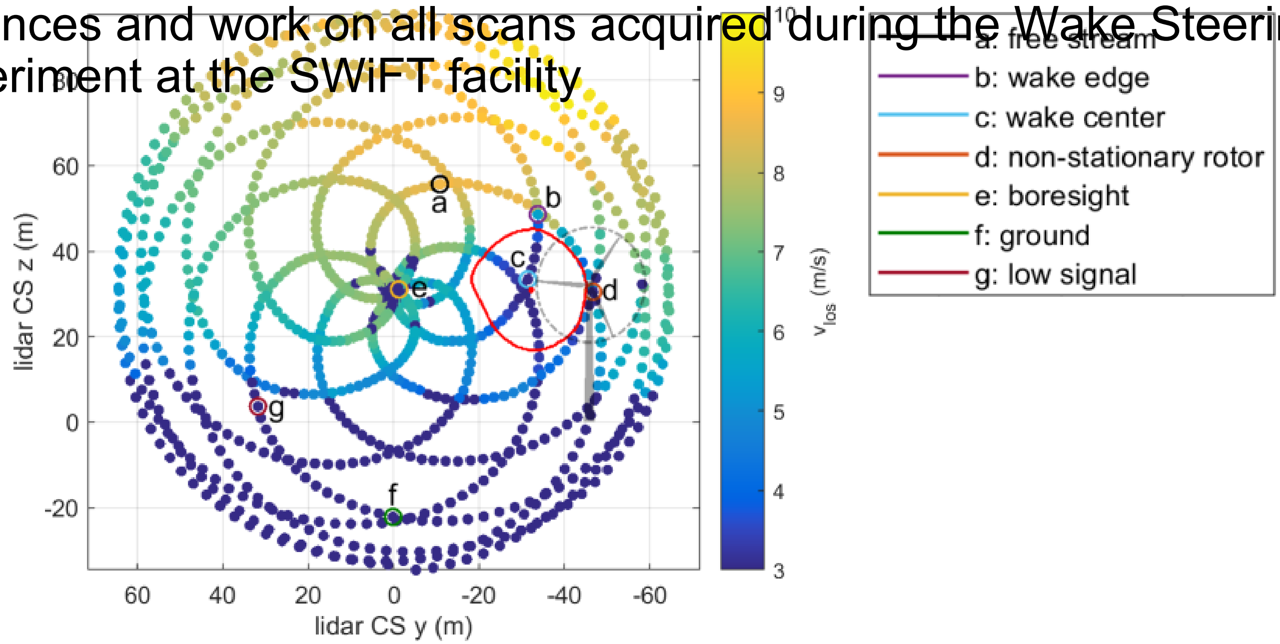




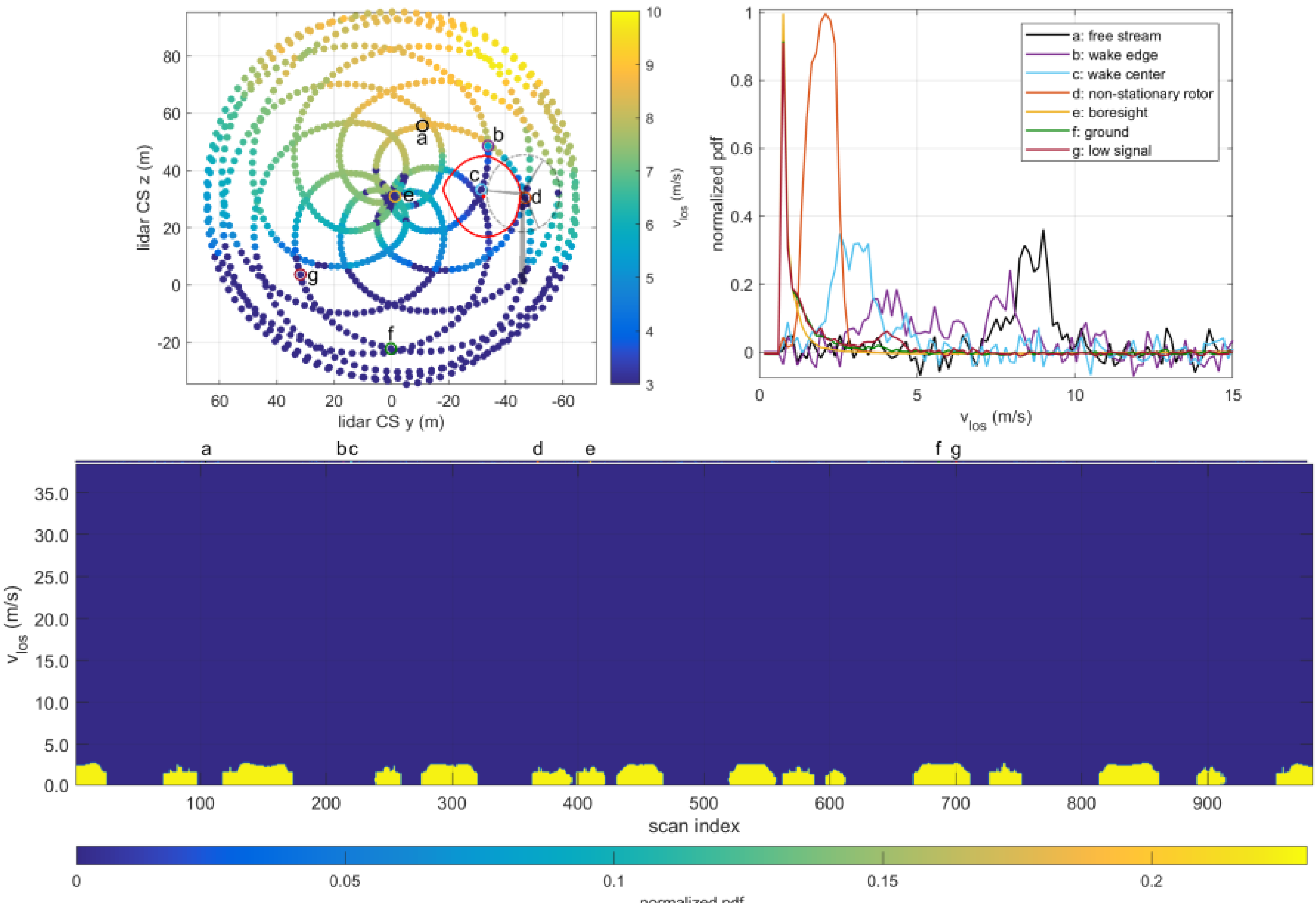


Example Scan to Show Processing Method

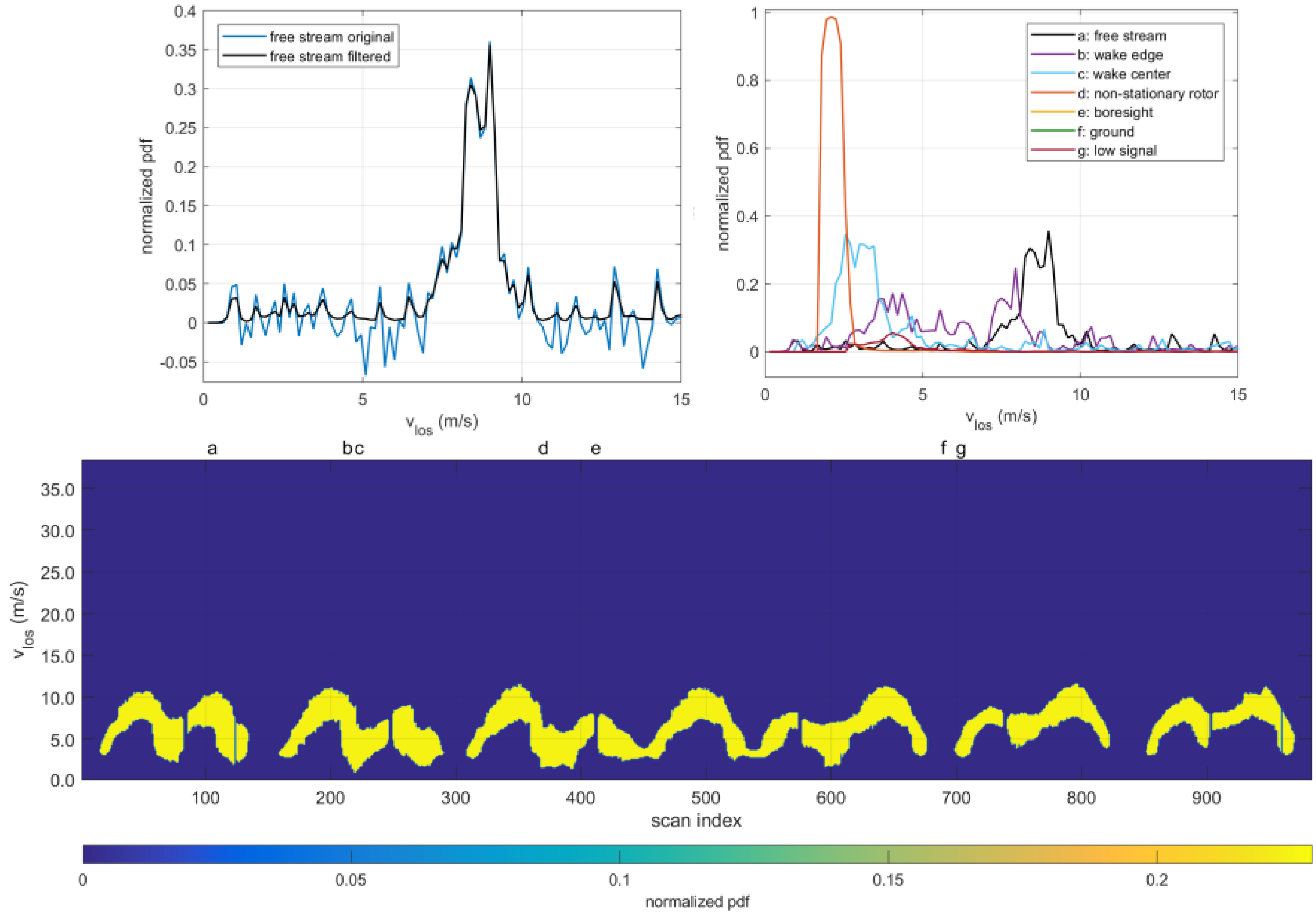
- Doppler power spectra image displays features, or patterns, of invalid measurements that can be isolated and removed
  - Stationary returns from boresight and ground
  - Non-stationary rotor returns
  - Low signal returns
- Will demonstrate the processing methodology using an example scan that contains all of these Doppler spectra features and we will step through each process
  - Processing methods were developed using many scans with various focus distances and work on all scans acquired during the Wake Steering Experiment at the SWiFT facility



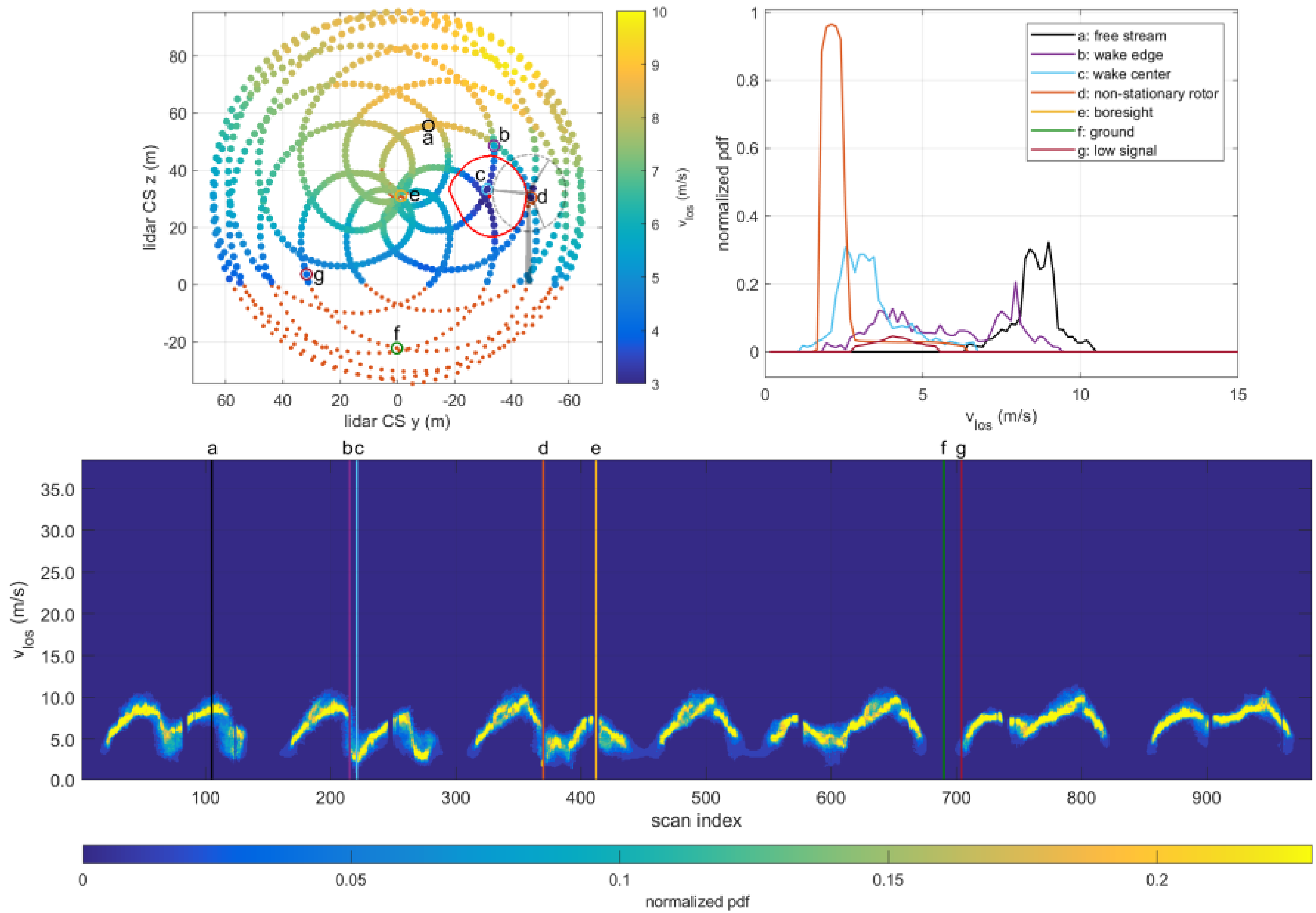
Original Scan



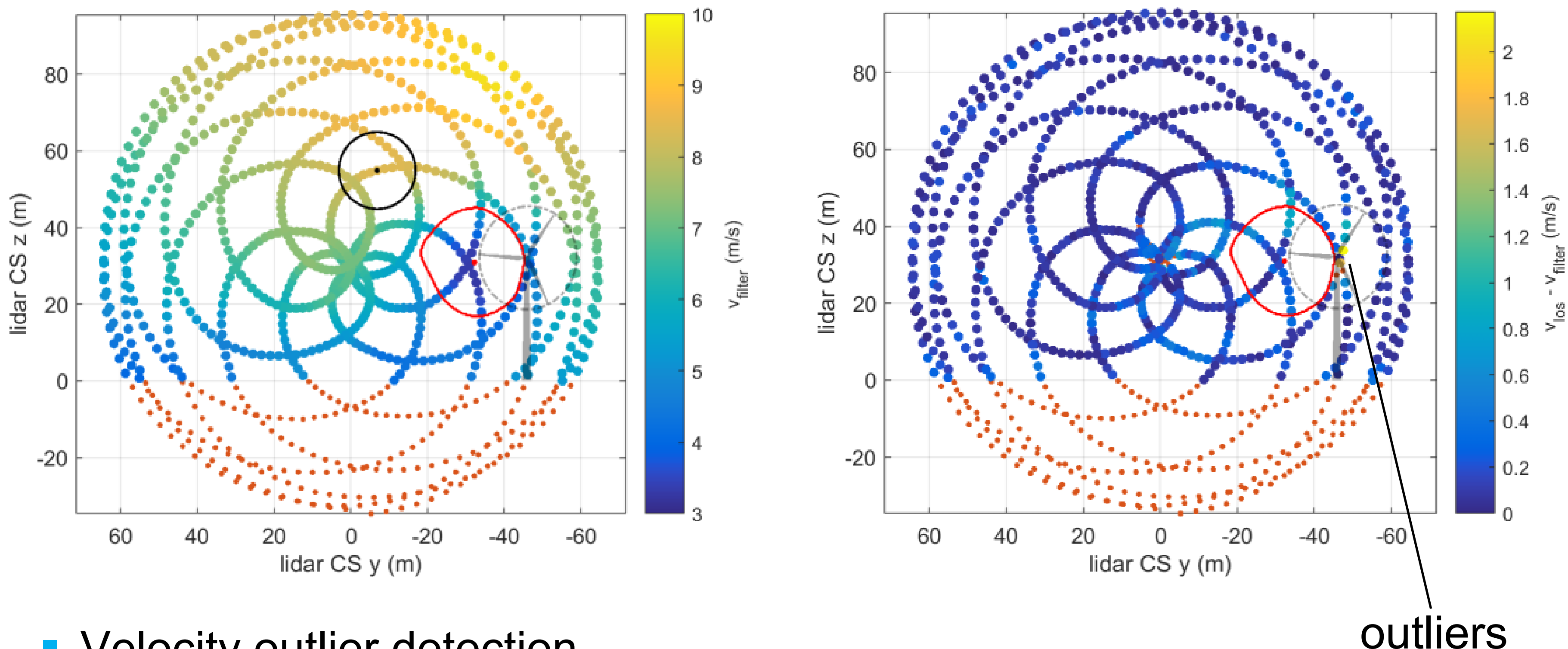
Hard Targets Removed and Bilateral Noise Filter



Isolated Region of Interest



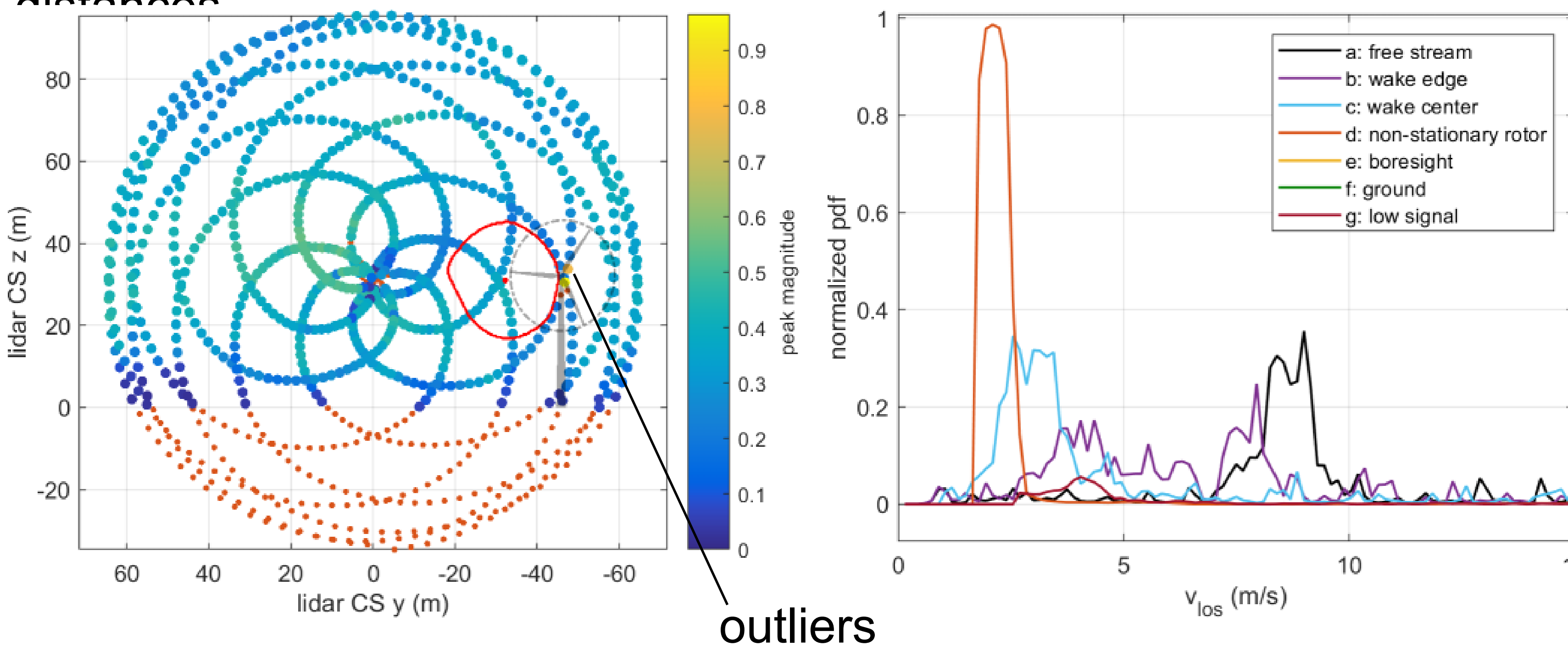
Additional Outlier Detection: V_{los}



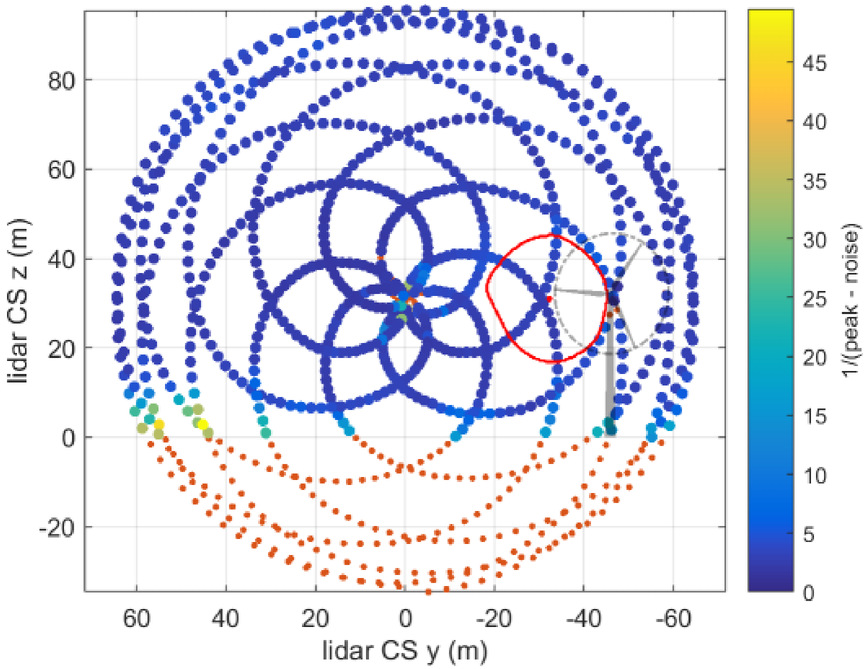
- Velocity outlier detection
  - Spatial smoothing filter of mean v_{los} within indicated sliding neighborhood
  - Area of circle remains constant to scan area for all focus distances
  - Time-weighted mean used to eliminate false outlier detection at scan intersection locations, or “crossing points”
  - Outlier threshold set above six standard deviations of the absolute difference between the filtered v_{los} and orginal v_{los} signals

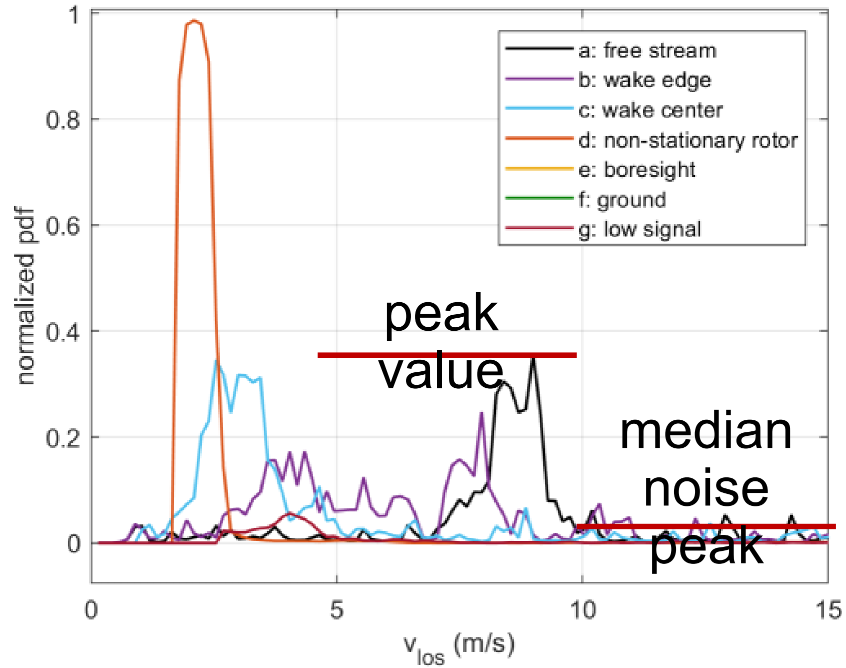
Additional Outlier Detection: Peak Magnitude

- Doppler power spectra peak magnitude
  - Large signal return from hard target clear at the moving rotor
  - Peak magnitude outlier detection threshold set at four standard deviations of the neighborhood above the non-time weighted average
- Outliers only detected when v_{los} and peak magnitude outlier detections were observed
- Works well at detecting outliers from moving hard targets at all focus distances



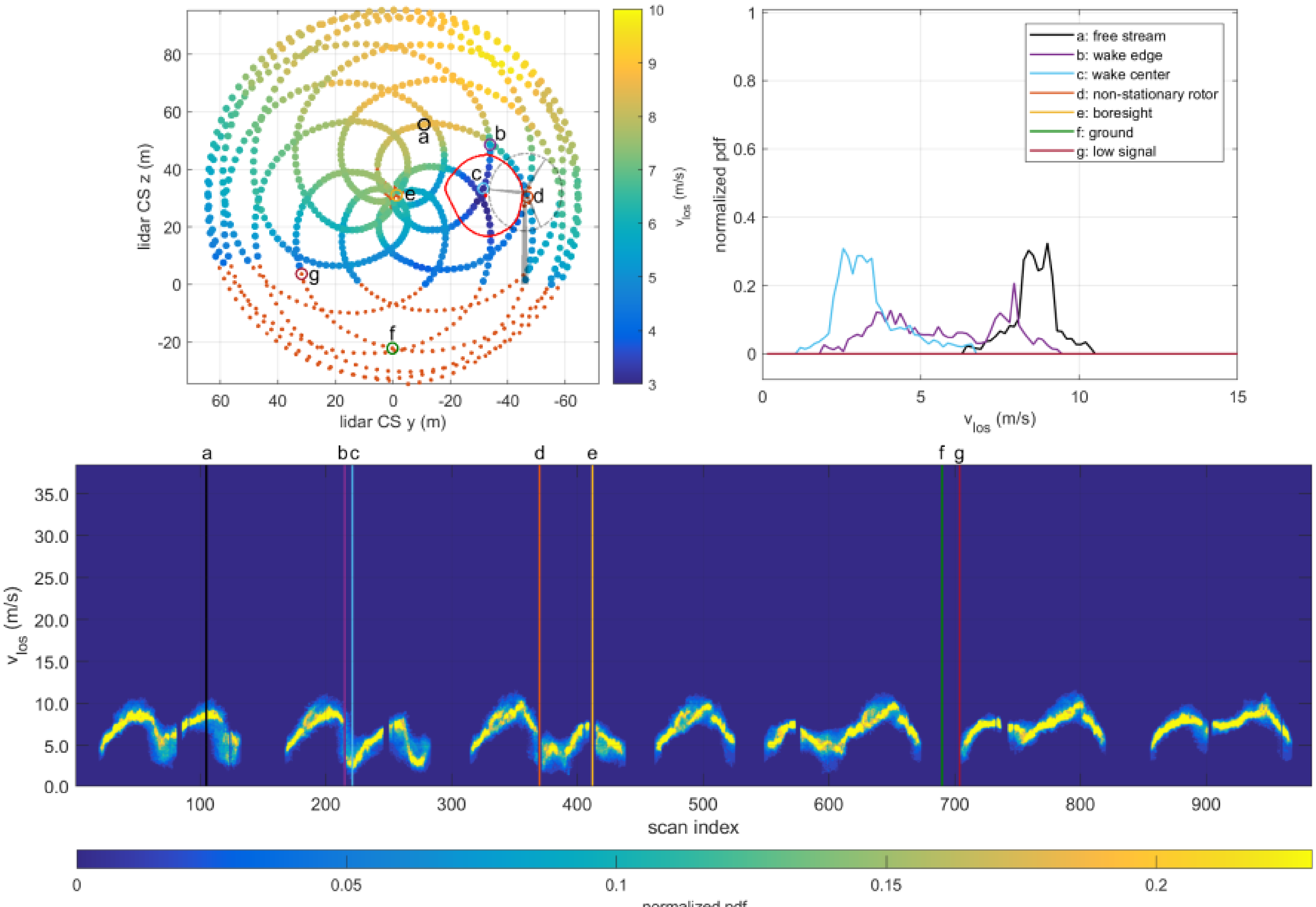
Additional Outlier Detection: Quality



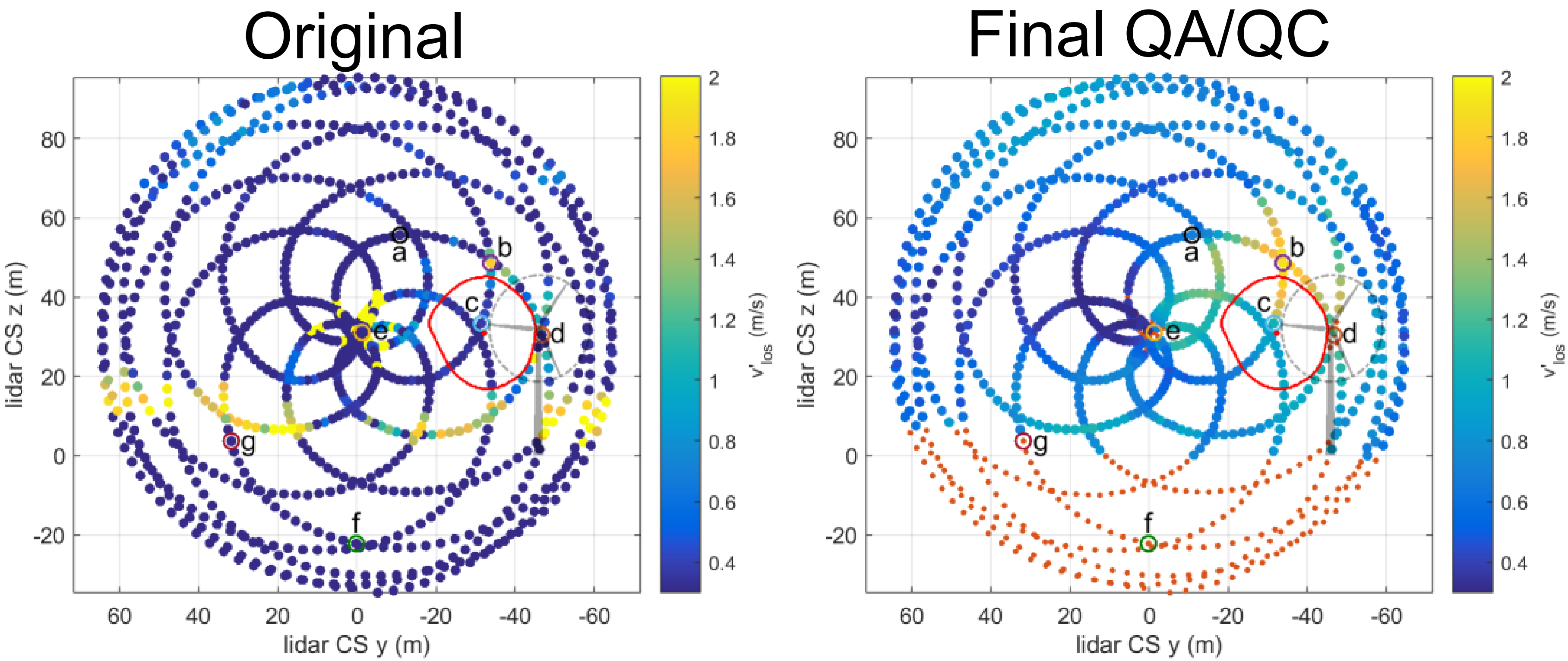


- Quality metric
  - Removes measurements with low-signal to noise
  - Outlier detected using reciprocal of the difference between peak value and median noise peak outside the Doppler spectra region of interest
  - Outlier set to a peak difference less than 5% or a reciprocal greater than 20
  - 5% value was empirically determined but worked of all focus distances
  - Removed points obscured by ground returns and periods of reduced aerosol within the atmospheric boundary layer.

Final Result



Enabled Quantities of Interest



- Distributions of velocities are physically present within probe volume
- Important to include in the calculation of median v_{los} and higher order line-of-sight velocity statistics
- Turbulence of line-of-sight velocities within probe volume estimated from the normalized second moment (standard deviation) of the Doppler spectra PDF
- Isolation of the region of interest and reduction of shot noise through filtering improves turbulence estimation

Conclusion

- Developed lidar processing method that:
  - Isolates region of interest within the Doppler power spectra
  - Reduces effects of shot noise
  - Removes effects of stationary returns
  - Removes non-stationary hard target returns
  - Removes measurements with low signal to noise ratio
- New processing methods improve median v_{los} estimation and enable the estimation of turbulence as a quantity of interest
- All SWiFT facility Wake Steering data is currently available on A2e DAP
  - Additional documentation to be added along with met and turbine data
  - Turbulence estimation not yet included
- Wake data currently being used as part of the IEA Task 31 WakeBench SWiFT benchmark

The complete Wake Steering SpinnerLidar dataset available for download at **a2e.energy.gov**

Questions?

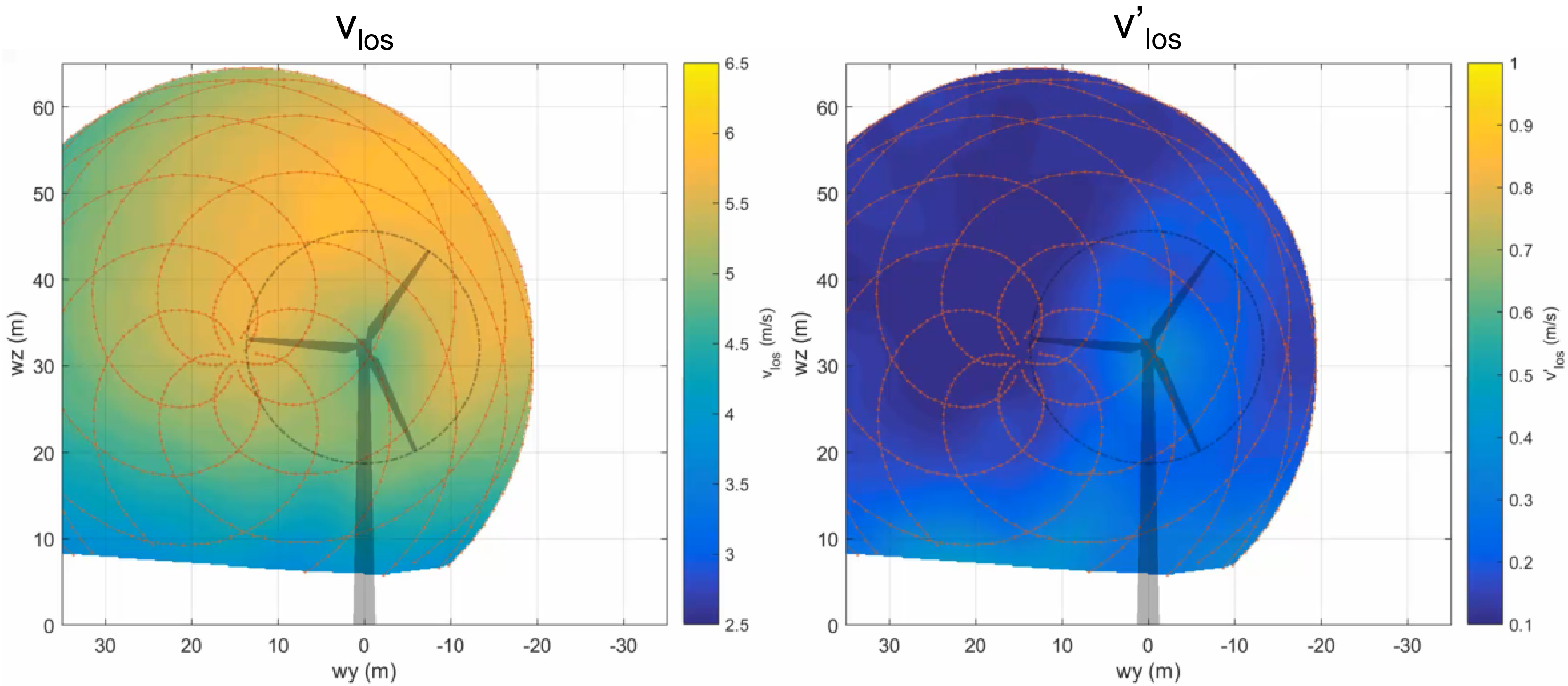
Thanks:

- Tommy Herges
- therges@sandia.gov

Stable BL Video at 2.5D

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

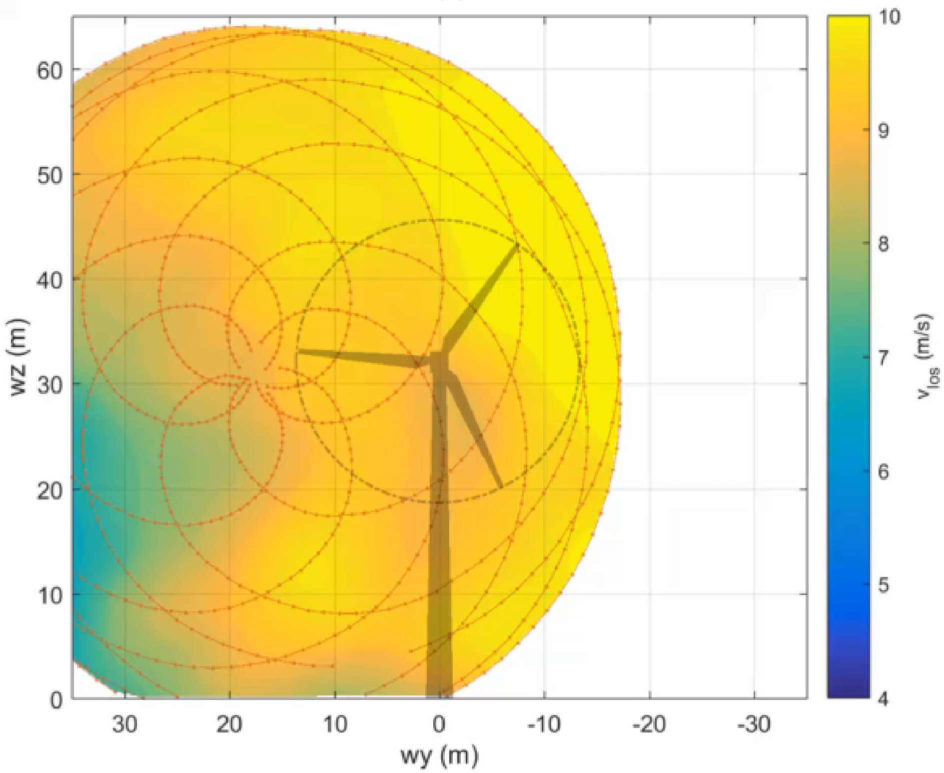
Note that you can see turbulence coming off the nacelle and tower before the turbine turns on and the wake forms



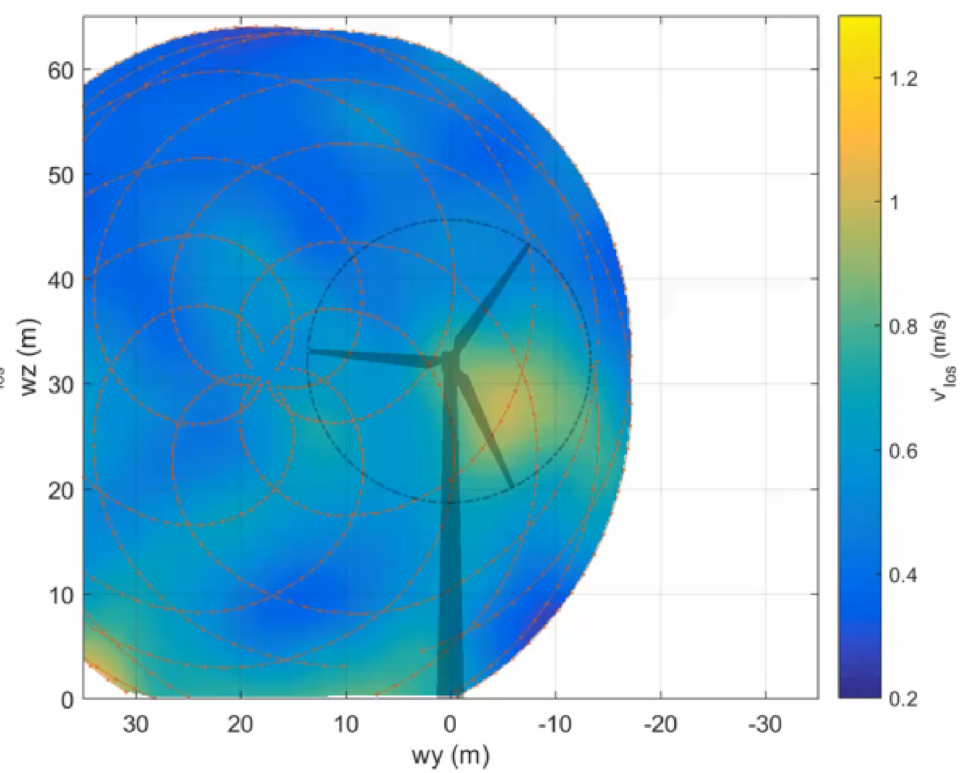
Neutral BL Video at 2.5D

Obukhov length *z/L* = 0.0
α = 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}

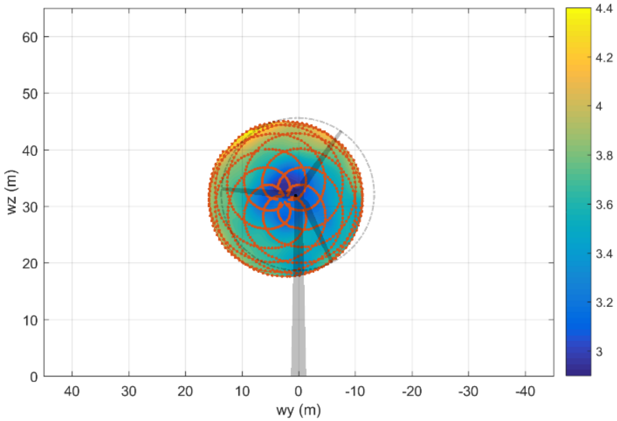


v'_{los}

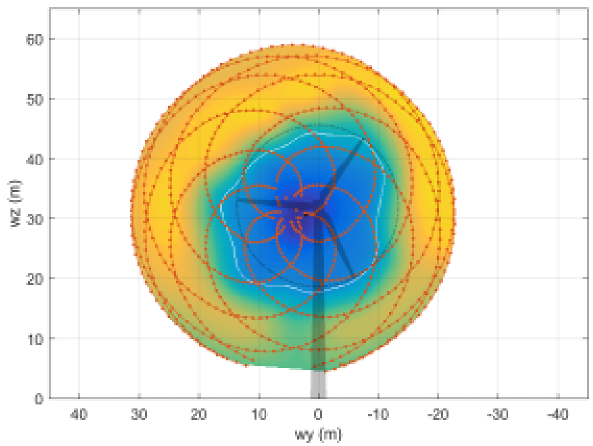


Stable No Veer BL v_{los}

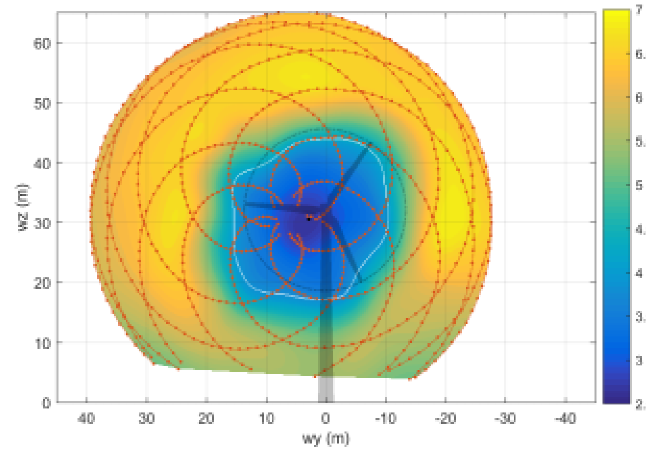
1D



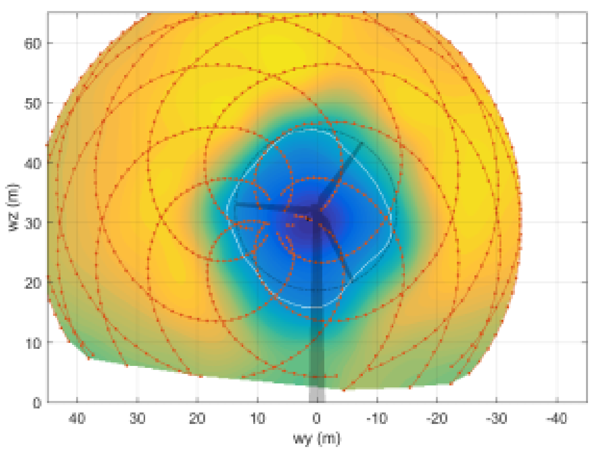
2D



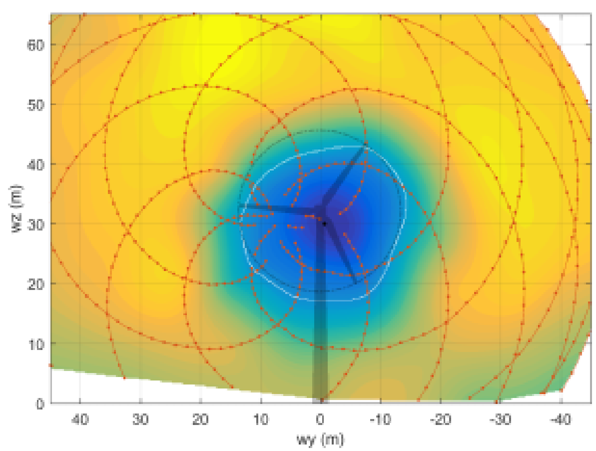
2.5D



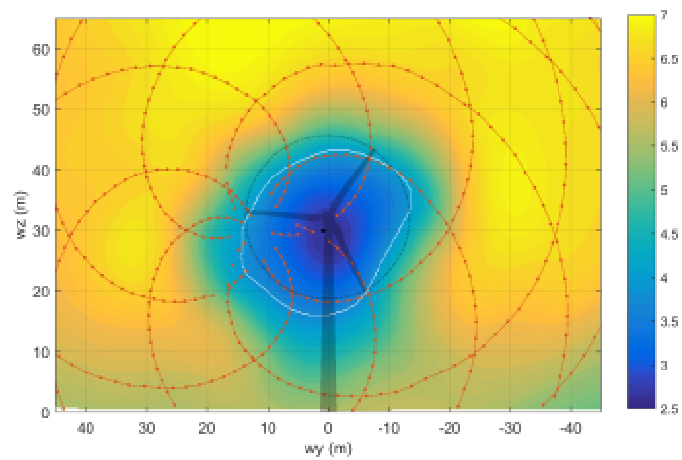
3D



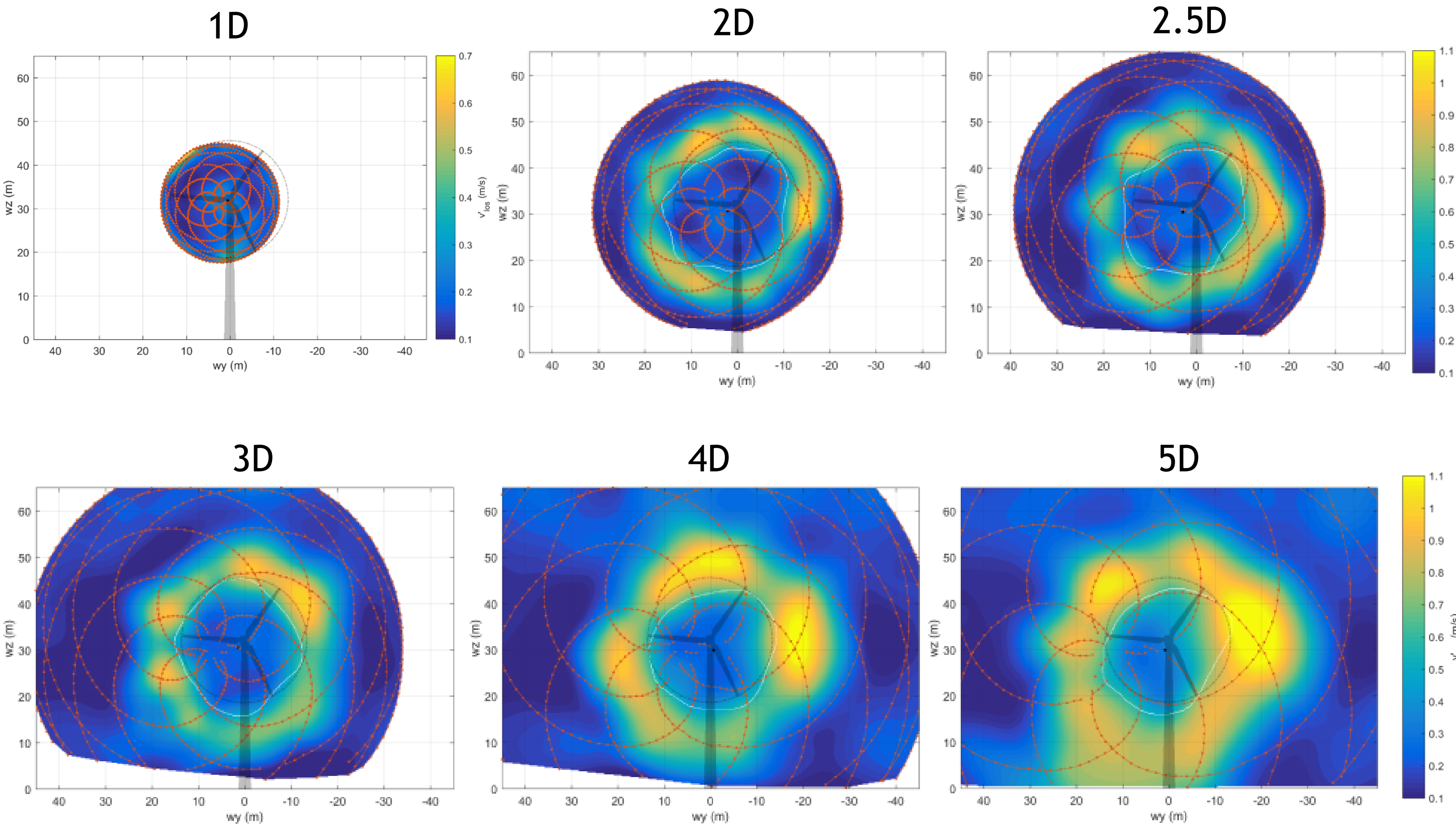
4D



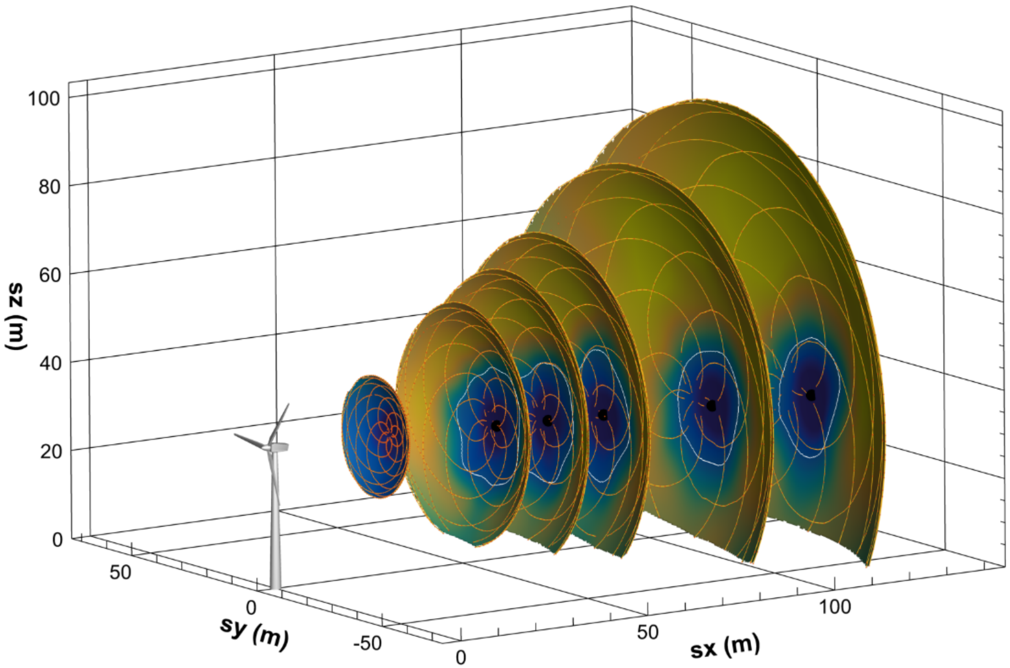
5D

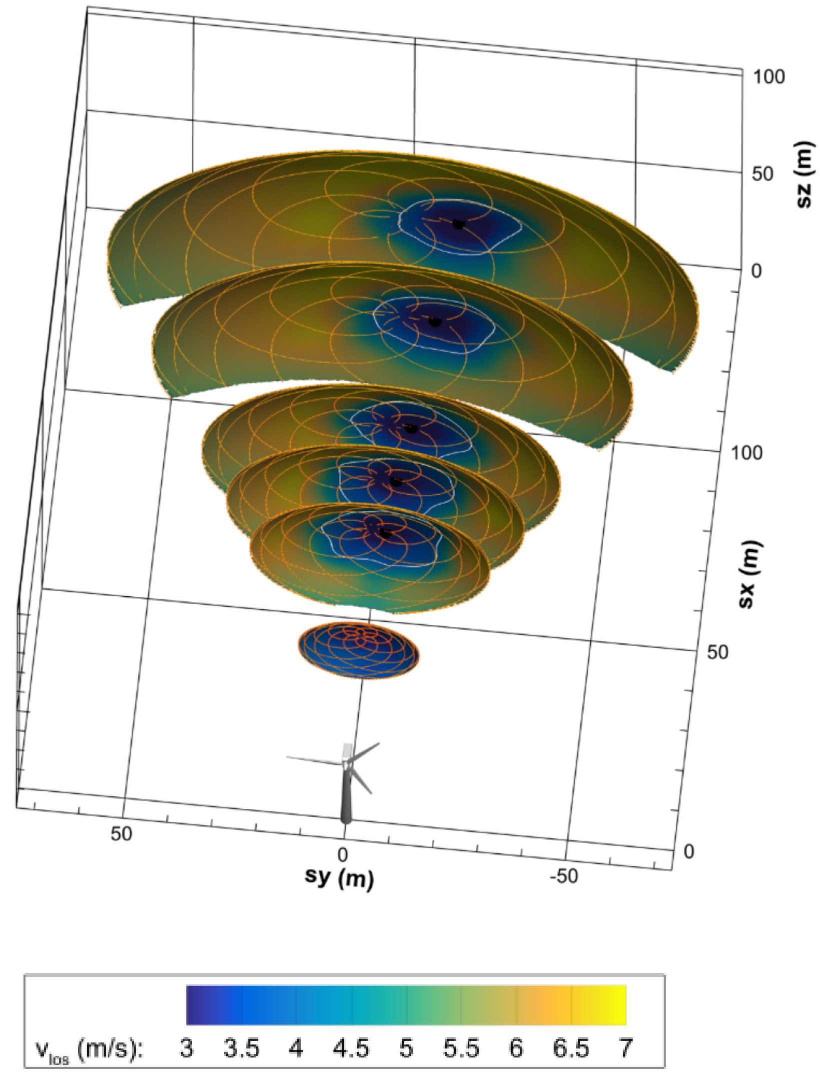


Stable No Veer BL v'_{los}



Measuring impact of inflow - Stable



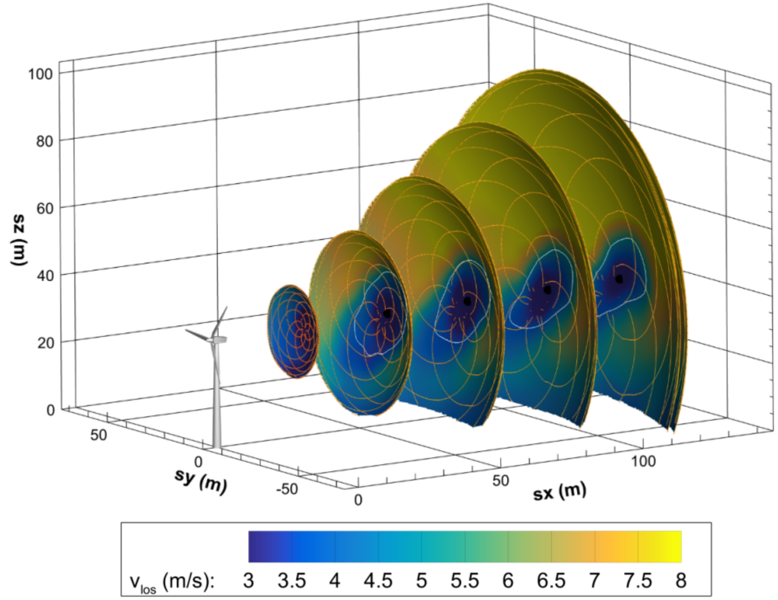


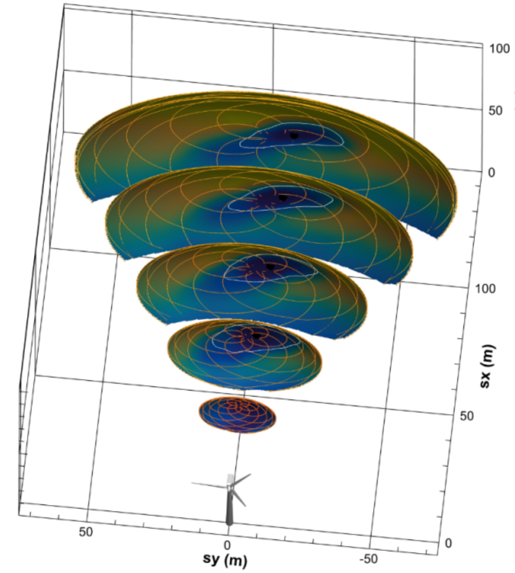
- Bulk Richardson = 1.7
- z/L = 3.4
- α = 0.19
- wind speed = 6.8 m/s
- TI = 0.05
- veer = 0.1°
- yaw offset = 4.0°
- yaw heading = 236.7 degN

Measuring impact of inflow

Stable ABL
Positive Veer

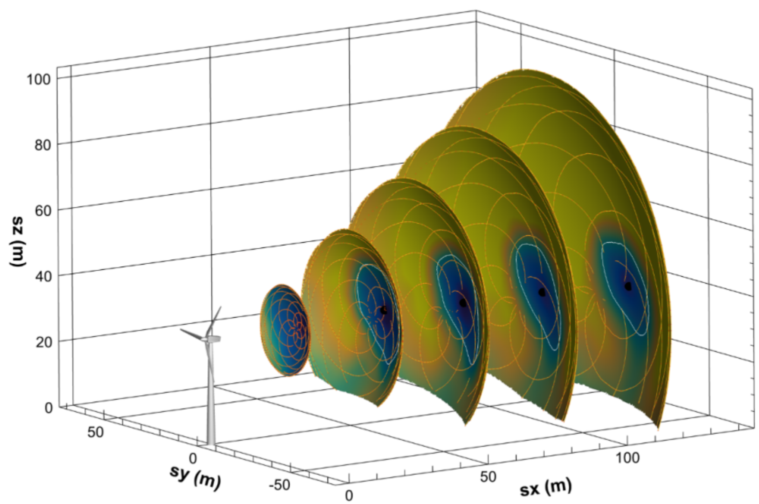
Bulk Rich = 0.7
z/L = 2.3
α = 0.37
TI = 0.04
veer = 14.6°
yaw offset = -0.12°

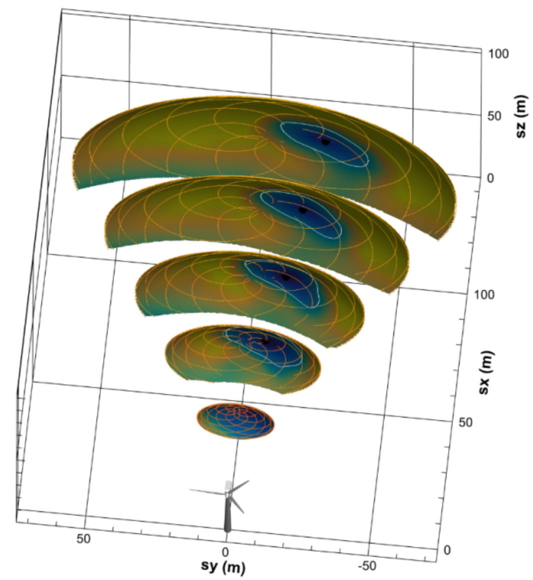




Stable ABL
Negative Veer

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





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