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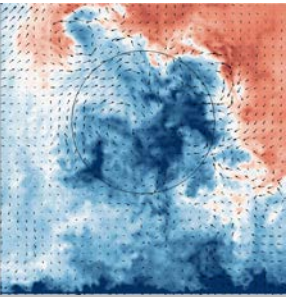

Sandia Wind Turbine Wakes Research Programs 2017

September 20, 2017

David Maniaci, Brandon Ennis, Tommy Herges, and Brian Naughton

Wind Energy Technologies Department

Sandia National Laboratories

Sandia National Laboratories

Exceptional service in the national interest

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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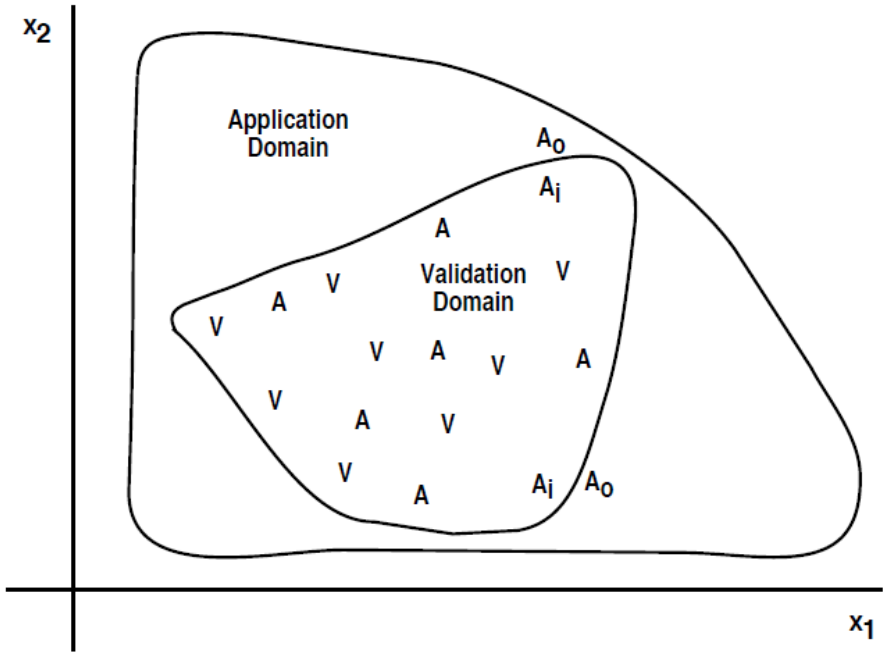
Topics

- Overall R&D approach
- Sandia Wake Imaging System
- National Rotor Testbed
- Wake Steering Experiment
- Partnerships

V&V Overview

- Verification and validation are integral parts of establishing a model's predictive capability for an intended application.
- Validation is not a pass/fail exercise for a simulation.
  - Assesses the uncertainty of the predictive capability that the user can utilize to judge its suitability for a given application.



x_1 and x_2 are model parameters

V&V Framework

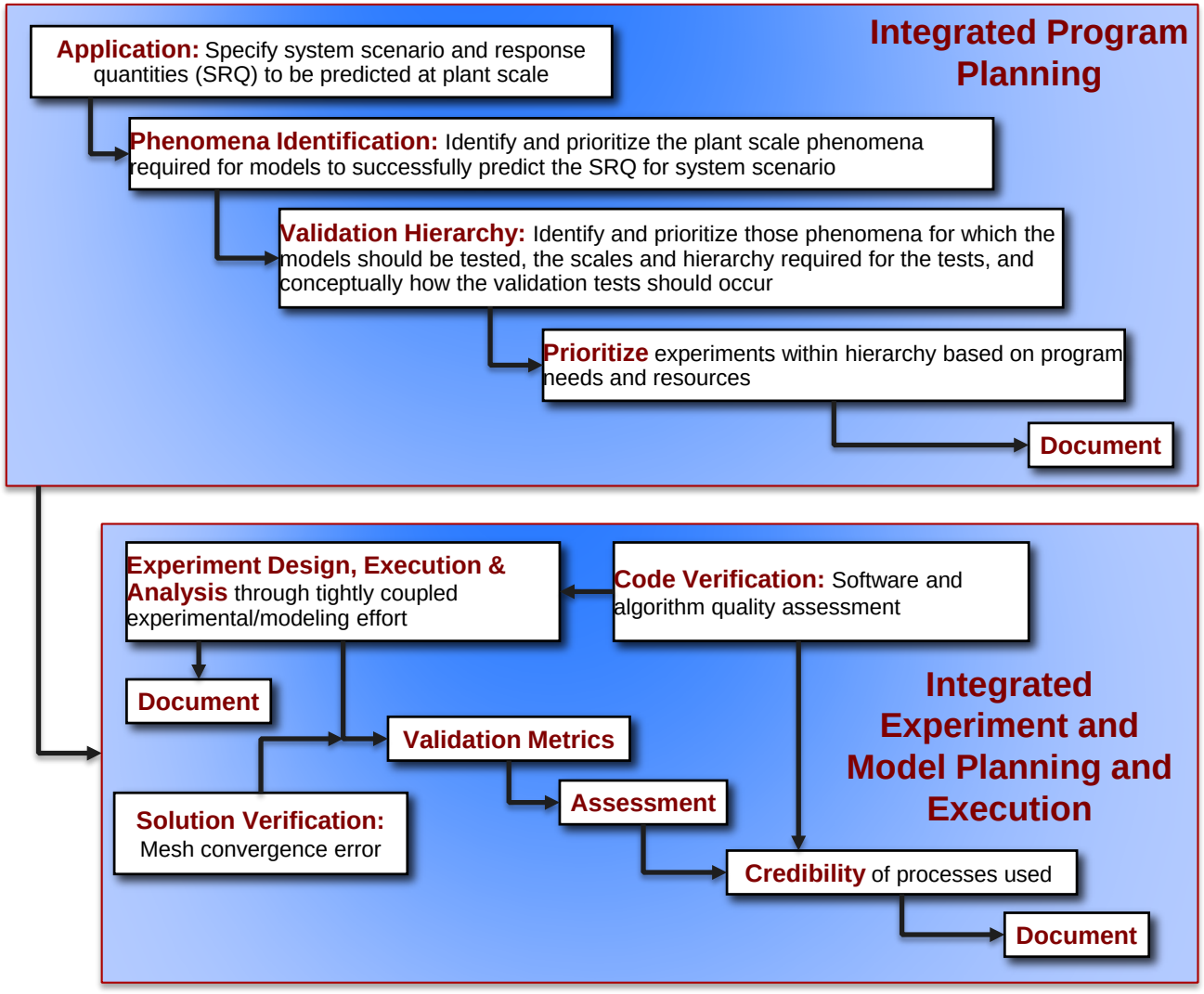
(2015 Hills, Maniaci, Naughton)

Integrated Planning

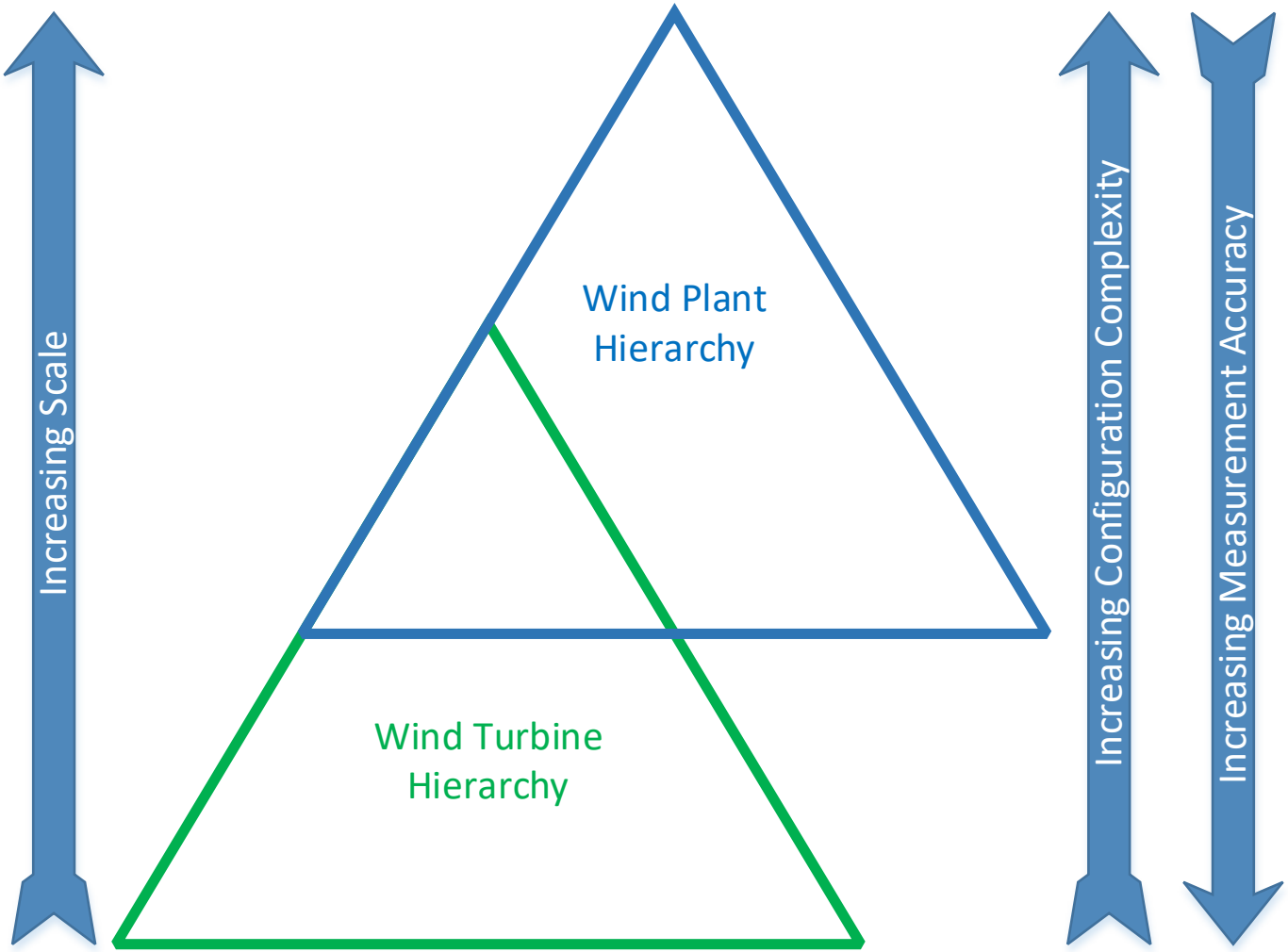
- Program leaders, modelers, software developers, experimentalists, V&V specialists

Validation Planning

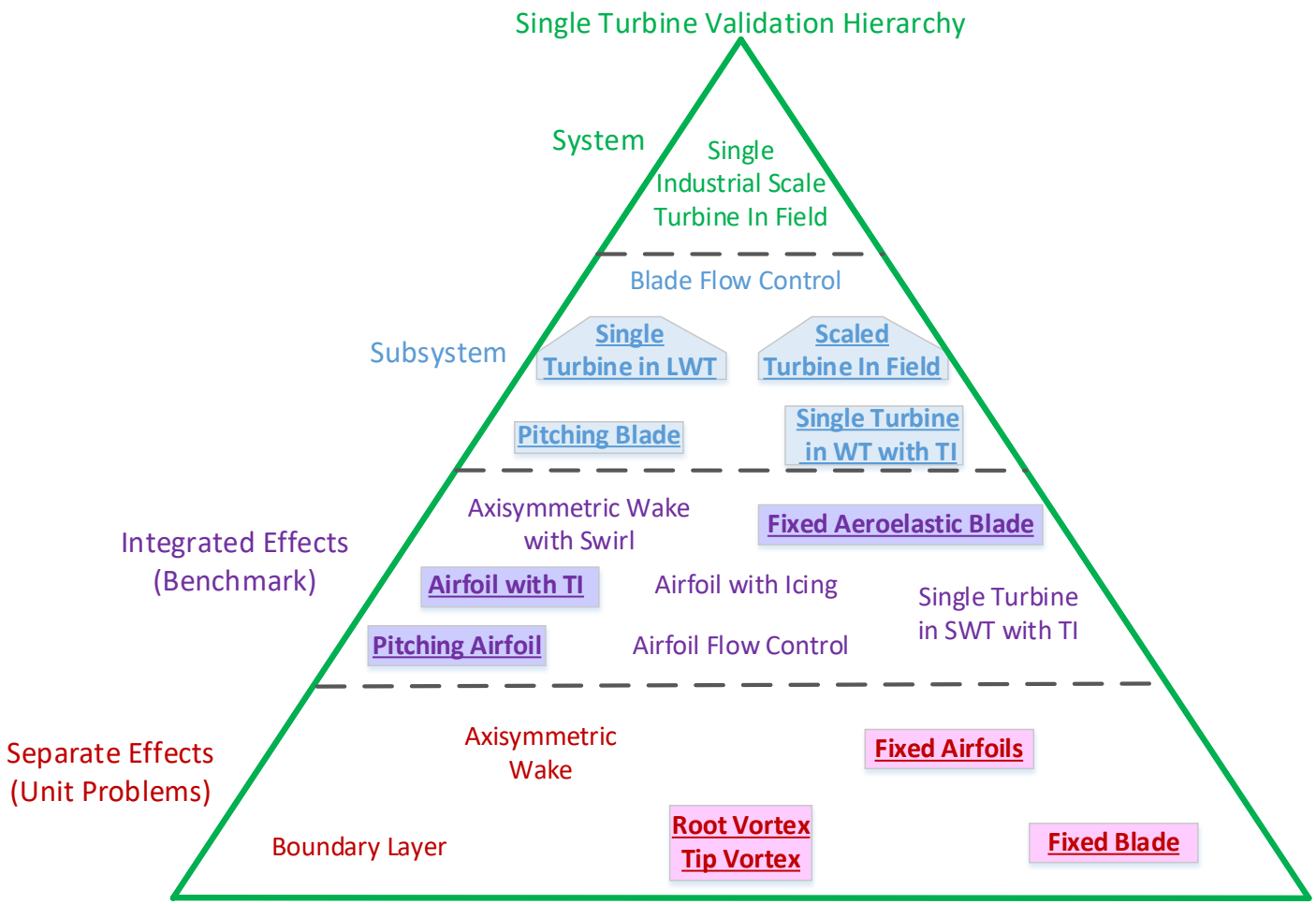
- Domain specific program leaders, modelers, experimentalists, V&V specialists, data acquisition specialists



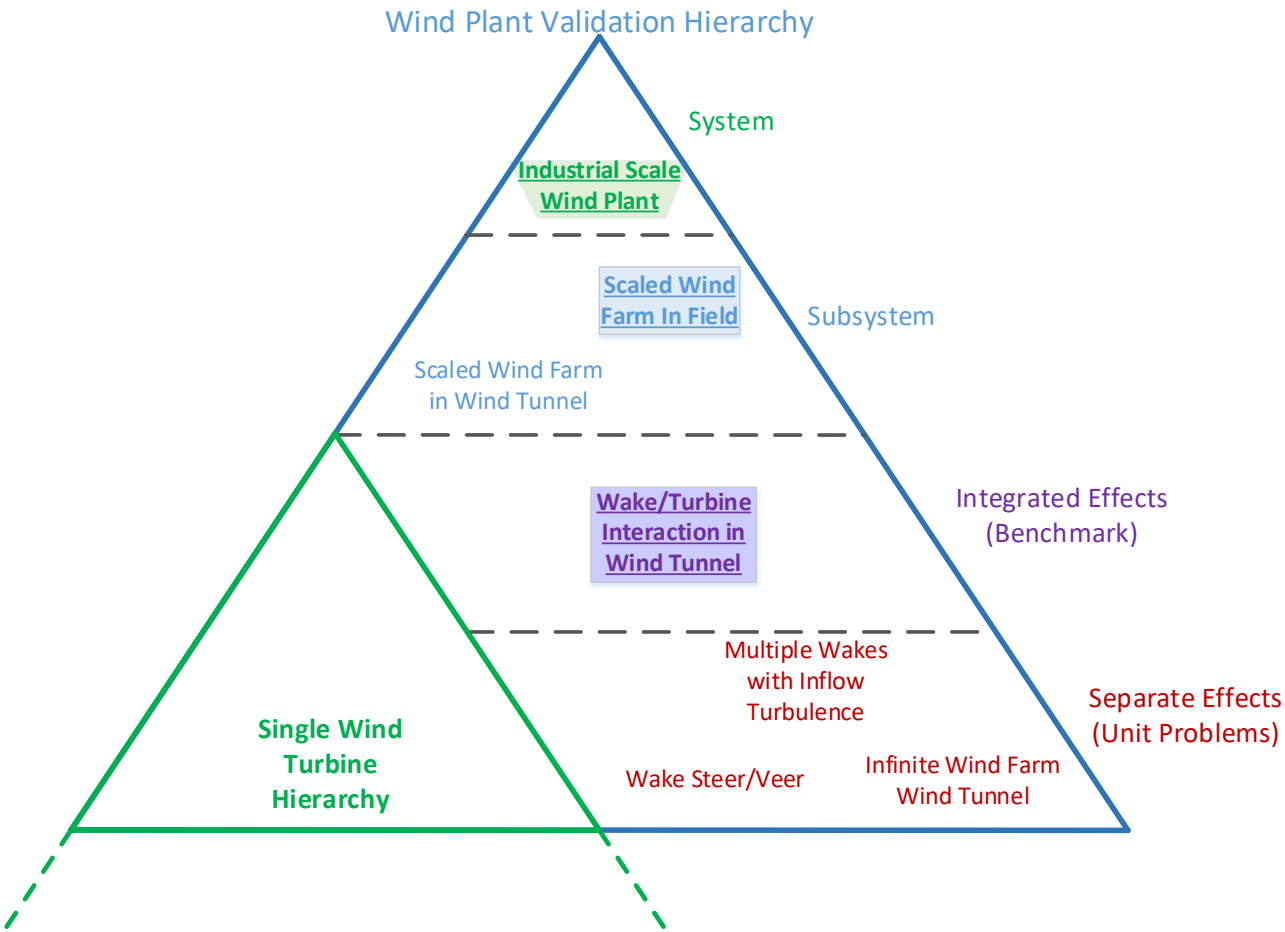
Validation Hierarchy



Wind Turbine Validation Hierarchy

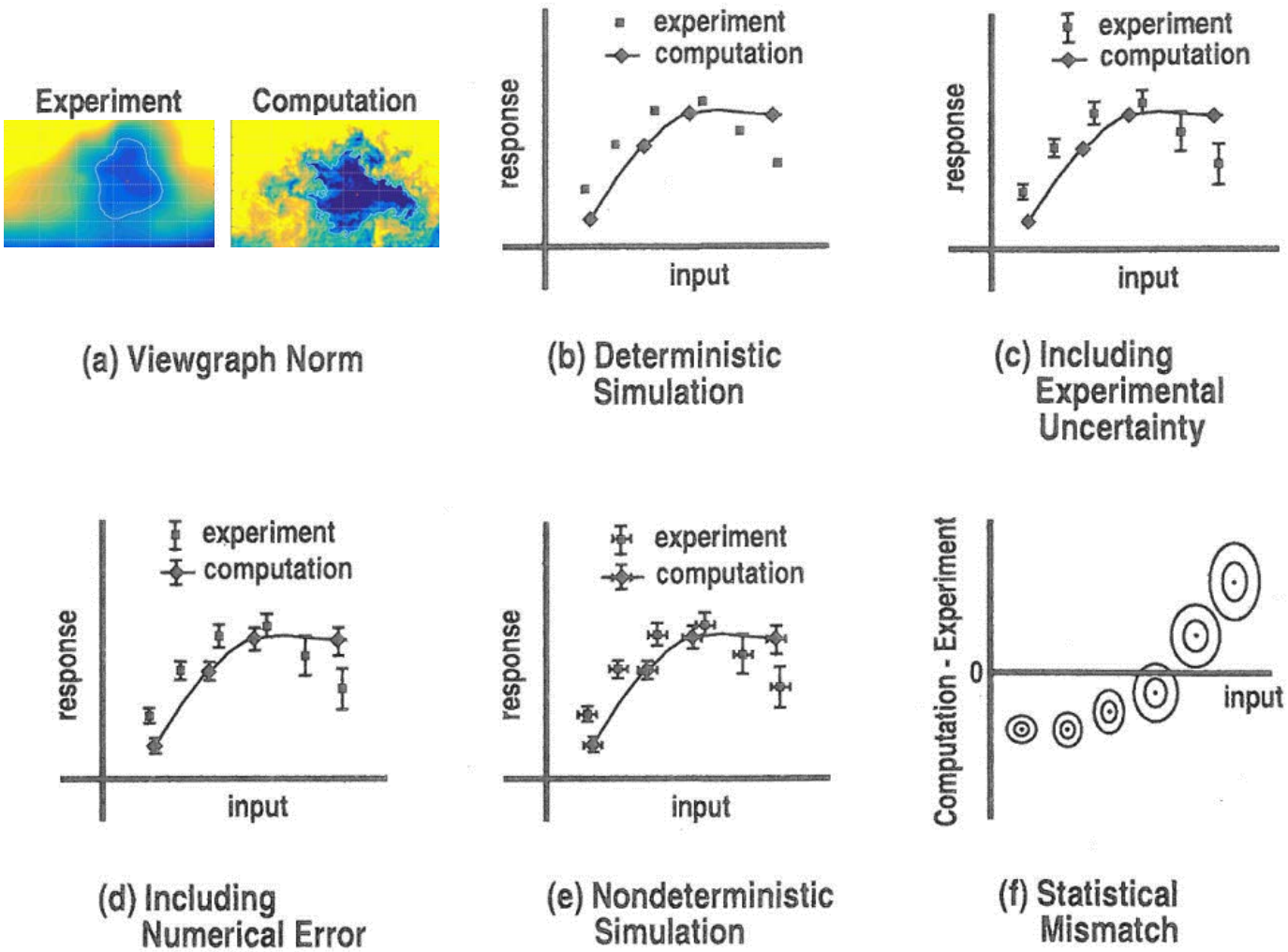


Wind Plant Validation Hierarchy



Uncertainty Quantification

Levels of Precision



Modified from Oberkamf and Roy, 2012

Case 1: V27/GE 1.5 Wake Steering

Objective: Perform a qualitative comparison of wake shape and deflection under similar inflow and turbine operating states for the SWiFT V27 and NWTC GE 1.5 turbines.

Outcome: Development of analysis methods to identify similar cases at two different scales and provide knowledge to design a future wake scaling validation experiment. Development of methods to run comparative simulations at two scales.

Case 2: NRT/GE 1.5 Wake Scaling

Objective: Design and conduct a wake scaling validation experiment with the National Rotor Testbed (NRT) blades at SWiFT and the GE 1.5 at NWTC.

Outcome: Verification of the design methodology for the NRT blades with quantified uncertainty. Validation of the predictive capability of Nalu to capture quantities of interest at two scales.

Case 3: SWiFT/OWEZ UQ

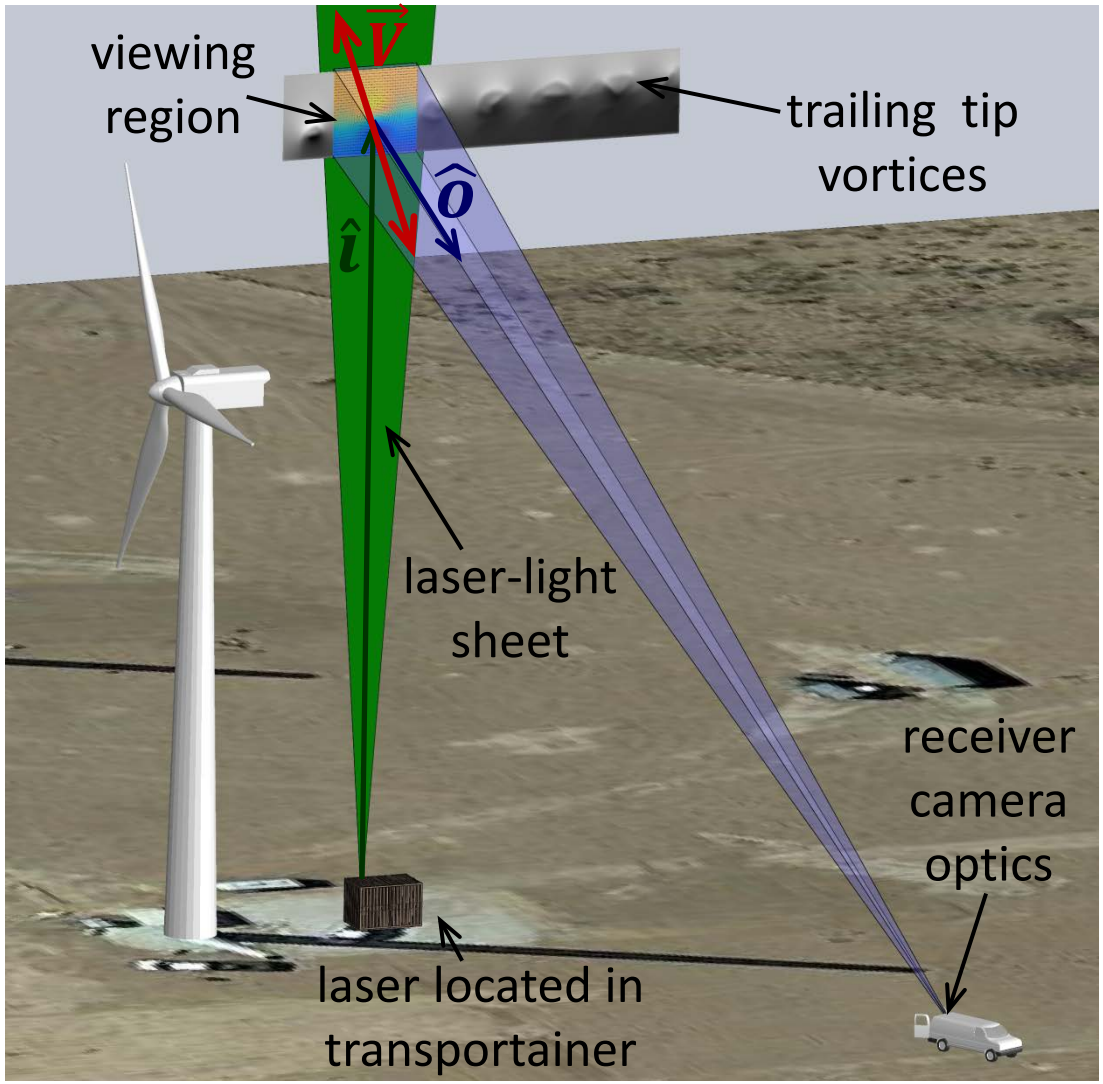
Objective: Conduct Uncertainty Quantification on experimental data from SWiFT V27 and OWEZ data sets for similar quantities of interest.

Outcome: A quantitative assessment of potential differences in precision for two data sets being used for validation of the Nalu code.

Instrumentation for reduced uncertainty

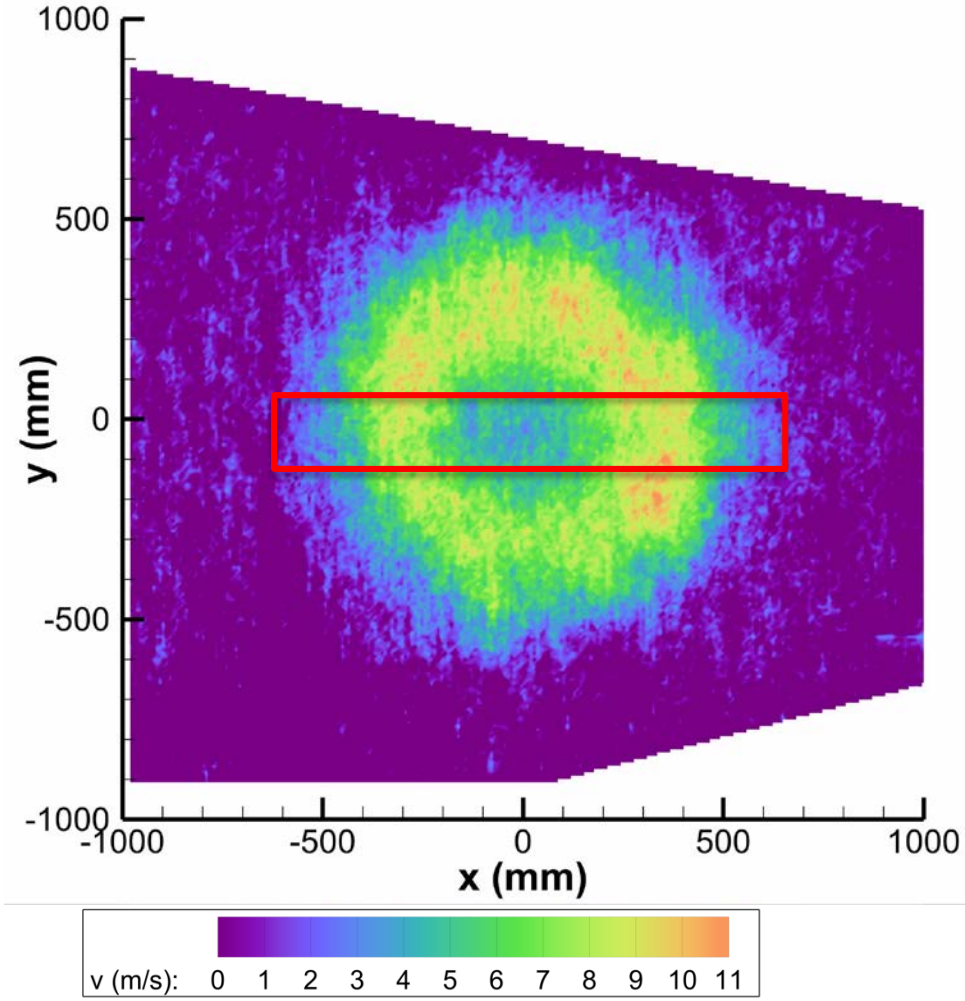
- Sandia Wake Imaging System
- National Rotor Testbed

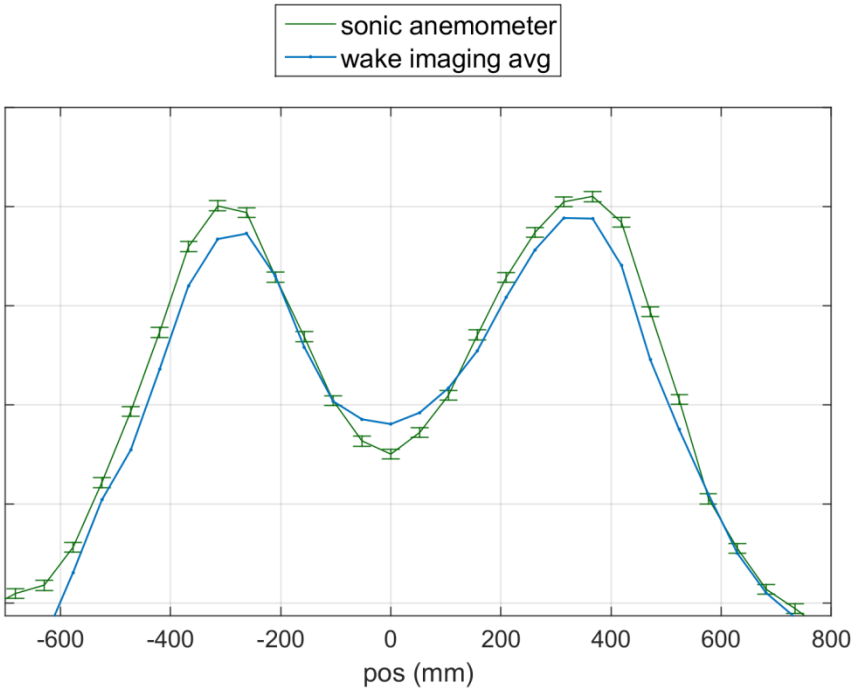
Sandia Wake Imaging System (SWIS)

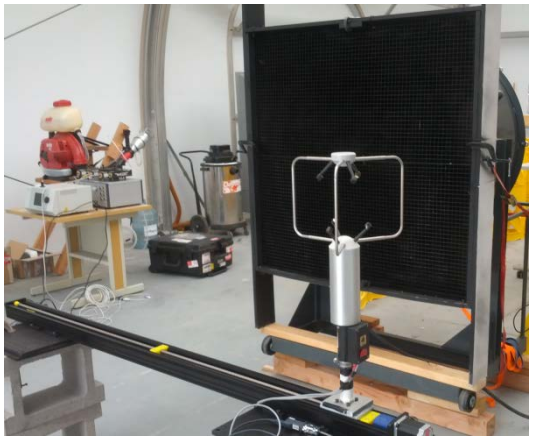


- Uses Doppler Global Velocimetry technique
- Position of laser and camera dictates the measured velocity component
- Measure velocity component along bisector angle between observation and incident vectors, $(\hat{\boldsymbol{o}} - \hat{\boldsymbol{i}})$
- Additional velocity components measured with additional observation angles

Sandia Wake Imaging System

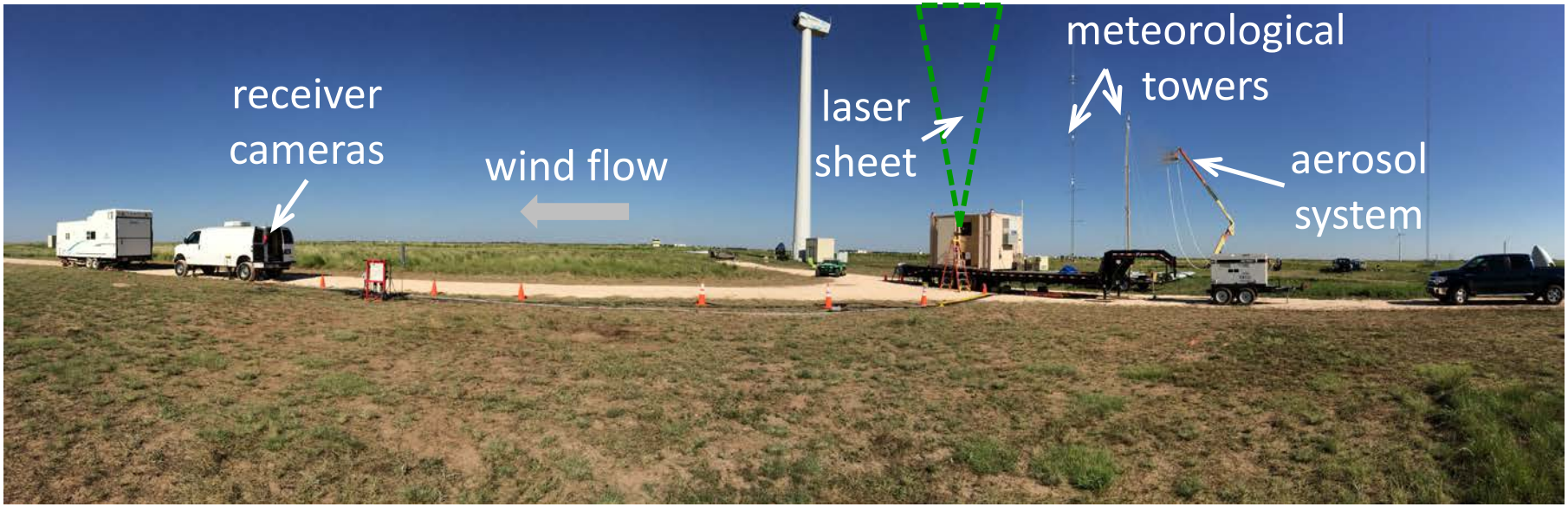


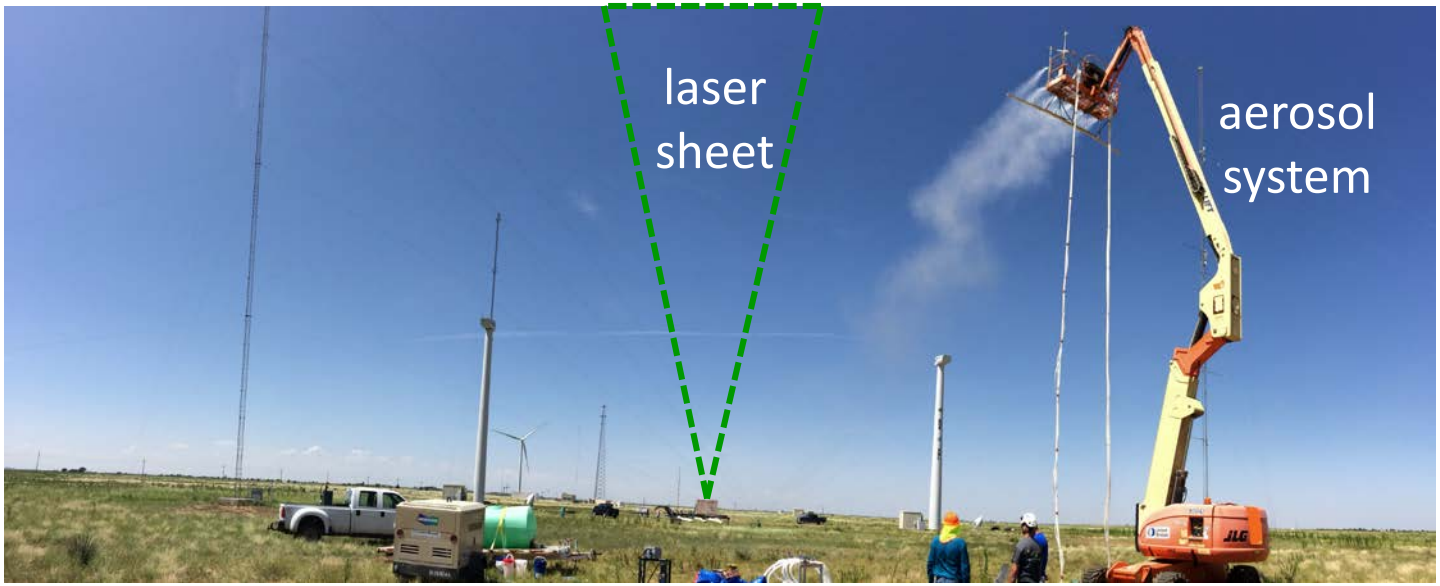




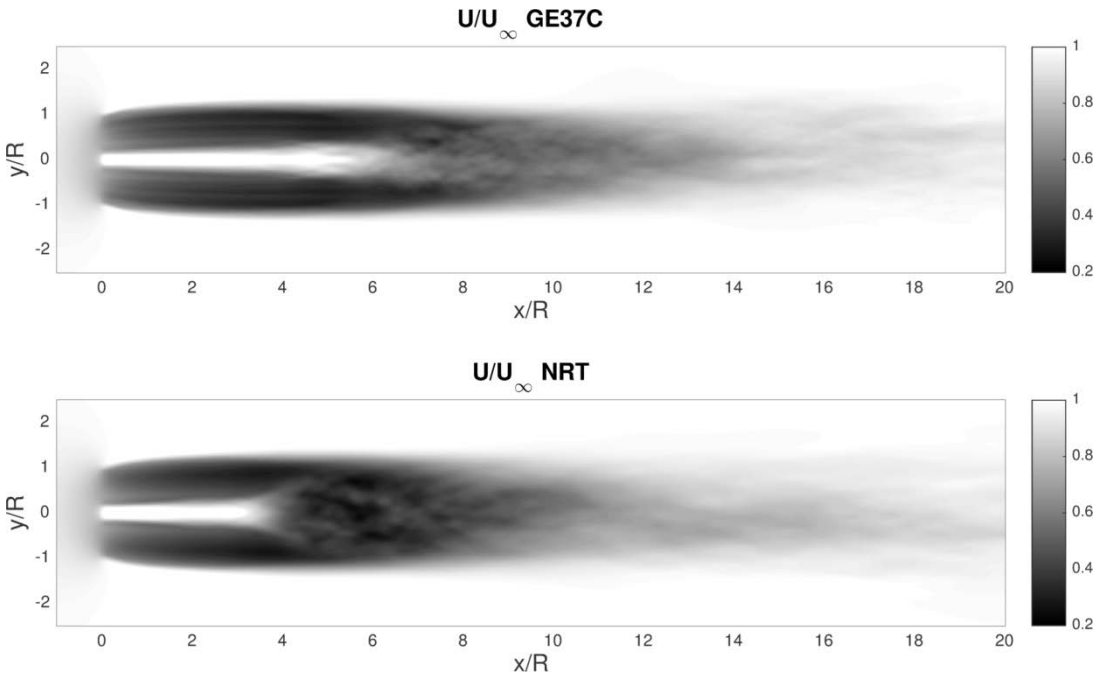
- Compares well to sonic anemometer
- Maximum resolution: 512 x 512 pixels at 15 Hz (almost **4 million** velocity measurements per second)

SWIS @ SWiFT


receiver
cameras
wind flow
laser
sheet
meteorological
towers
aerosol
system

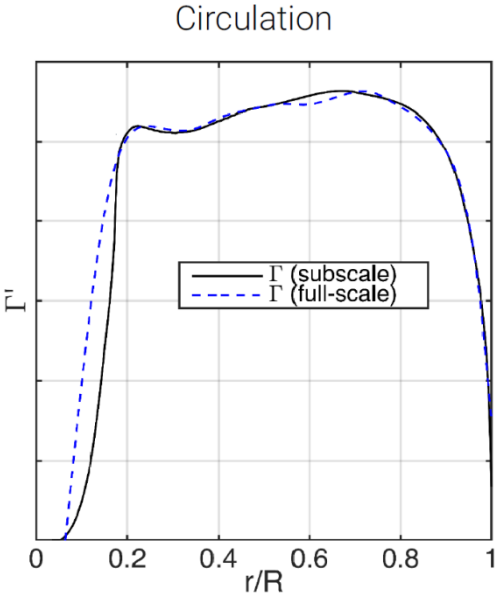

laser
sheet
aerosol
system

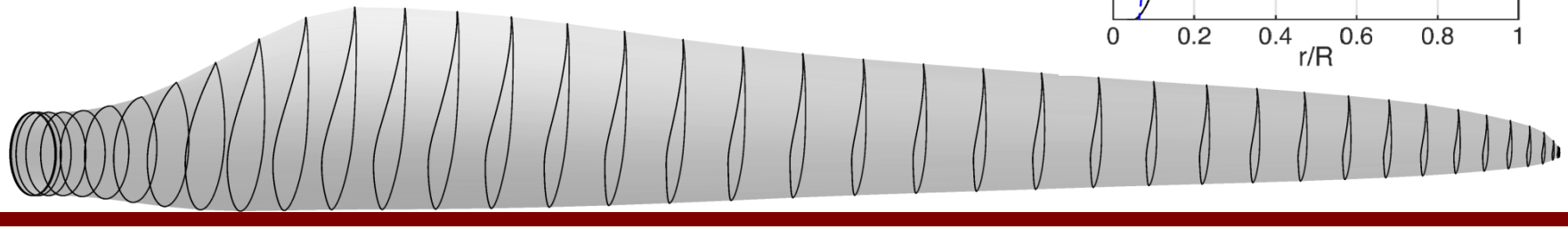
National Rotor Testbed Design



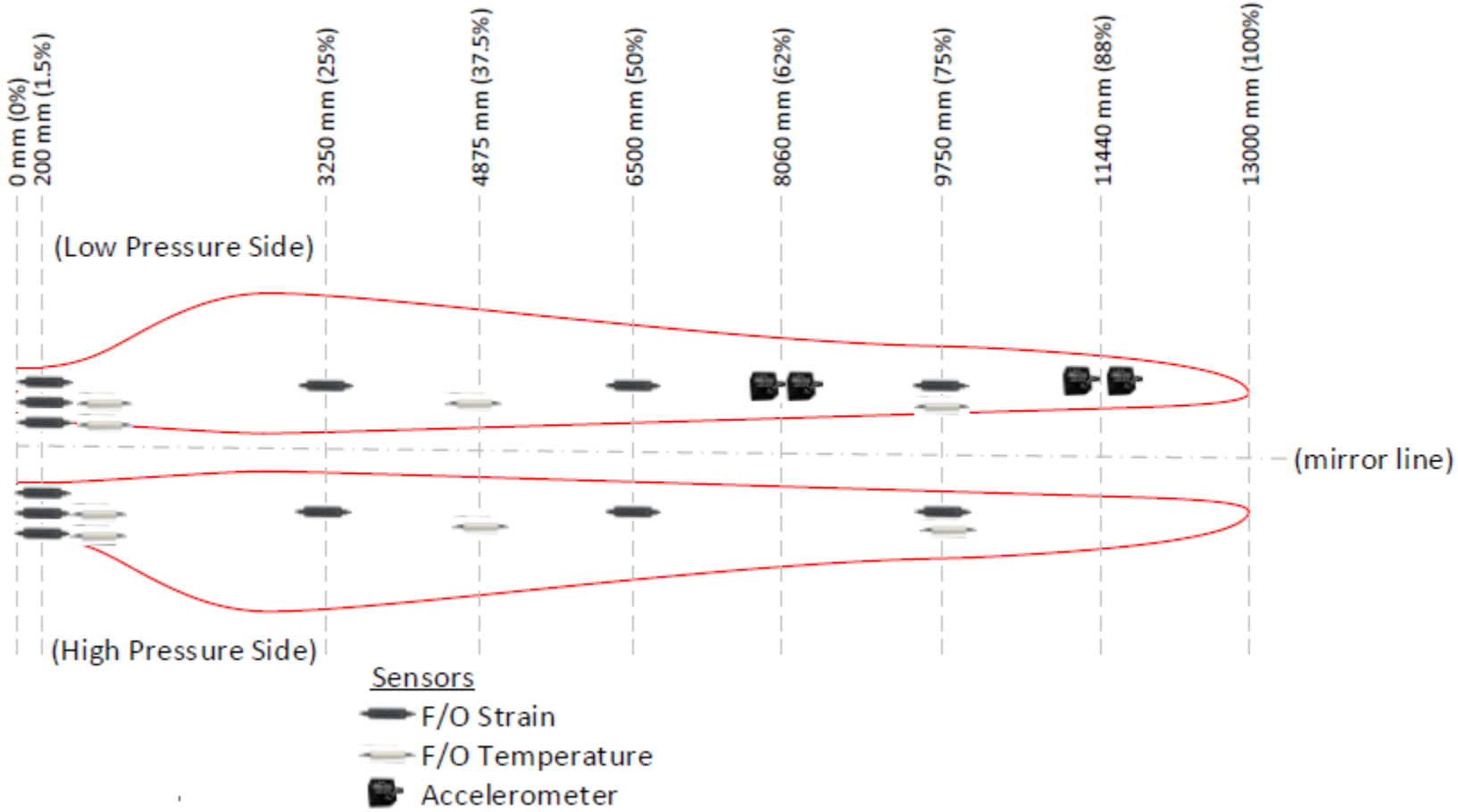
Free wake vortex simulation of the two rotors in neutral inflow.

Developed a unique design method using a variety of computational tools to functionally scale the circulation distribution of a utility-scale blade to a 14m blade to be manufactured and installed at the SWiFT facility. This enhances wake research and validation capabilities.





NRT Sensors


0 mm (0%)
200 mm (1.5%)
3250 mm (25%)
4875 mm (37.5%)
6500 mm (50%)
8060 mm (62%)
9750 mm (75%)
11440 mm (88%)
13000 mm (100%)
(Low Pressure Side)
(mirror line)
(High Pressure Side)
Sensors
F/O Strain
F/O Temperature
Accelerometer

NRT Manufacturing

NREL structural testing of NRT-00

Oak Ridge National Laboratory additive manufacturing of molds

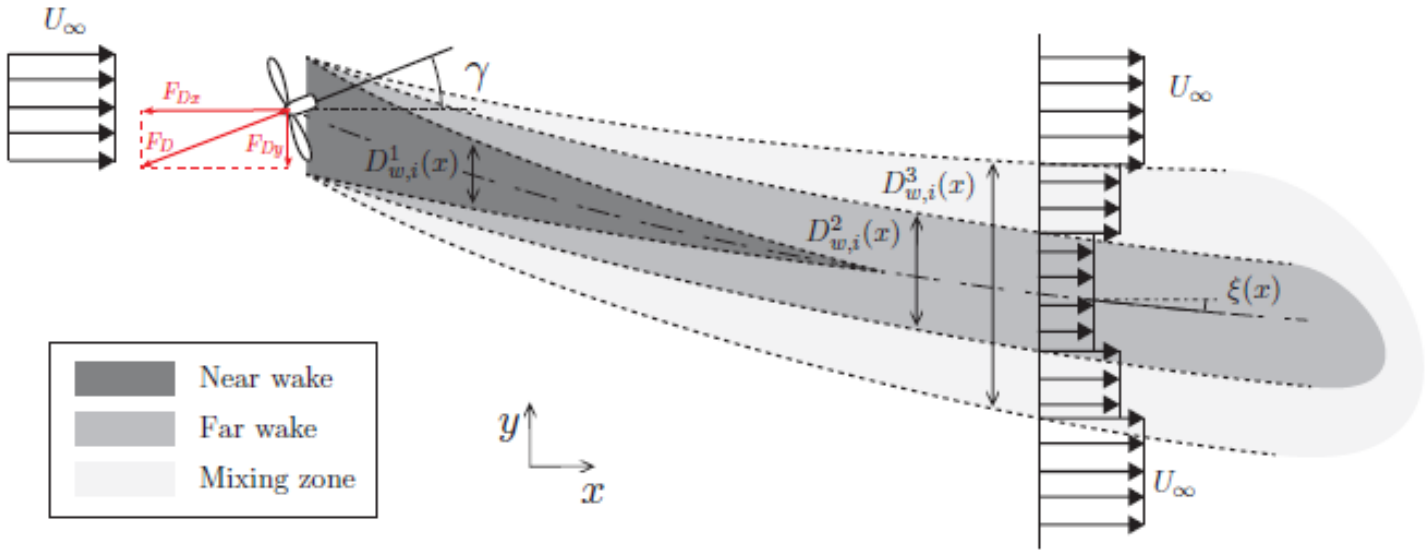
NRT Flight test

- NRT blades will be installed on WTGa1 in Oct. 2017
- The turbine will undergo commissioning tests related to the new rotor and controller for 1-2 months
- Testing will begin in October to verify the NRT design performance
- Later testing will be used to compare turbine and wake QoI to the GE 1.5 at NWTC

Wake Steering Experiment

- Goal
  - Demonstrate capability of wake steering control to improve total wind turbine array power production through an experimental campaign at the SWiFT Facility
- Structure
  - Phase I: Correlate inflow and turbine operating state to impact on wake characteristics
  - Phase 2: Compare power and loads for two turbines operating with and without yaw-based wake steering control

FLORIS Model



Key parameters (Guided experimental design):

- Relationship between yaw-offset and wake-steering
- Recovery to mean wind direction
- Velocity deficits, recovery and expansion of the wake zones

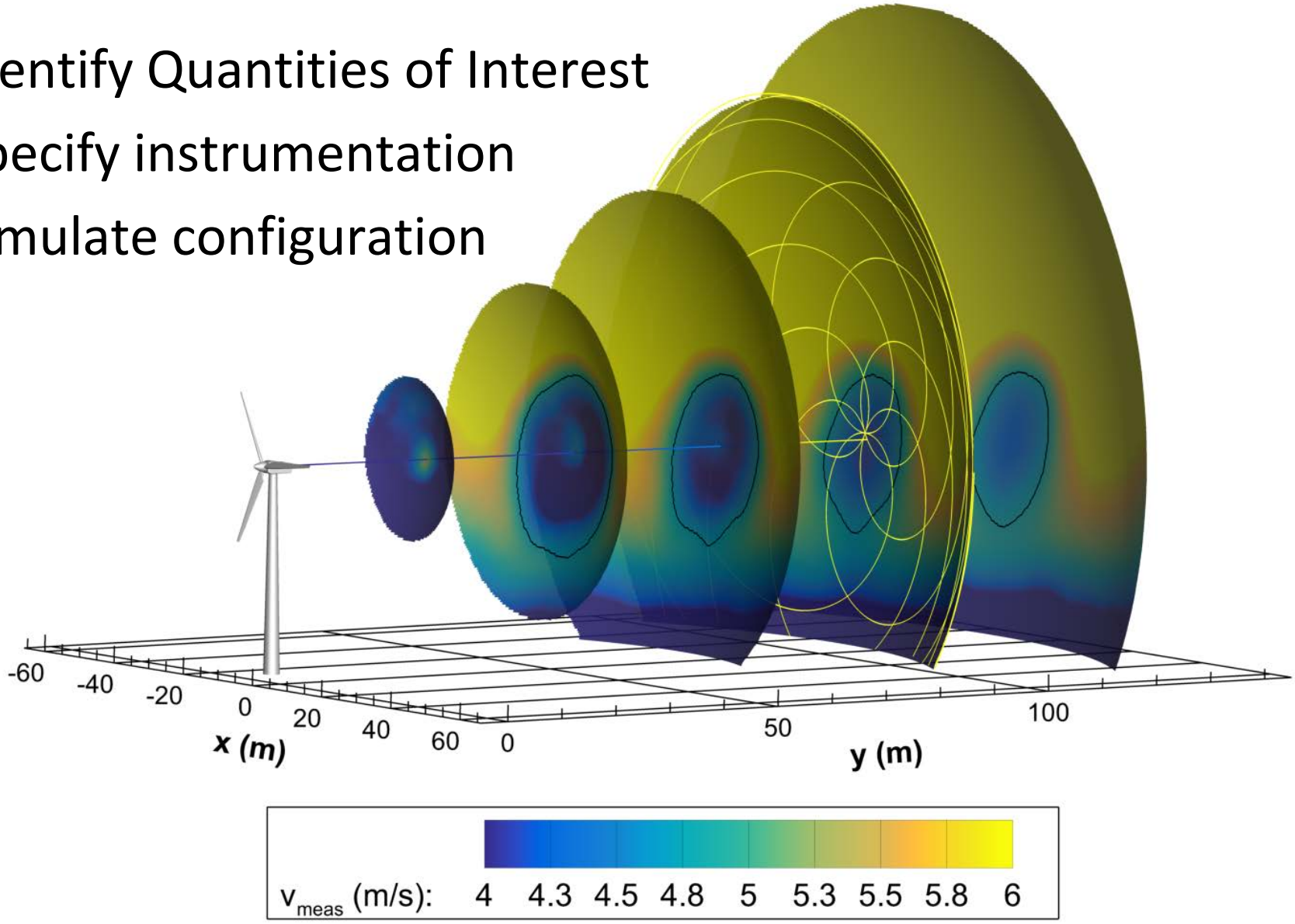
Atmospheric relationships (Functionality being added):

- Turbulence intensity
- Wind veer and shear
- Stability

Source: Wright - NREL

Experiment Planning

- Identify Quantities of Interest
- Specify instrumentation
- Simulate configuration



Lidar Simulation and Selection

SOWFA Simulated Velocity	Simulated Lidar Measurements

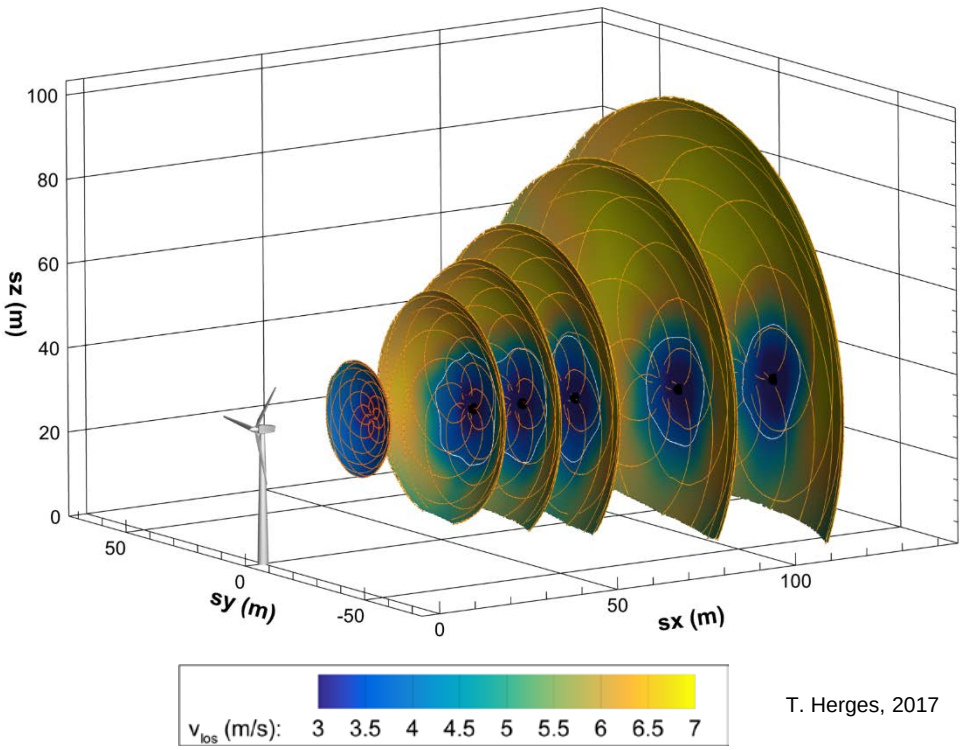
- Comparison of identical time steps in order to show effect of SpinnerLidar on measurements and how that impacts wake position determination
- Measurements at 3D downstream of turbine

- Simulations conducted by Matt Churchfield using SOWFA

SWiFT Wake Measurements

DOE/SNL Scaled Wind Farm Technology (SWiFT) facility hosted by Texas Tech University (TTU)

Objective: Assess the ability of models to predict ***wake shape, strength, and deflection***.

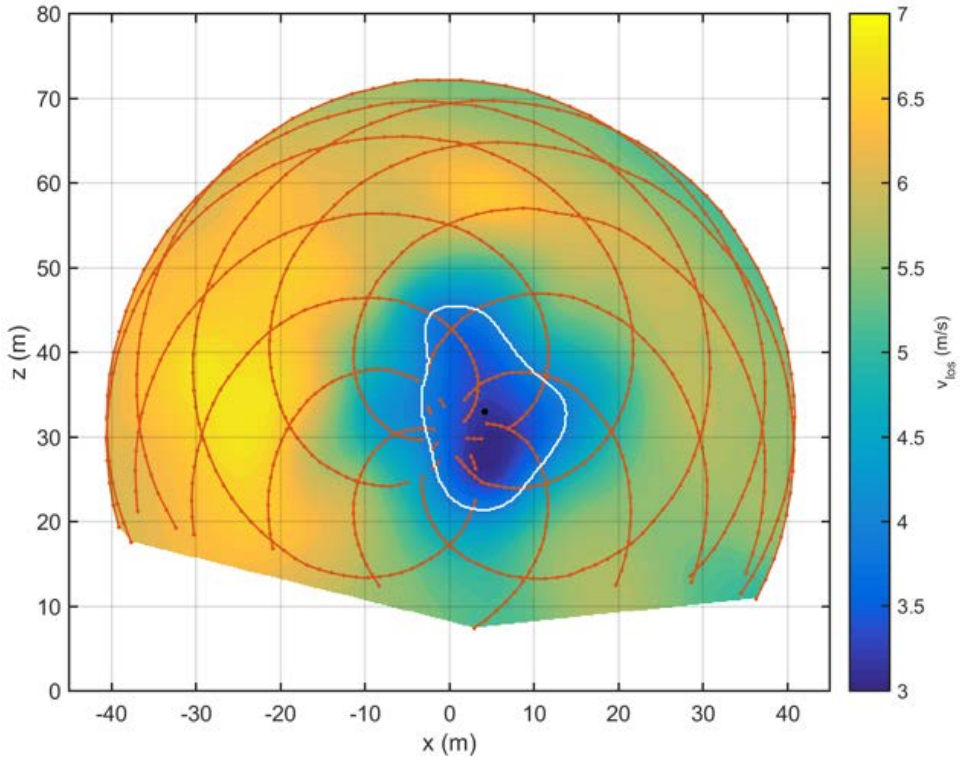


T. Herges, 2017

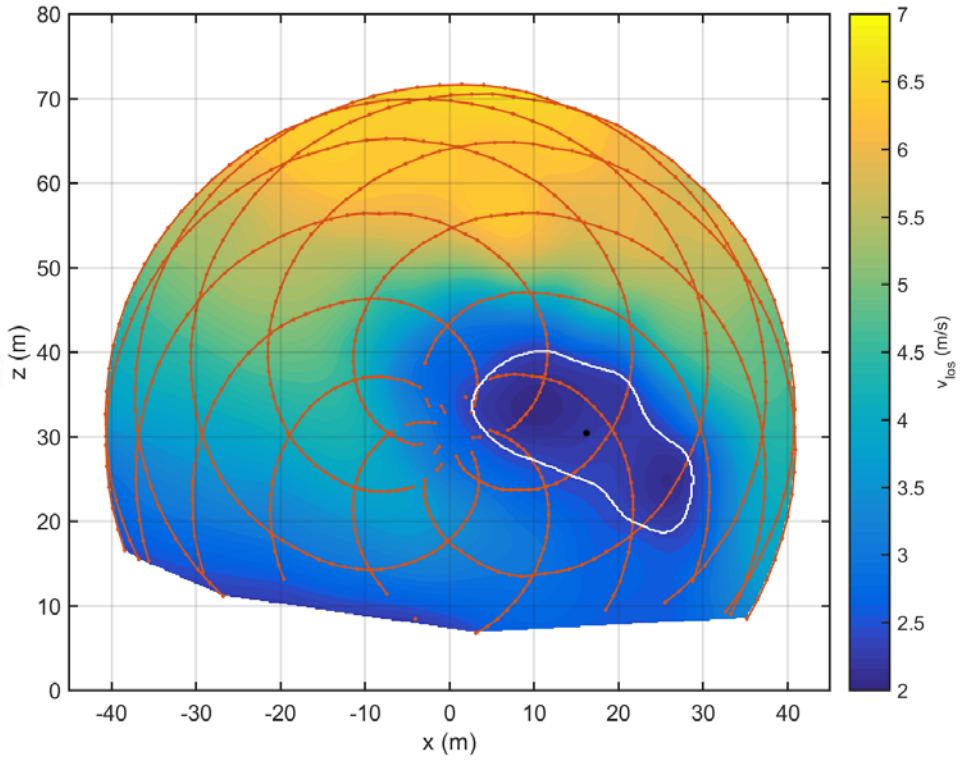
Analysis: Wake Tracking

Stability Video

Unstable BL



Stable BL



Measuring impact of turbine state

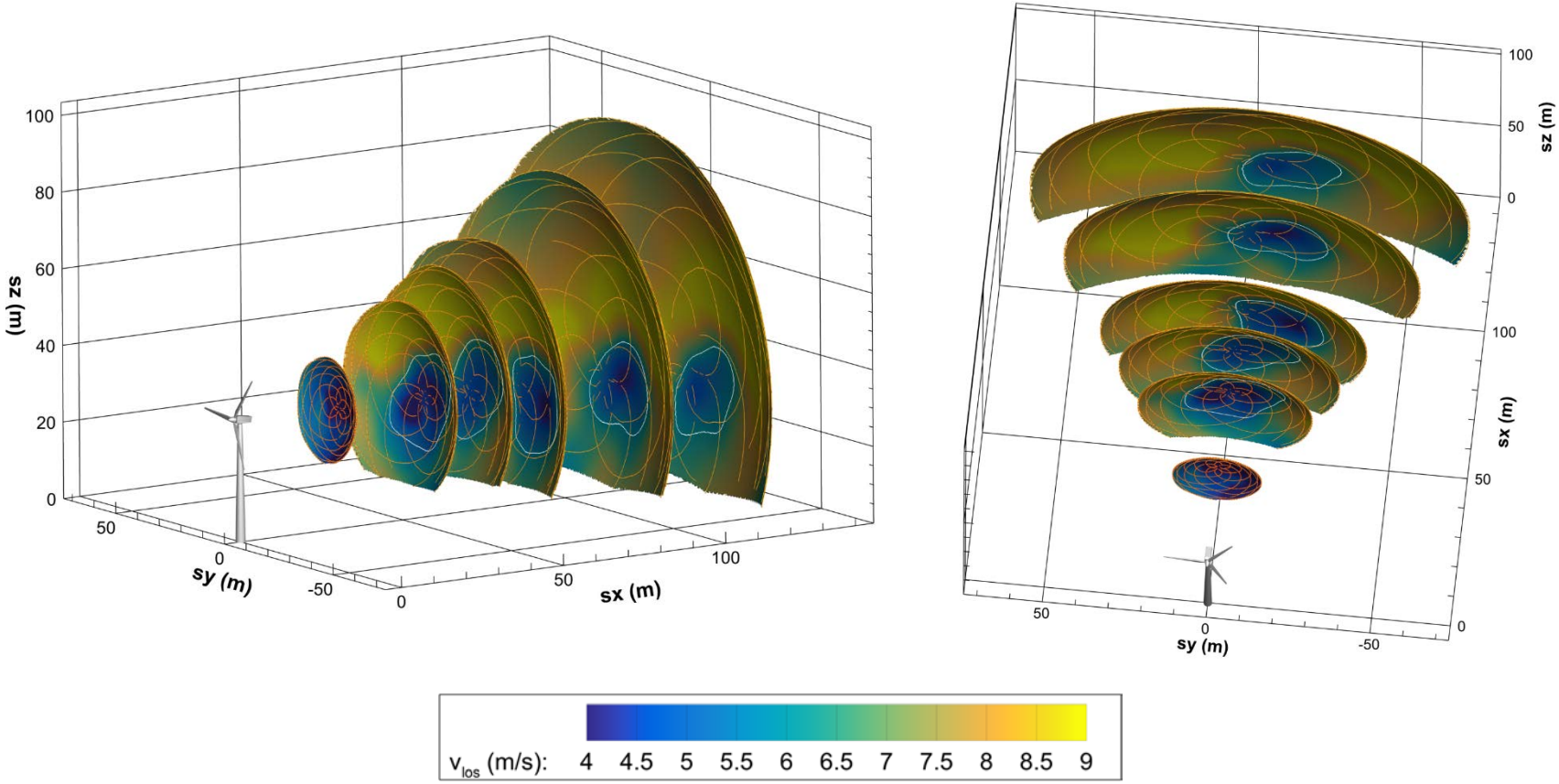
- Bulk Richardson = 0.7
- z/L = 3.1
- α = 0.3

- wind speed = 7.5 m/s
- TI = 0.08
- veer = 4.4°

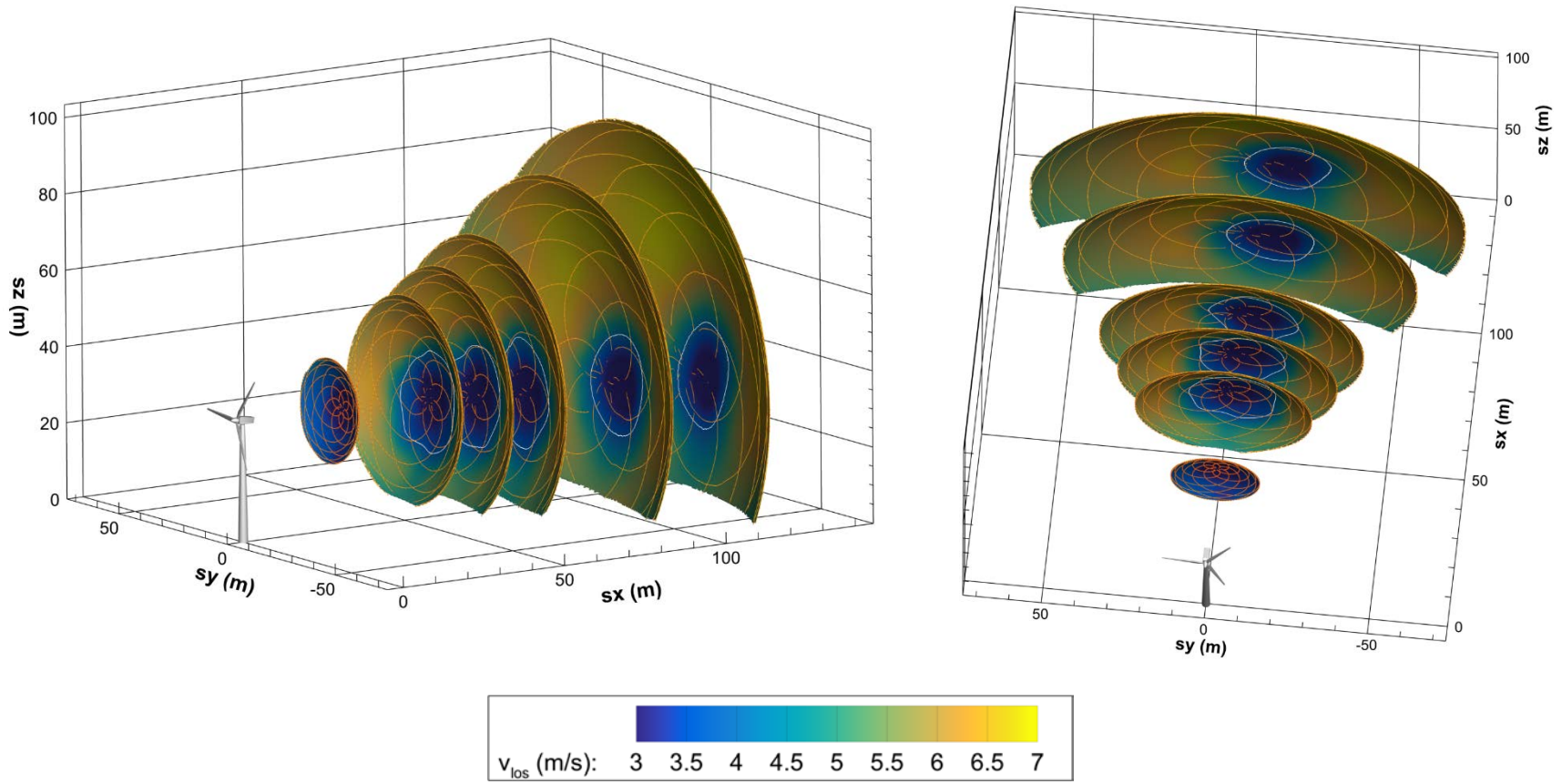
- yaw offset = -7.5° to 15°
- Yaw heading = 159.5 degN

Field Guide To Wakes

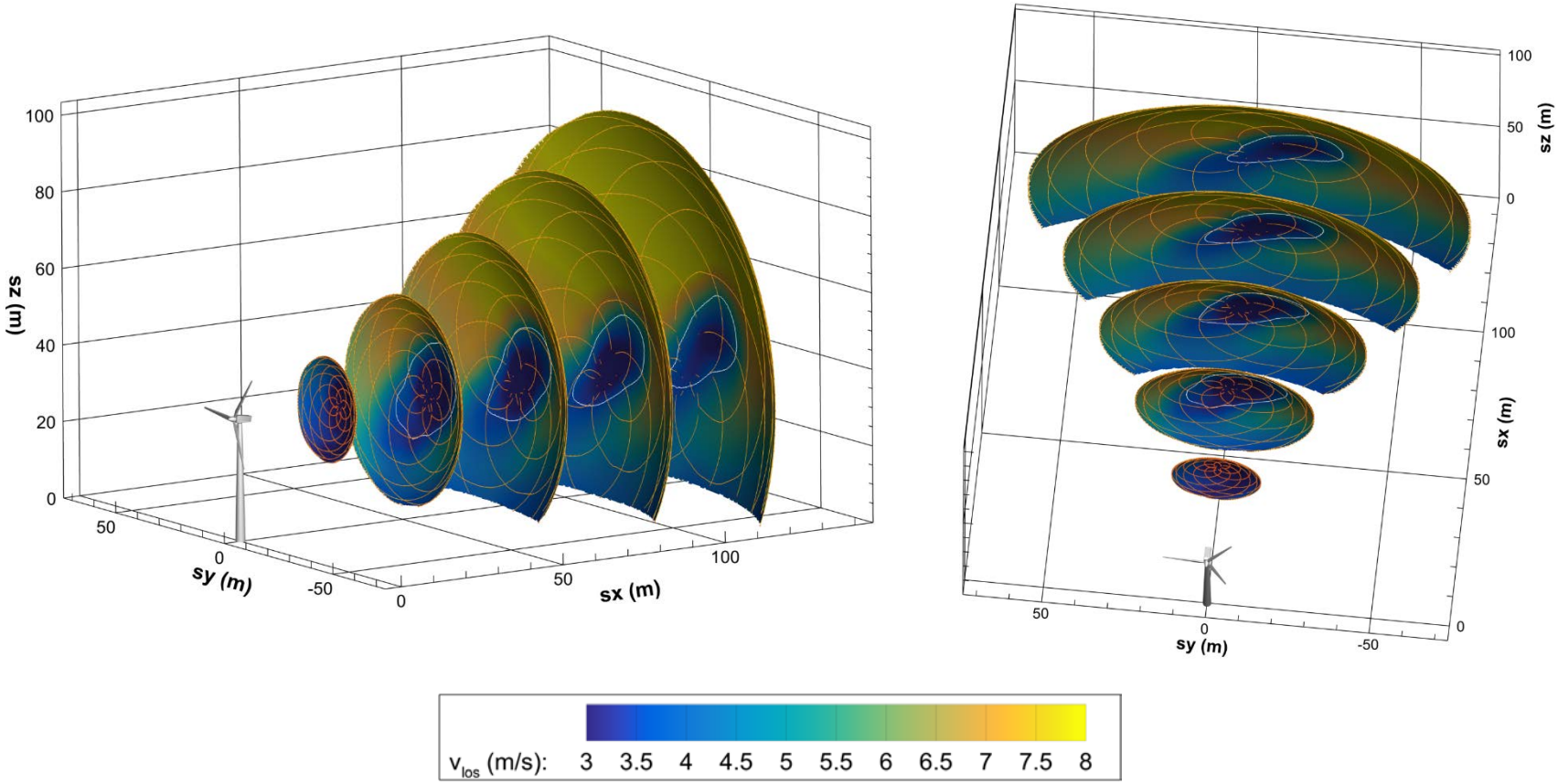
Neutral Atmosphere



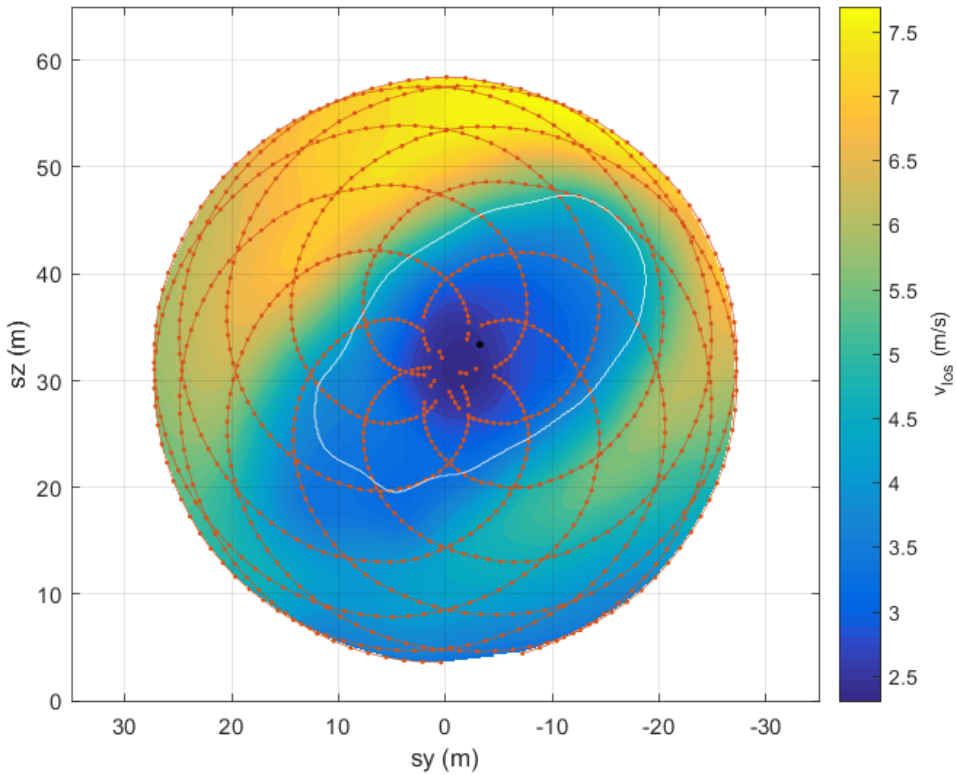
Stable Atmosphere No Veer

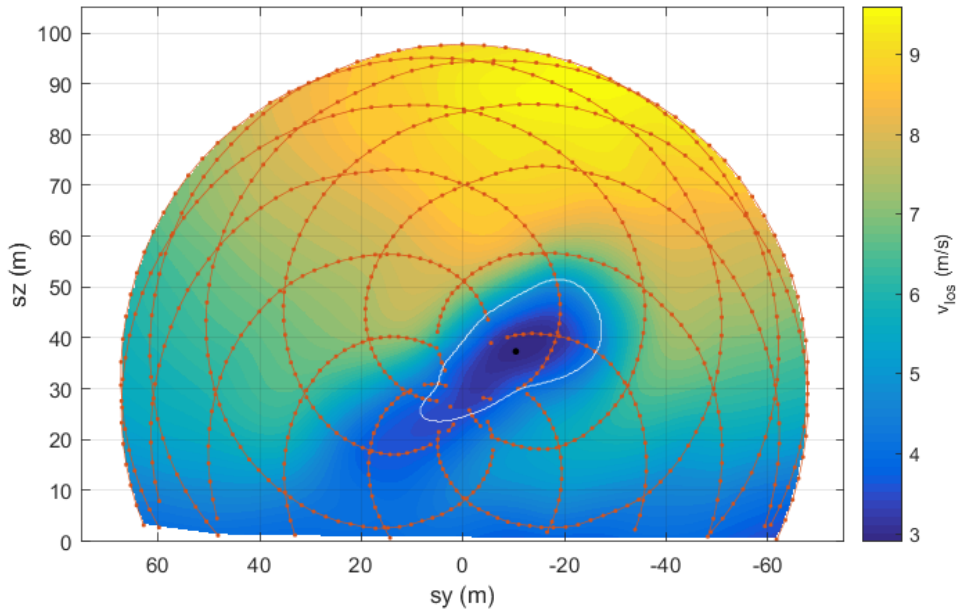


Stable Atmosphere Positive Veer

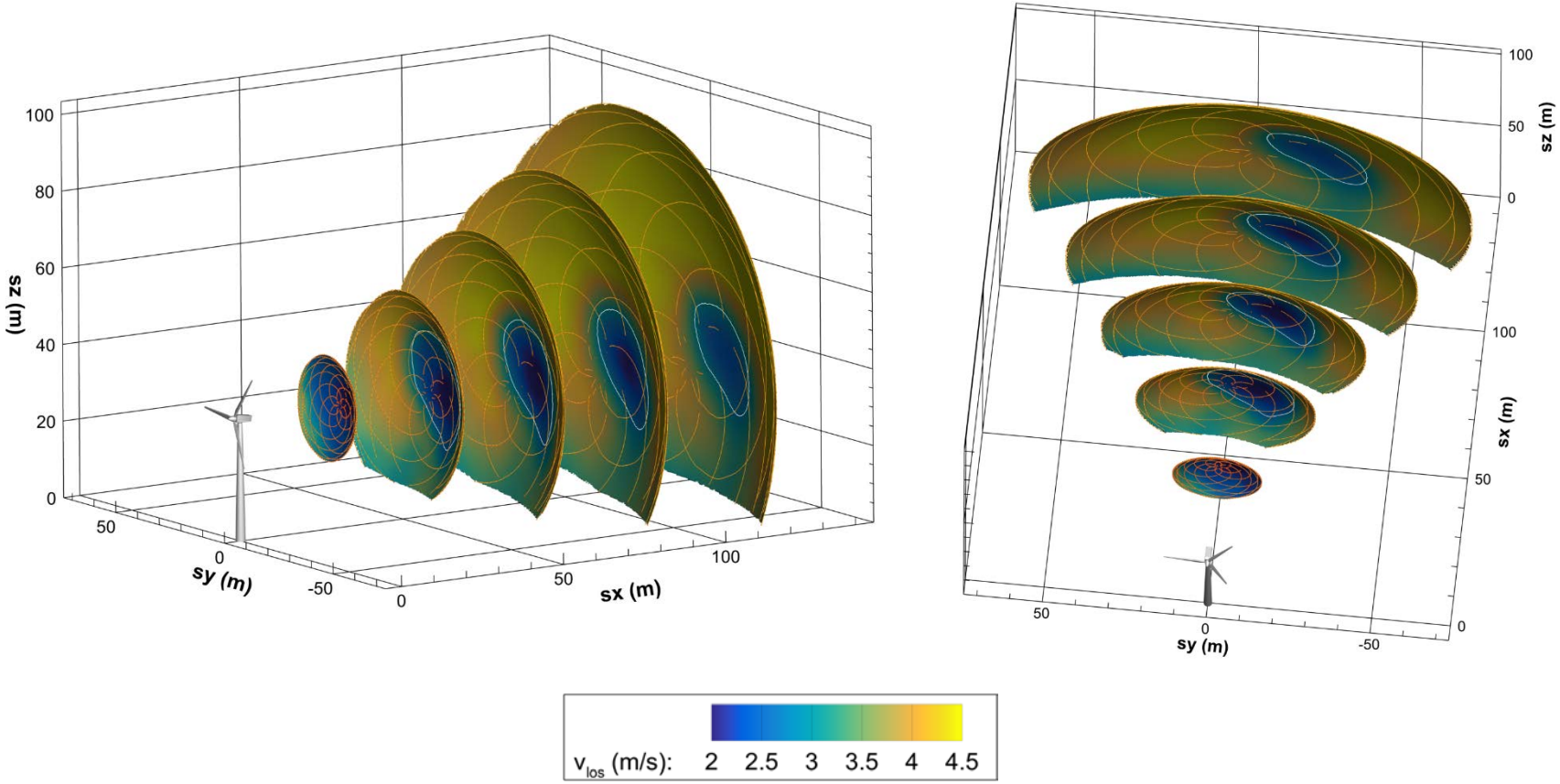


Stable Atmosphere Positive Veer

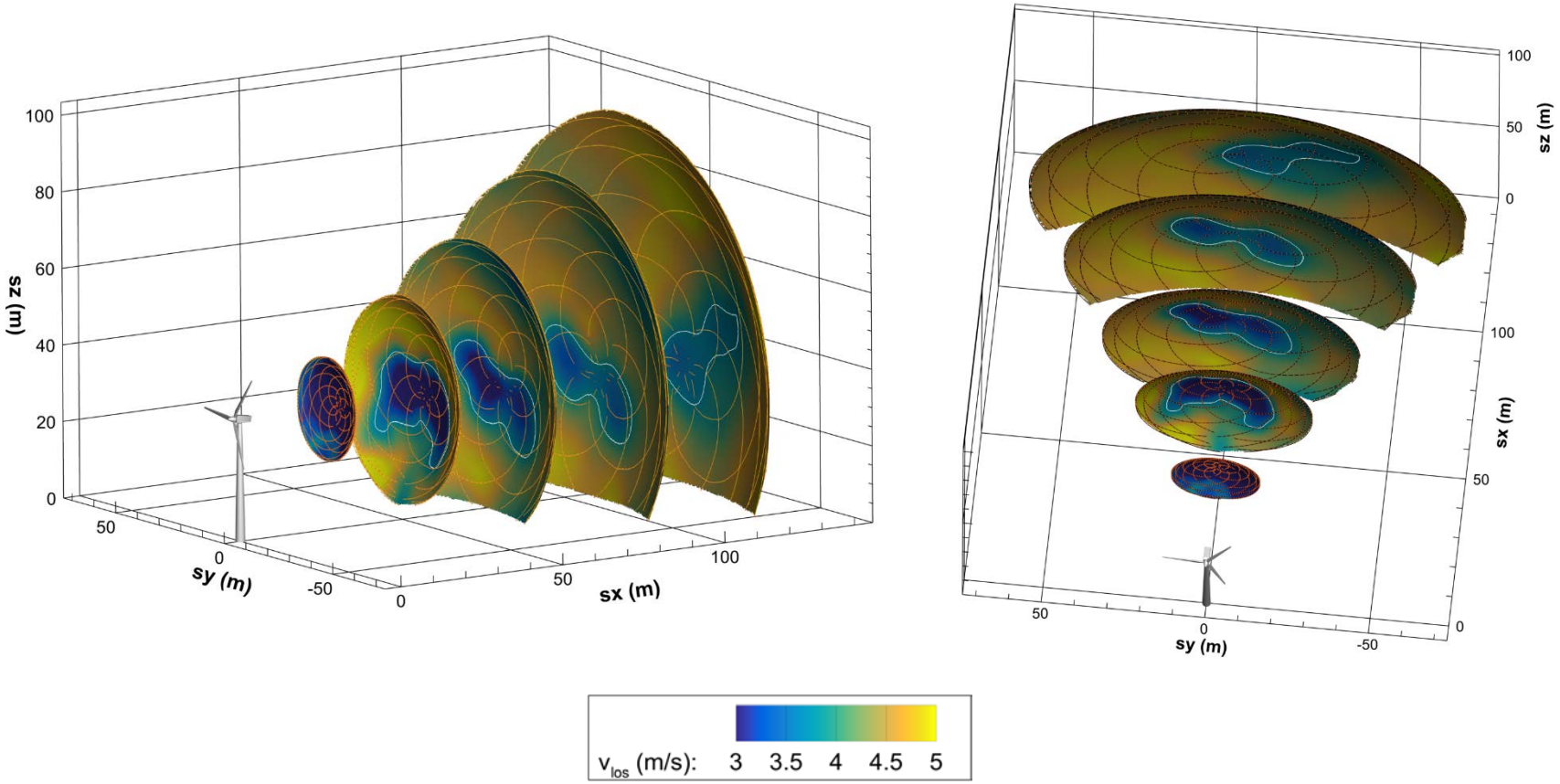




Stable Atmosphere Negative Veer



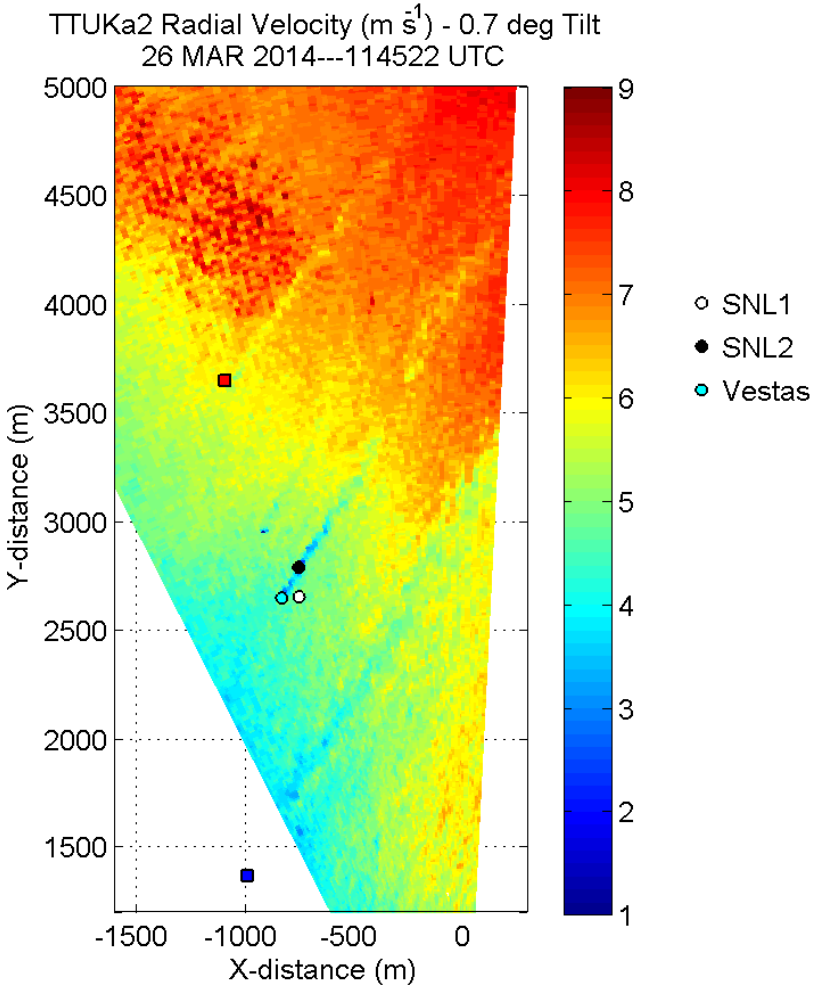
Unstable Atmosphere



TTU Collaboration

Atmospheric Characterization

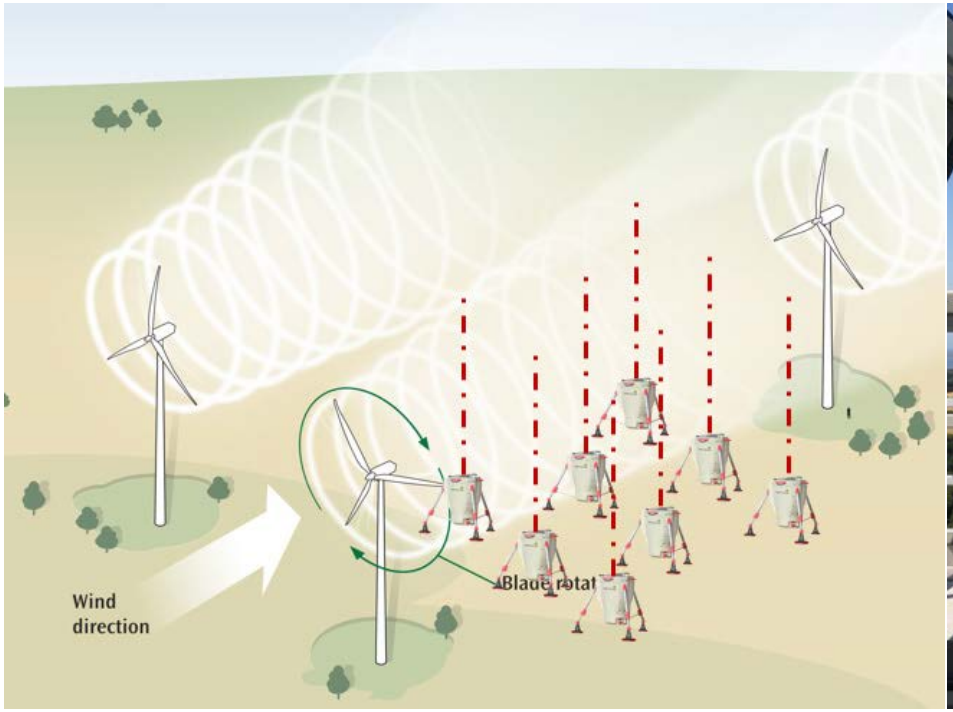
- Doppler Radar
- NWI site assets



TTU Collaboration

Pentalum SpiDAR – reconfigurable virtual met towers

Windar – Inflow and wake measurements. Control integration.



Industry Collaboration

Sandia National Laboratories

Vestas Wind. It means the world to us.™

LM WIND POWER

GE Energy

SIEMENS Siemens Wind Power

NIR GROUP Renewable Energy Solutions

MICRON OPTICS

PENTALUM

WINDAR PHOTONICS

ABB Power and productivity for a better world™

SKYSPECS

NATIONAL INSTRUMENTS

BIRD Israel-U.S. Binational Industrial Research and Development Foundation

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
ADVANCED MANUFACTURING OFFICE

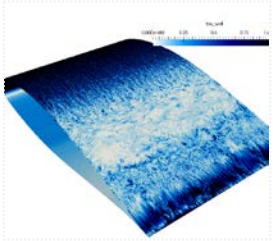
TEXAS TECH UNIVERSITY

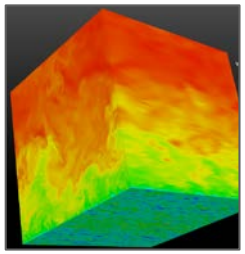
DTU Technical University of Denmark

UT DALLAS

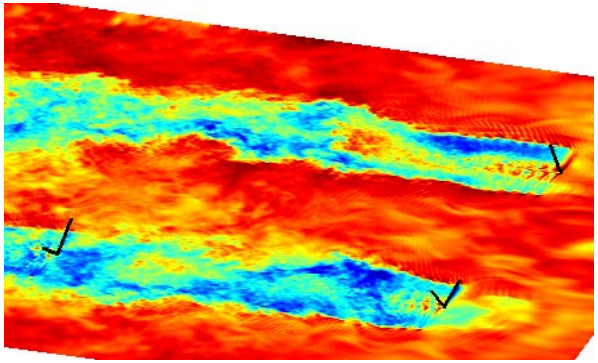
NREL

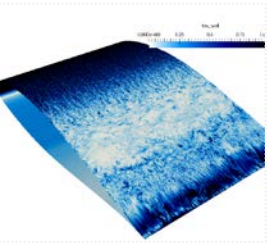
Small Business Vouchers Pilot
U.S. DEPARTMENT OF ENERGY

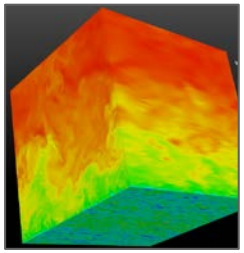




HIGH FIDELITY MODELING







High Fidelity Modeling

August 15, 2017

David Maniaci

Sandia National Laboratories

Exceptional service in the national interest

SAND2017-8790 O

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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A2e HFM and ExaWind Overview and Objectives

Parallel HFM funding and development efforts:

A2e HFM: Create a predictive modeling capability, with multiple levels of fidelity, that is backed by rigorous V&V (with UQ).

ExaWind: Ensure that the HFM capability is highly scalable on today's peta-scale HPC systems, and tomorrow's exascale systems

> ***10-year ExaWind Challenge Problem:*** Predictive simulation of a wind plant composed of O(100) multi-MW wind turbines sited within a 10 km×10 km area with complex terrain.

SAND2014-15367M

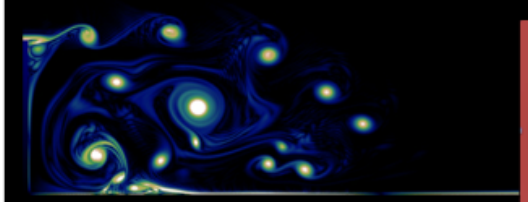
Nalu V1.0

Nalu
low Mach

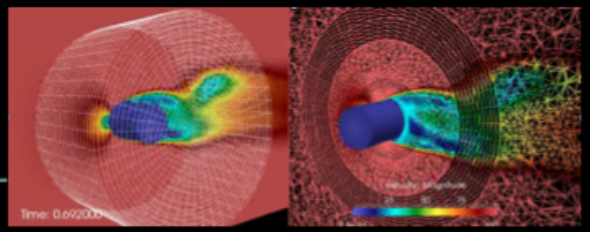
Open Source: BSD license has been granted (5/2014)

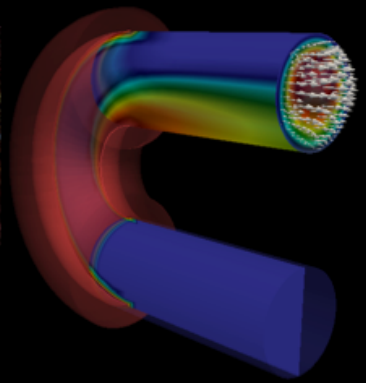
Weak scaling demonstrated to 524,000 core with 10 billion unstructured hex mesh

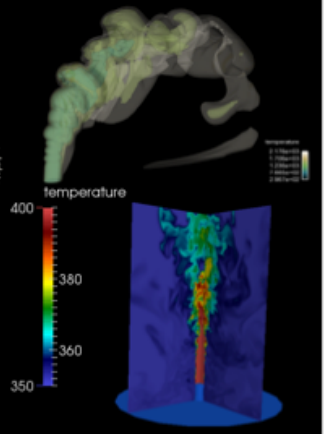
Generalized unstructured (CVFEM and EBVC supported)

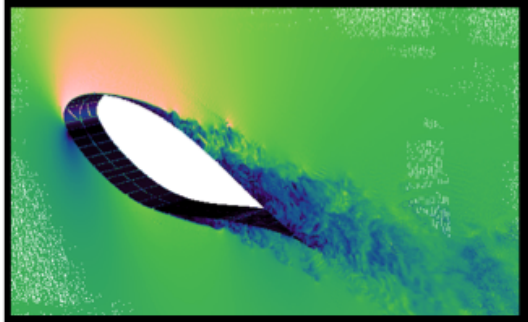


Backstep (vorticity)

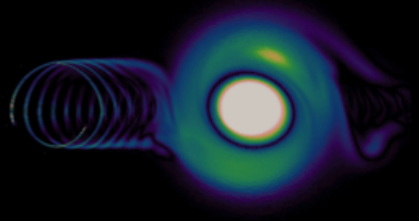








2D/3D periodic

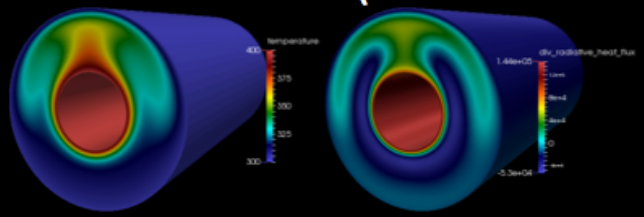


Time: 60.000000

2D/3D sliding mesh

Multiphysics CHT

LES Jet
(cold and reacting)



Multiphysics Fluids/PMR

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Trilinos

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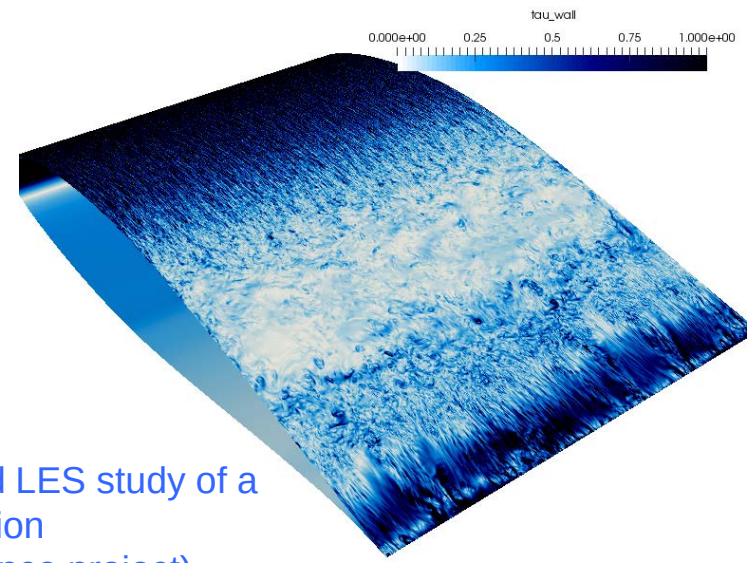
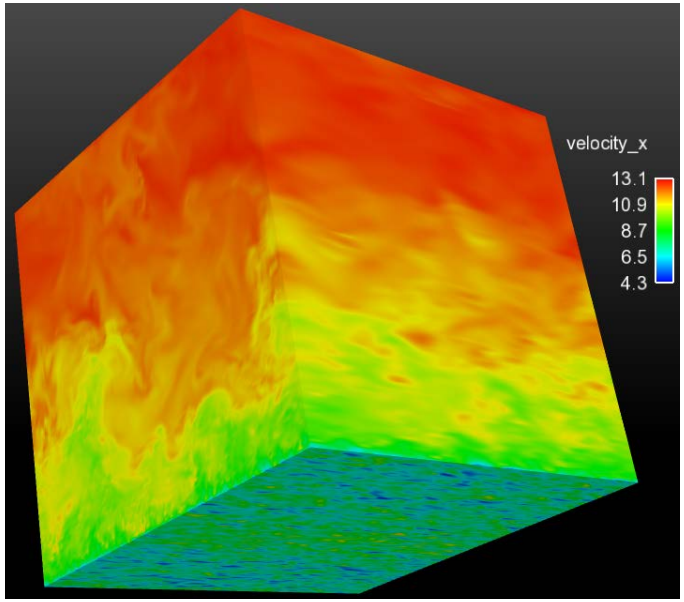
Long-term HFM research activities

- Use the code to understand the complicated wind farm flow physics, including turbine-wake interactions, multiple-wake interactions, atmospheric turbulence, and flow over complex terrain
- Ensure that the code is correctly implemented and predictive of wind plant physics through a formal verification and validation program
- Enable a next generation of lower fidelity tools that will be used for decision making and analysis in the design process



Nalu wall-resolved LES study of a turbine blade section
(Trinity Open Science project)

Nalu ABL simulation



Partnering and Access

A2e Data Archive and Portal https://a2e.energy.gov/about/dap

Public validation data including experimental and simulation results.

Nalu:https://github.com/spdomin/Nalu

Open-source CFD code, available on github. Core development supported for both petascale computing applications now, and next-generation exascale computing platforms in ~10 years.