NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Calibration & Initial Validation of FAST.Farm Against SOWFA

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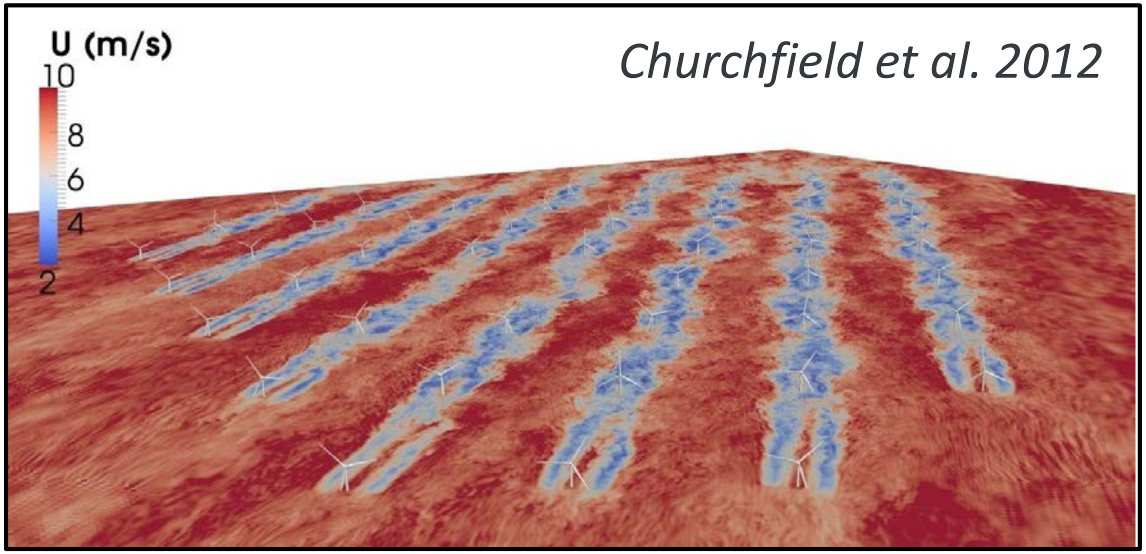
The Challenge

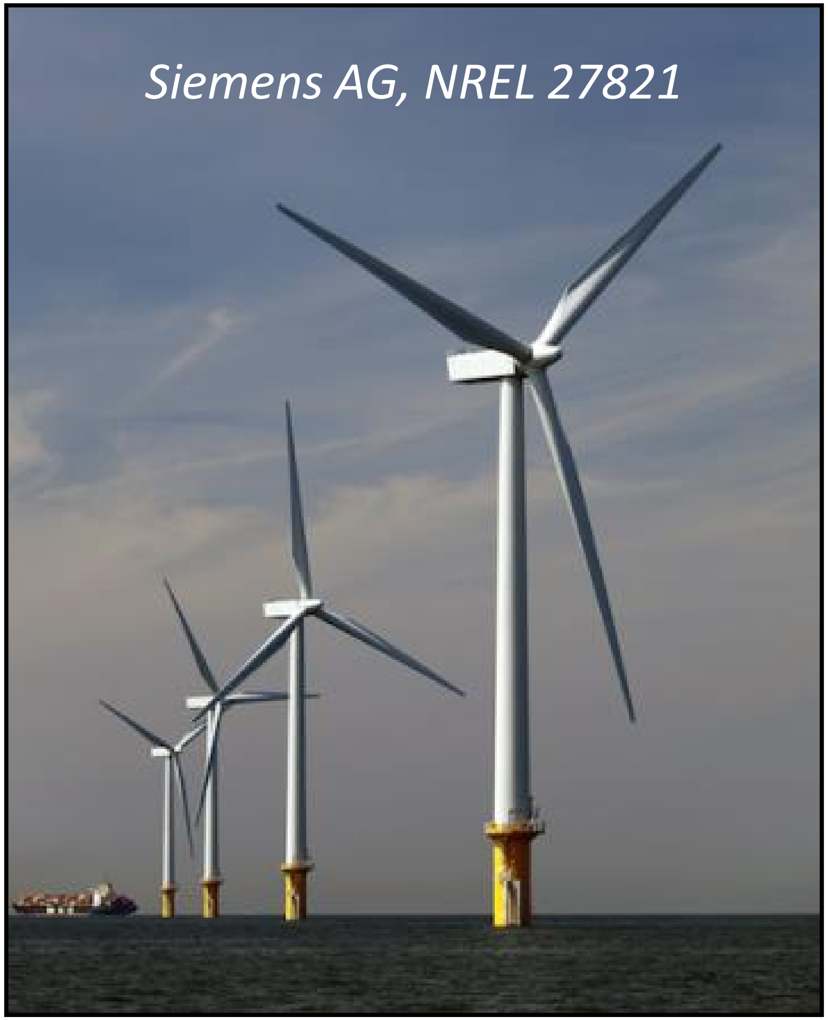
- Wind industry plagued by underperformance, failures, & expenses:
  - Improvements required in wind-farm performance & reliability, together w/ reduced uncertainty & expenditures to achieve cost targets
  - Improvements eluded by complicated nature of wind-farm design, especially interaction between atmospheric phenomena & wake/array effects
- Range of wind-farm tools exist, but none fully meet engineering needs, e.g.:
  - **FLORIS**: Steady-state wind-farm performance & controls, but no turbine loads
  - **DWM**: Both performance & loads, including dynamics, but individual or serial solution limits accuracy & usefulness
  - **SOWFA**: Large-eddy simulation (LES CFD) computational demand means very few runs

*Example **SOWFA** Simulation*

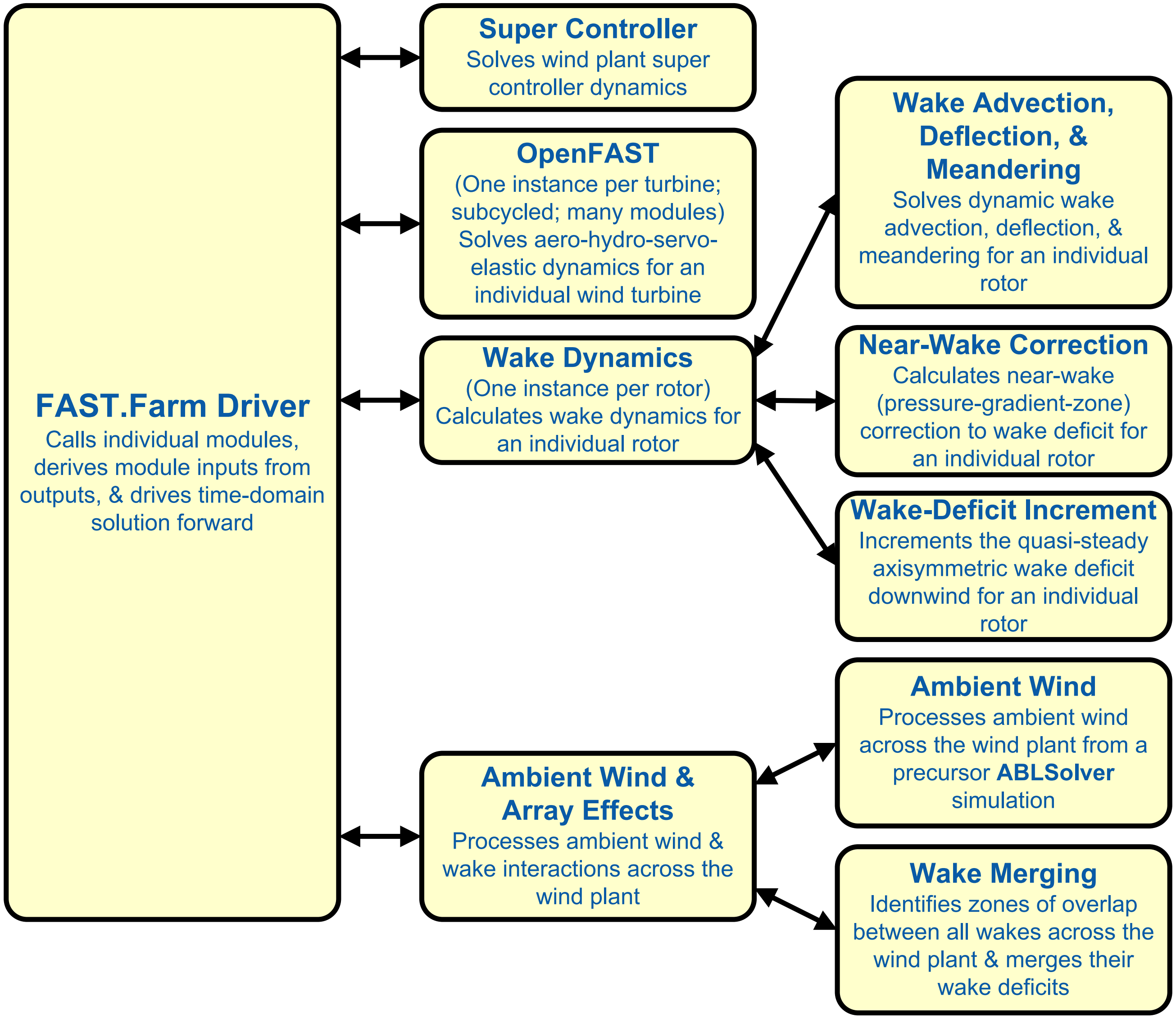


Objective & Approach

- *Objective*: Develop, validate, & demonstrate new multiphysics tool (**FAST.Farm**) applicable to engineering problems involving wind-farm design
  - This presentation focuses on calibration
- **FAST.Farm** aims to balance need for:
  - Accurate modeling of relevant physics for predicting performance & structural loads
  - Maintain low computational cost to support highly iterative & probabilistic design process & system-wide optimization
- **FAST.Farm**:
  - Relies on some **DWM** modeling principles
  - Avoids many limitations of existing **DWM** implementations
  - Compliments controls capability of **FLORIS**
  - Functions more like **SOWFA/Nalu**
- Insight from **SOWFA** simulations being used to support development, parameter calibration, & validation of **FAST.Farm**

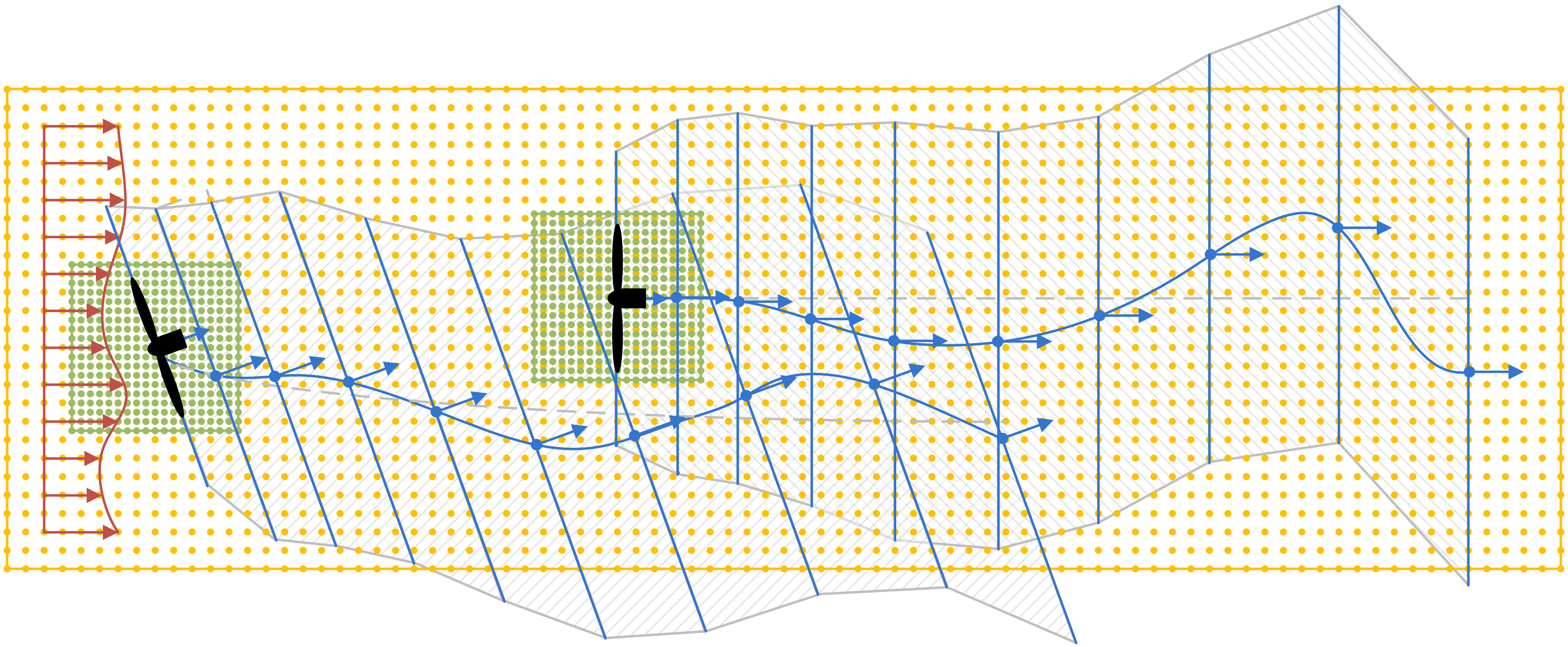


FAST.Farm **Submodel Hierarchy**

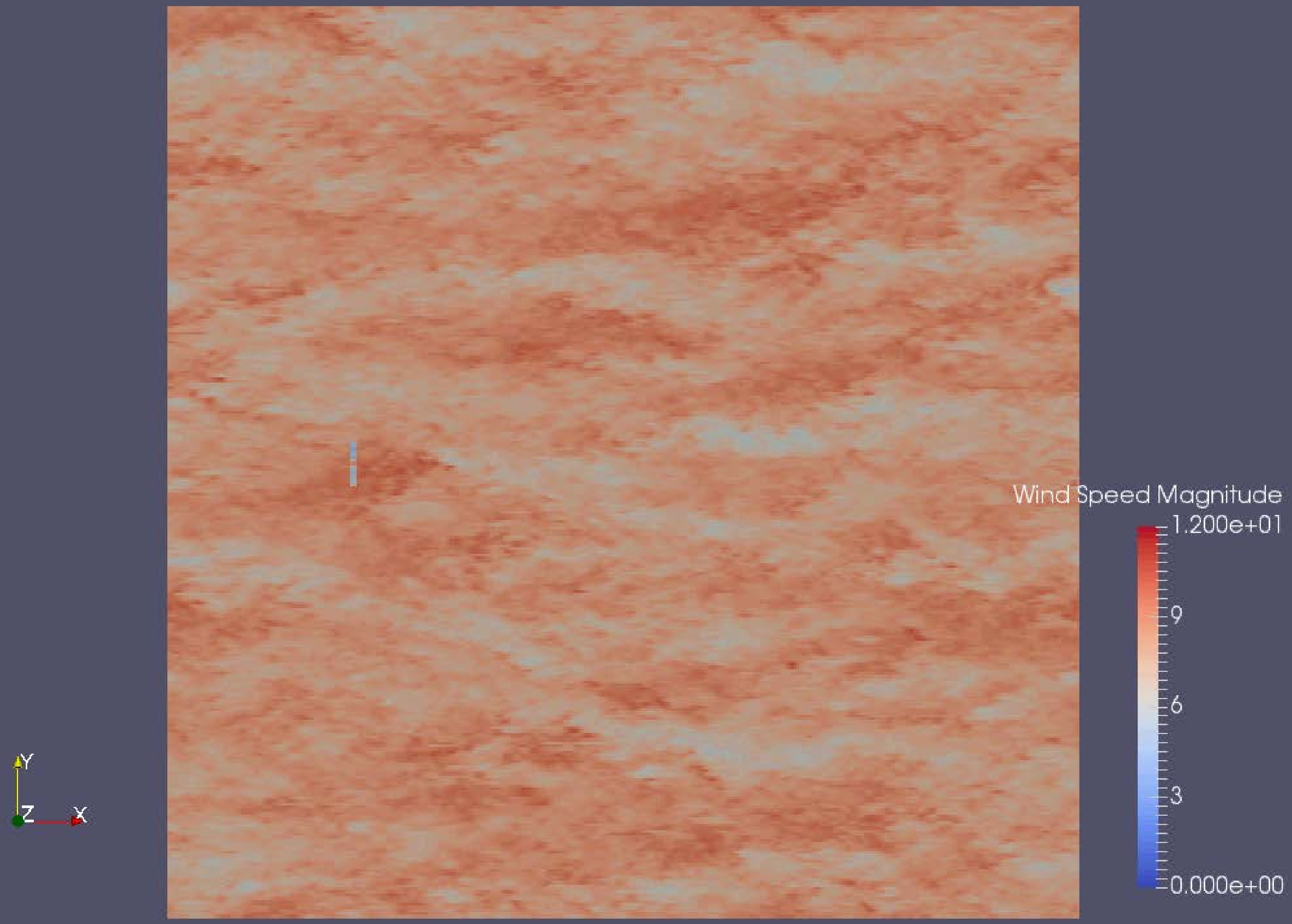


- **FAST.Farm** functions nonlinearly in time-domain
- **FAST.Farm** follows requirements of **OpenFAST** modularization framework
- Unique innovations:
  - Use LES precursor for ambient wind
  - Developed new models for wake advection, deflection, & merging
  - Inclusion of a super controller
  - Solve entire wind farm in serial or parallel
  - Calibration of model parameters against HFM

Wake Planes, Wake Volumes, & Zones of Overlap

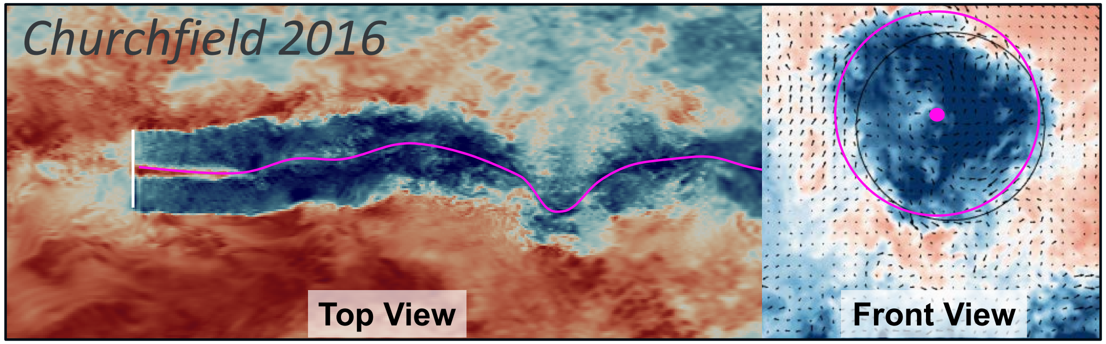


FAST.Farm-**Generated w/ Stepped Yaw – 8m/s Neutral**



Calibration of FAST.Farm Against SOWFA

- **FAST.Farm** contains many (20) parameters that can be used to influence wake dynamics
- A calibration approach is used to set default parameter values
- Approach:
  - Identify calibration cases & approach
  - Identify starting values of calibration parameters
  - Run **SOWFA** & extract wake characteristics
  - Run **FAST.Farm** w/ varied parameters (sequenced grid search)
  - Identify parameters that minimize wake-deficit & wake-meandering error between **FAST.Farm** & **SOWFA**



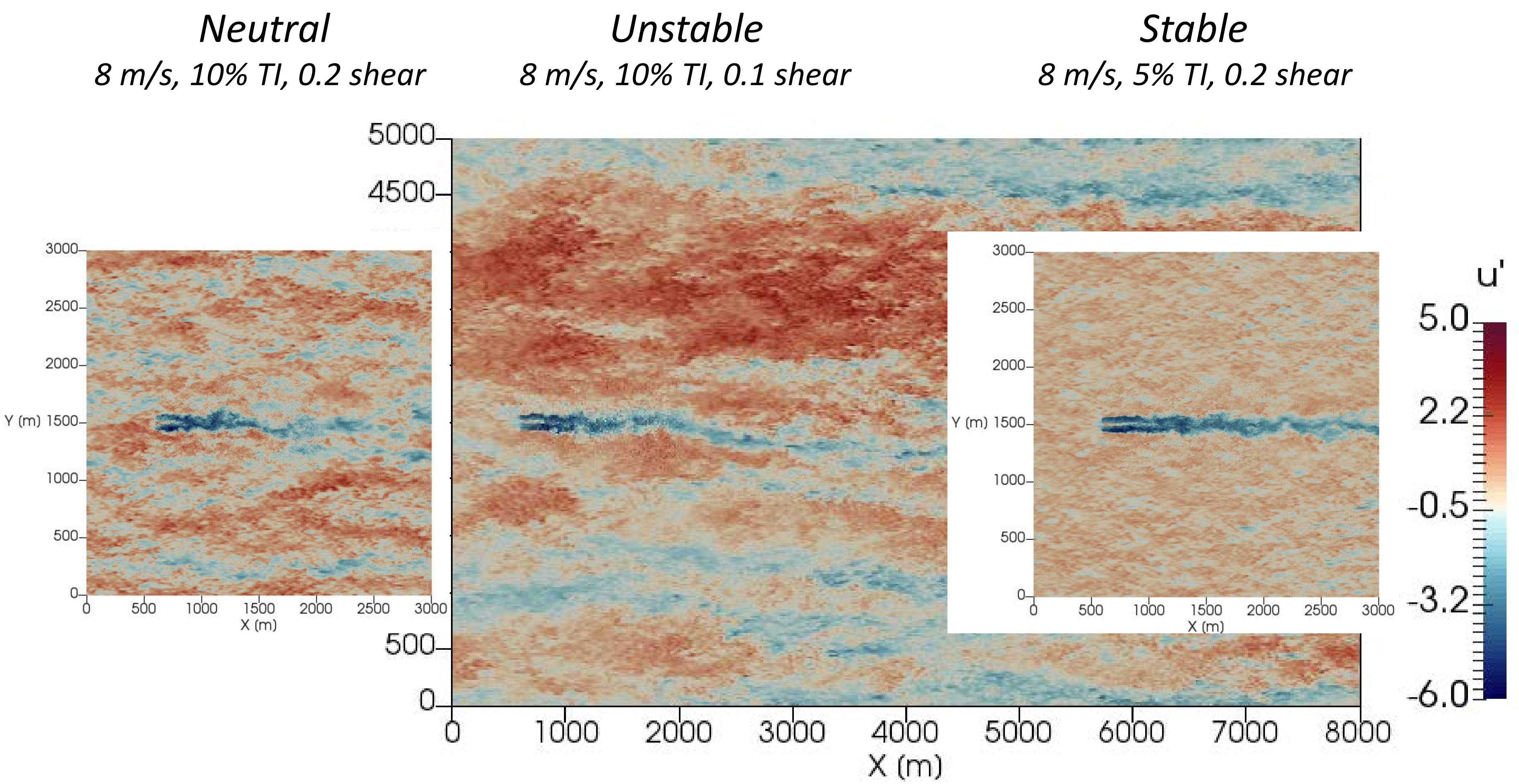
***SOWFA**-Derived Wake Deficit & Centerline*

Case	Name	Description
1	N	8 m/s, neutral, 10% TI, 0.2 shear, normal operation
2	U	8 m/s, unstable, 10% TI, 0.1 shear, normal operation
3	S	8 m/s, stable, 5% TI, 0.2 shear, normal operation
4	SHS	8 m/s, stable/high shear, 10% TI, 0.4 shear, normal operation
5-8	N_{-25}, N_{-10}, N_{+10}, N_{+25}	8 m/s, neutral, 10% TI, 0.2 shear, operation under fixed yaw error
9	N_{Step}	8 m/s, neutral, 10% TI, 0.2 shear, operation with yaw steps

Calibration Approach

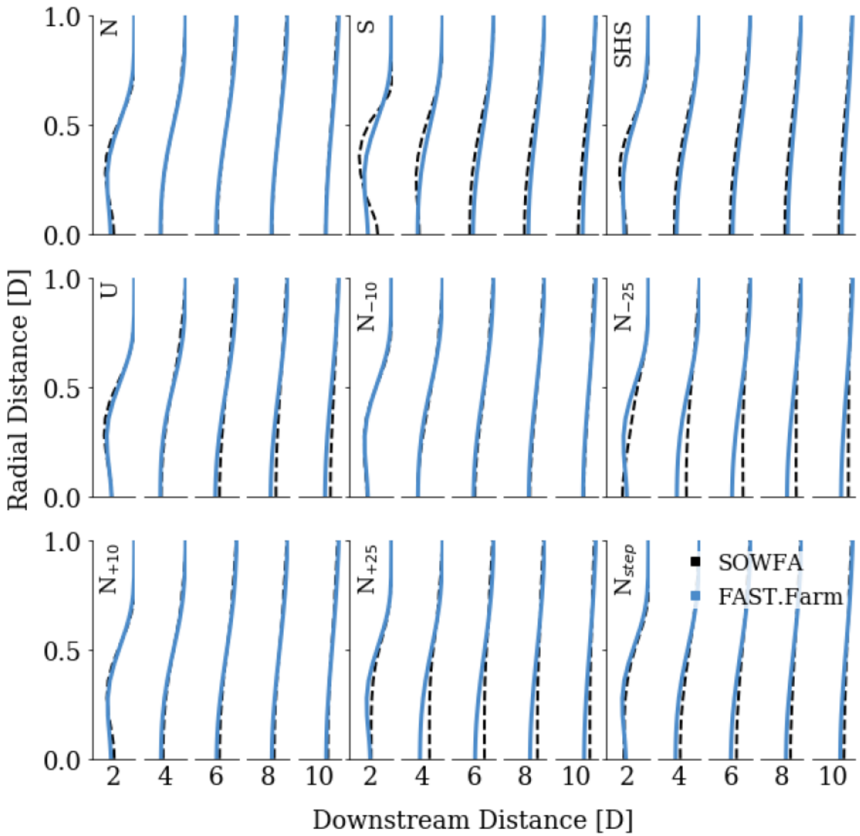
Step	Name	Cases Run	Parameters Calibrated
1	Fixed Yaw	N, N_{-25}, N_{-10}, N_{+10}, N_{+25} (5)	Wake deflection (4)
2	Eddy	N, U, S, SHS (4)	Near-wake correction & eddy viscosity (3)
3	Eddy - Amb	N, U, S, SHS (4)	Eddy viscosity for ambient turbulence(4)
4	Eddy - Shr	N, U, S, SHS (4)	Eddy viscosity for wake-shear layer (4)
5	Meander	N, U, S, SHS (4)	Spatial averaging (2)
6	Step Yaw	N, N_{step} (2)	Low-pass filter (1)

SOWFA **Solutions**

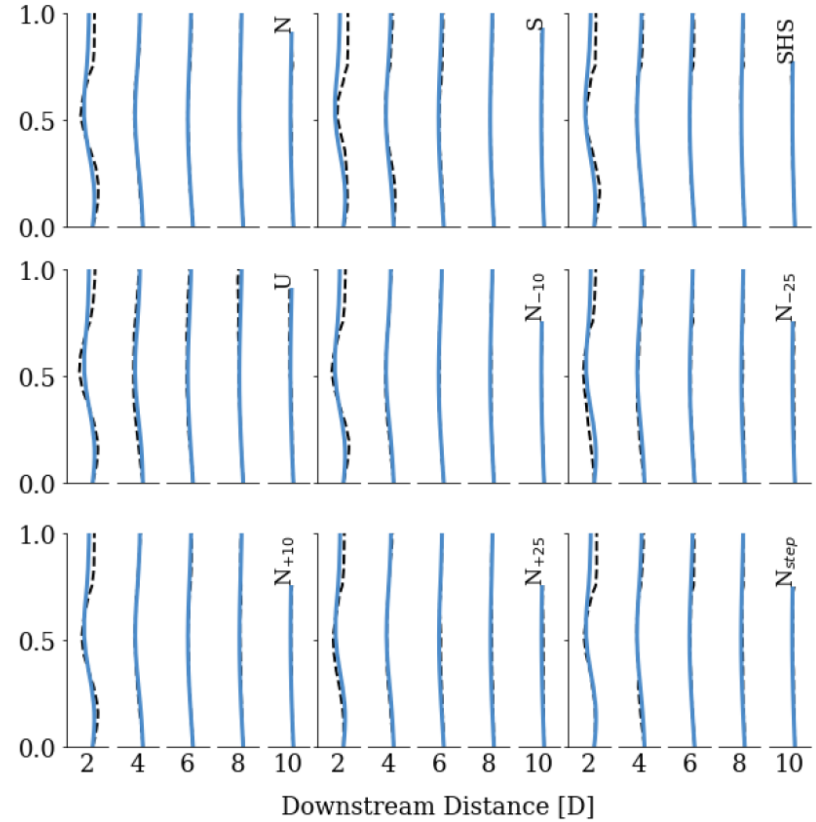


***SOWFA** Solutions*

Calibration Results



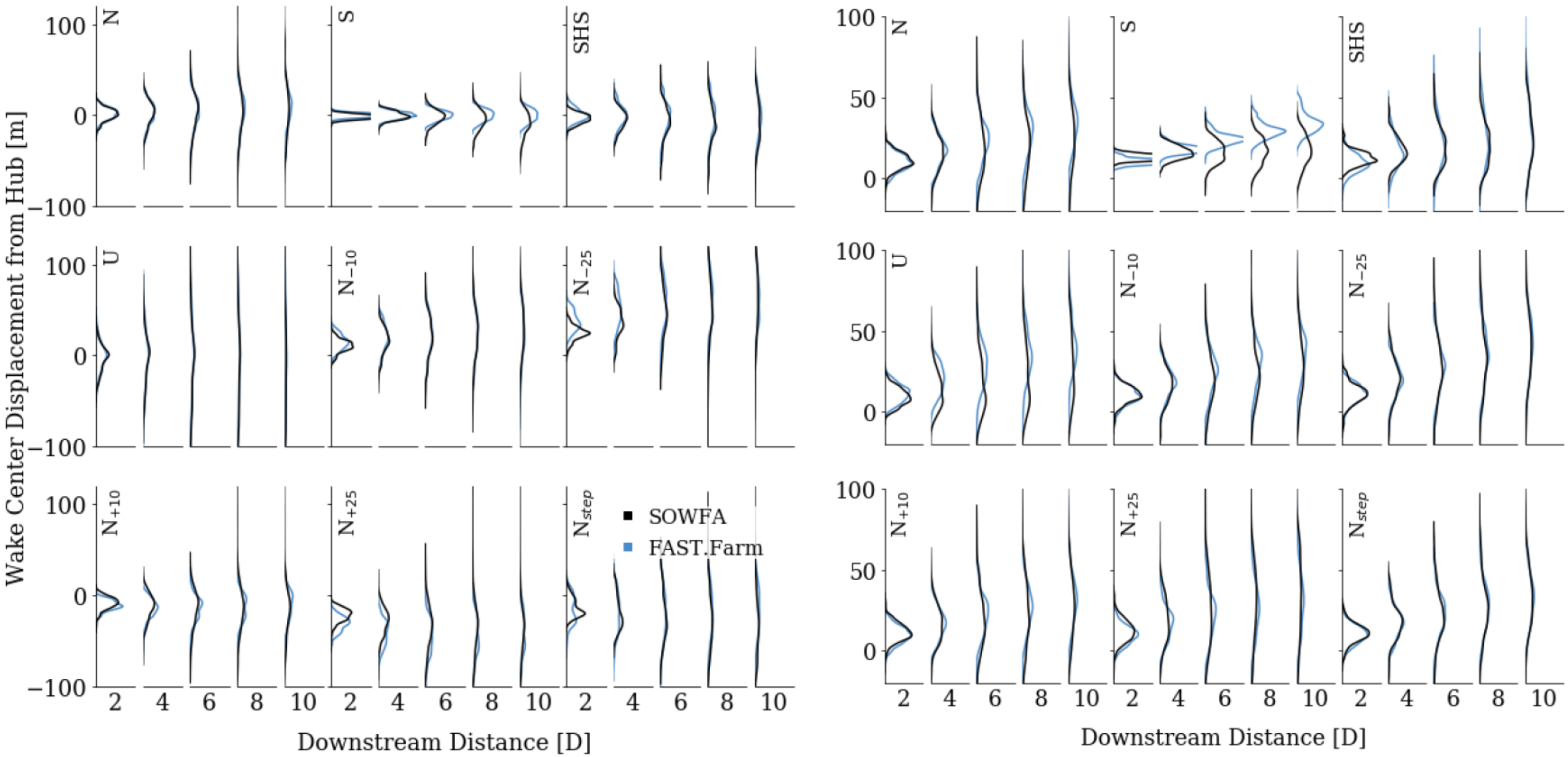
Axial Wake Deficits



Radial Wake Deficits

- **FAST.Farm** captures change in wake-deficit evolution w/ downstream distance, but doesn't fully capture change predicted by **SOWFA** across different stability conditions or yaw errors
- Still reviewing, but think **SOWFA** predicts fast wake recover in U due to anisotropic turbulence
- Results suggest that **FAST.Farm** would benefit from:
  - Different calibration parameters for different stability conditions or yaw errors
  - Improved physics in the eddy-viscosity formulation

Calibration Results



Horizontal Meandering *Vertical Meandering*

- **FAST.Farm** captures overall wake-meandering statistics predicted by **SOWFA** across different stability conditions, w/ some underprediction for S
  - Meandering in **SOWFA** for S likely driven by more than just large-scale ambient turbulence (e.g. smaller scales or wake-induced turbulence & boundary layer)
- Comparisons hampered by lack of statistical convergence (30-min/case)

Ongoing Work – Validation of FAST.Farm Against SOWFA

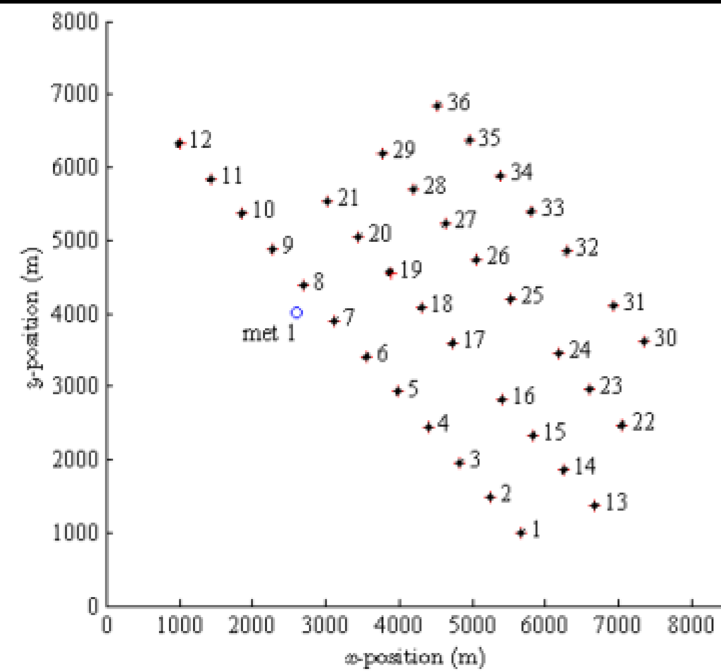
- Currently running **SOWFA** simulations—w/ modest variations in inflow & control, independent from those used to support calibration—to validate **FAST.Farm**
- **FAST.Farm** calibration parameters are untouched to check their robustness & range of applicability
- Results will be presented at TORQUE 2018

Validation Cases

Case	Number of turbines	Turbine spacing	Mean hub-height wind speed	Atmospheric stability	Turbulence intensity	Shear exponent	Yaw error
N^6	1	-	6	Neutral	10%	0.2	0°
N^{18}	1	-	18	Neutral	10%	0.2	0°
N_{+15}	1	-	8	Neutral	10%	0.2	15°
S_{+10}	1	-	8	Stable	5%	0.2	10°
N3	3	8D	8	Neutral	10%	0.2	0°
$N3_{+10/+10/0}$	3	8D	8	Neutral	10%	0.2	10°/10°/0°
S3	3	8D	8	Stable	5%	0.2	0°
U3	3	8D	8	Unstable	10%	0.1	0°

Next Steps

- Complete initial validation of **FAST.Farm**
- Release **FAST.Farm** as public, open-source software through **OpenFAST**
- Apply **FAST.Farm** by including turbine loads in wind-farm controls design/ testing
- Use **FAST.Farm** with HFM symbiotically in a multi-fidelity approach to support validation, UQ, & design
- Host a meeting of experts (likely @ TORQUE 2018) to discuss current capabilities & uses of mid-fidelity wind-farm engineering tools such as **FAST.Farm** & to outline their limitations, needs, & future development direction
- Address **FAST.Farm** limitations through more development



OWEZ Offshore Wind Farm [Churchfield et al 2014]

Carpe Ventum!

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