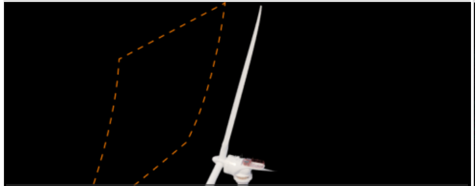
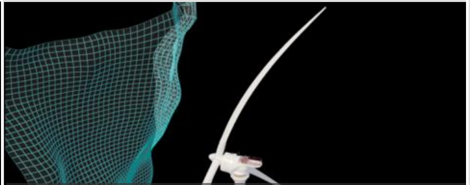
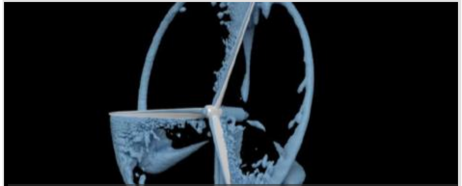
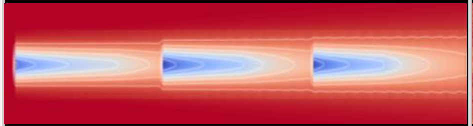
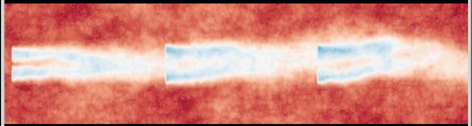
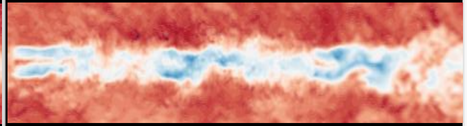
NREL/DOE Wind Modeling Tools

Paul Veers

March 31, 2021

NREL/DOE Open-Source Modeling Tool Overview

Model Fidelity / Computational Intensity →

Application	Design Exploration	Detailed Design	Highly Resolving
Single Turbine Performance and Loads	**WISDEM** Multidisciplinary design optimization and cost modeling  **Other Tools:** Turbine Architect, CpMax, HawtOpt2	**OpenFAST** Turbine loads analysis, detailed turbine design, IEC standards  **Other Tools:** Bladed, HAWC2, FLEX 5	**ExaWind/SOWFA** Understand physics, final turbine design check, calibrate / validate lower fidelity  **Other Tools**: EllipSys3D-HAWC2, STAR-CCM+
Full Wind-Plant Performance and Loads	**FLORIS** Wind-plant controls and siting optimization  **Other Tools**: WAsP, WindFarmer, Fuga	**FAST.Farm, WindSE** Turbine siting within plant, wind-plant controls, plant loads analysis, detailed plant design  **Other Tools:** openWind, MeteoDyn WT, DWM	**ExaWind/ERF/SOWFA** Understand physics, final plant design check, calibrate / validate lower fidelity  **Other Tools**: EllipSys3D, PALM, WRF-LES, W2A2KE3D, VFS-Wind

* **Other Tools** are other widely-used tools with similar capabilities

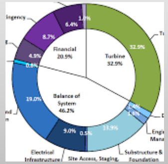
Key WISDEM Modules

SE = Systems Engineering

LandBOSSE

ORBIT

Plant_FinanceSE

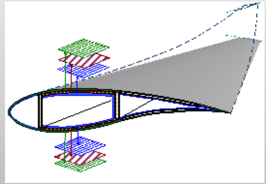


LCOE

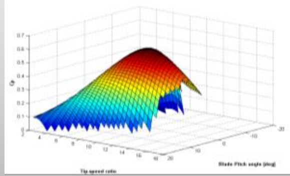
Turbine_CostsSE

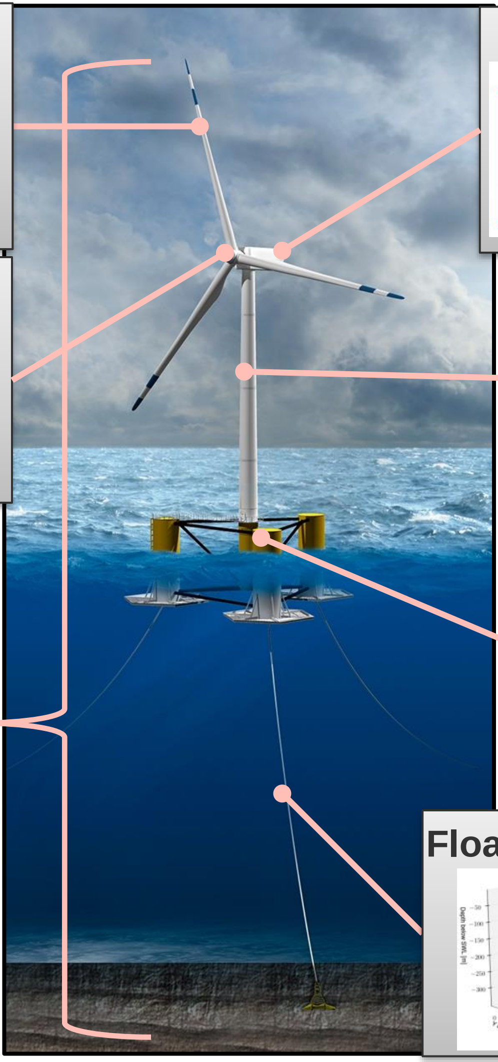
$

RotorSE-pBeam

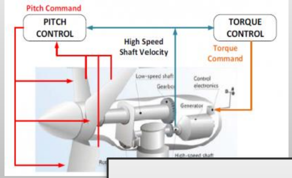


RotorSE-CCBlade

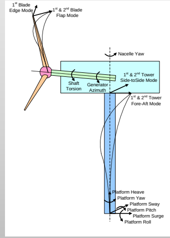




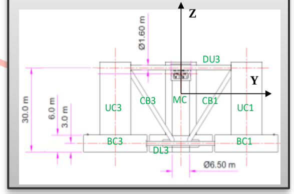
DrivetrainSE



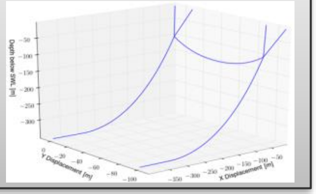
TowerSE



FloatingSE



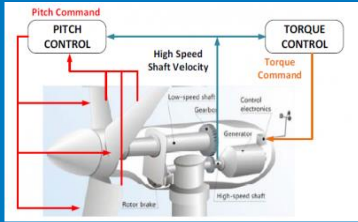
FloatingSE-pyMAP



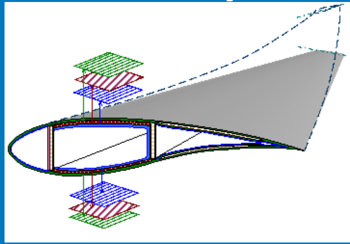
OpenFAST Modules

Dyn = Dynamics

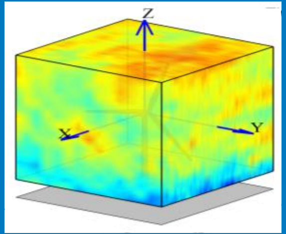
ServoDyn

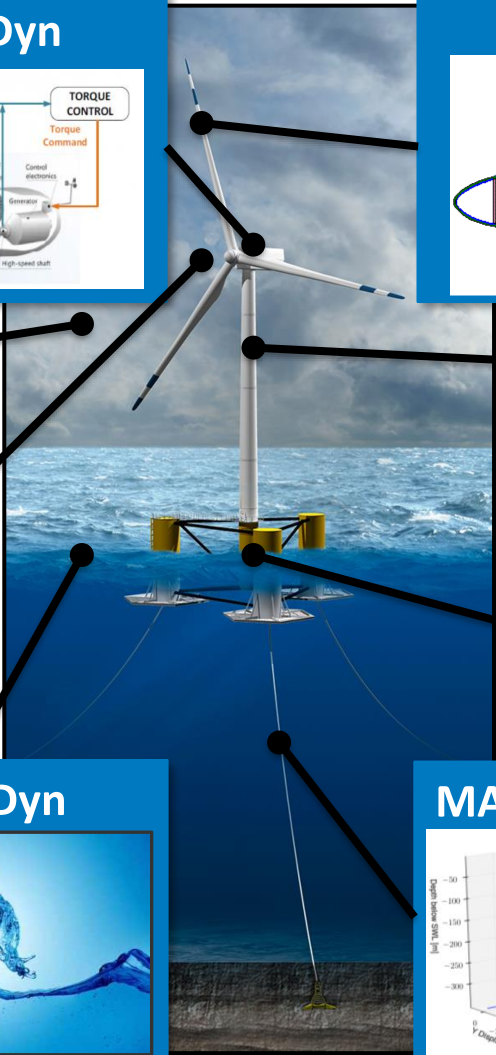


BeamDyn

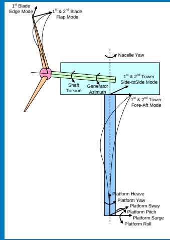


InflowWind

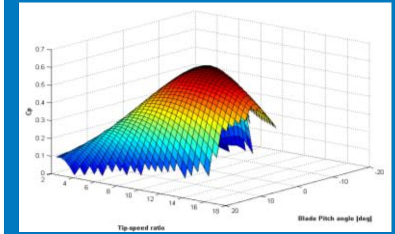




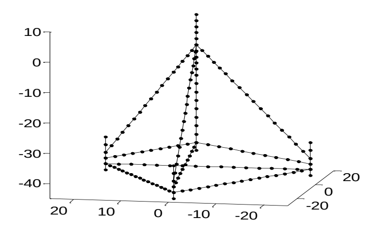
ElastoDyn



AeroDyn

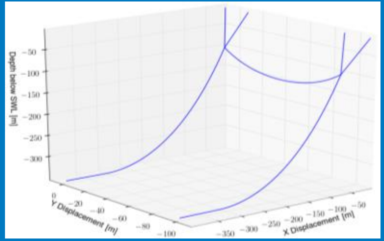


SubDyn



HydroDyn

MAP++, MoorDyn



InflowWind

- Undisturbed wind inflow:
  - Steady
  - Uniform, but time-varying (e.g., deterministic gusts from IEC)
  - Full-field (FF) turbulence (**TurbSim**, **Mann**)
  - User-defined

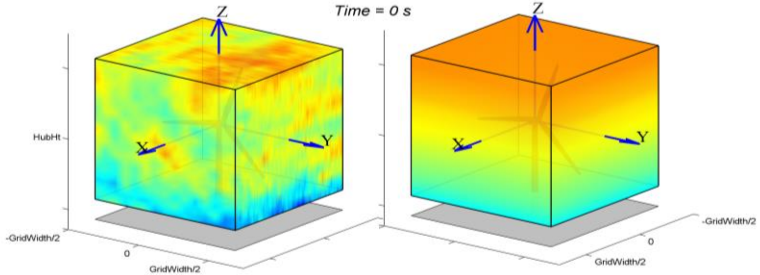
InflowWind

Inputs:
- Positions

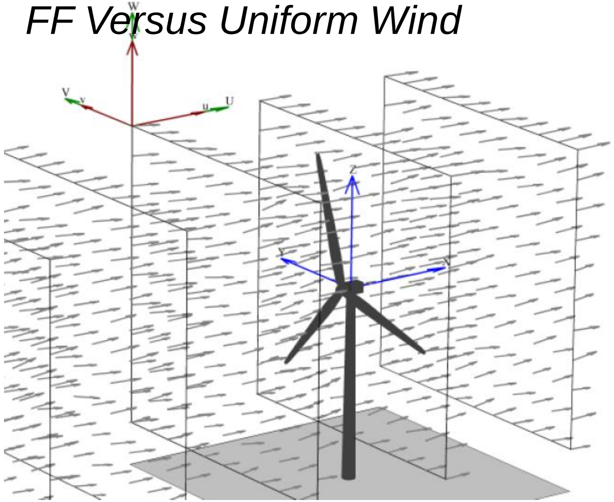
States:
- None

Parameters:
- Undisturbed wind inflow

Outputs:
- Wind @ input positions



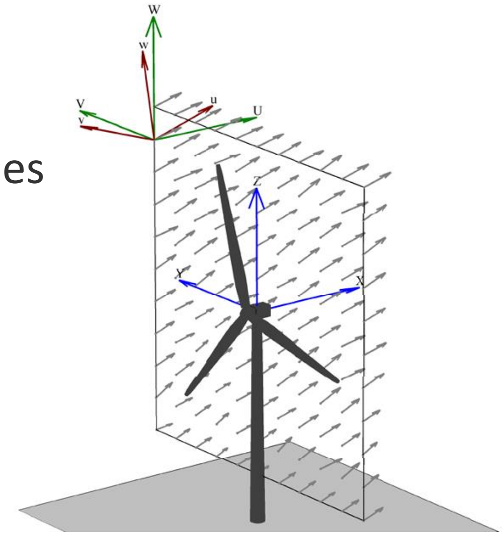
FF Versus Uniform Wind



FF Wind Treated w/ Taylor's Frozen Turbulence Hypothesis

TurbSim

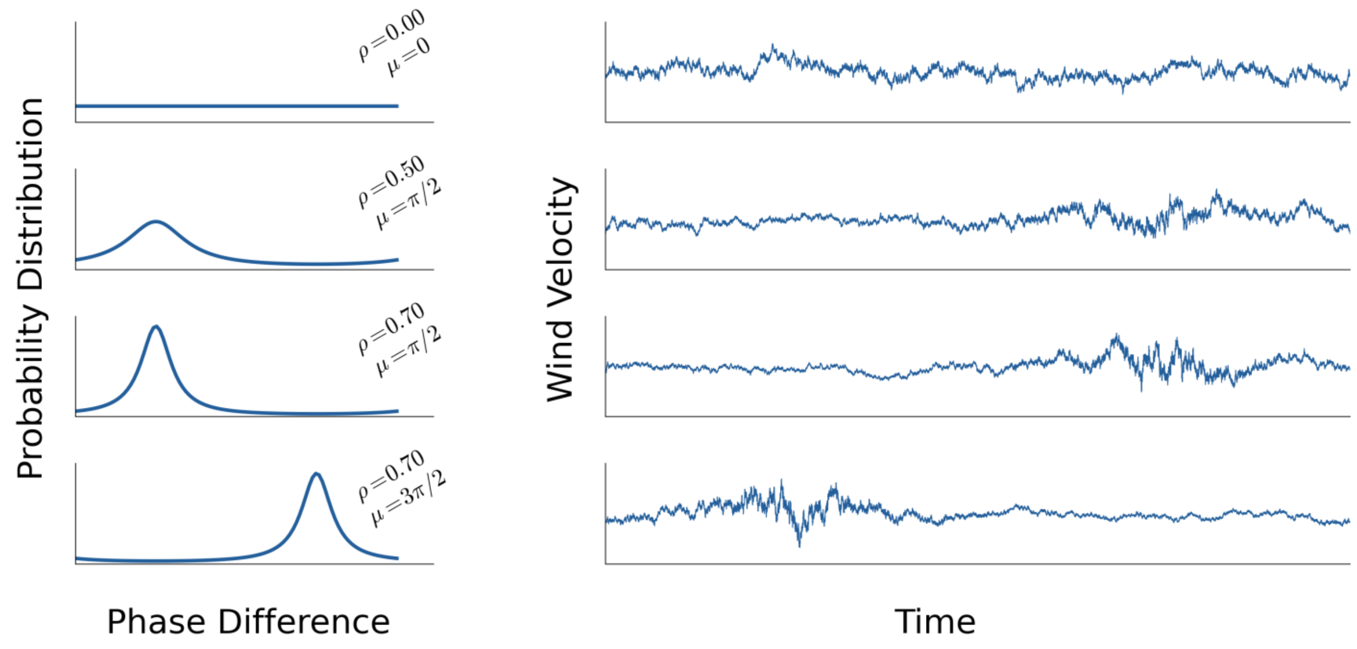
- **Computes full-field stochastic wind realizations:**
  - Inputs are desired wind profile & turbulence characteristics
  - Includes IEC- & site-specific turbulence models
  - Option to generate coherent structures from LES & DNS output
- **Past changes:**
  - Added a model for tidal turbines
  - Added option for generating periodic wind for long time series
  - Construct wind field around known time history at points
  - PY-TurbSim: Python implementation
  - Temporal non-stationarity (Phase Correlation)
- **Current opportunities:**
  - Include more site-specific models
  - Use for precursor wind fields



Full-Field Turbulence Grids

PDD parameters have direct effect on time domain behavior

PDD=Phase Difference Distribution

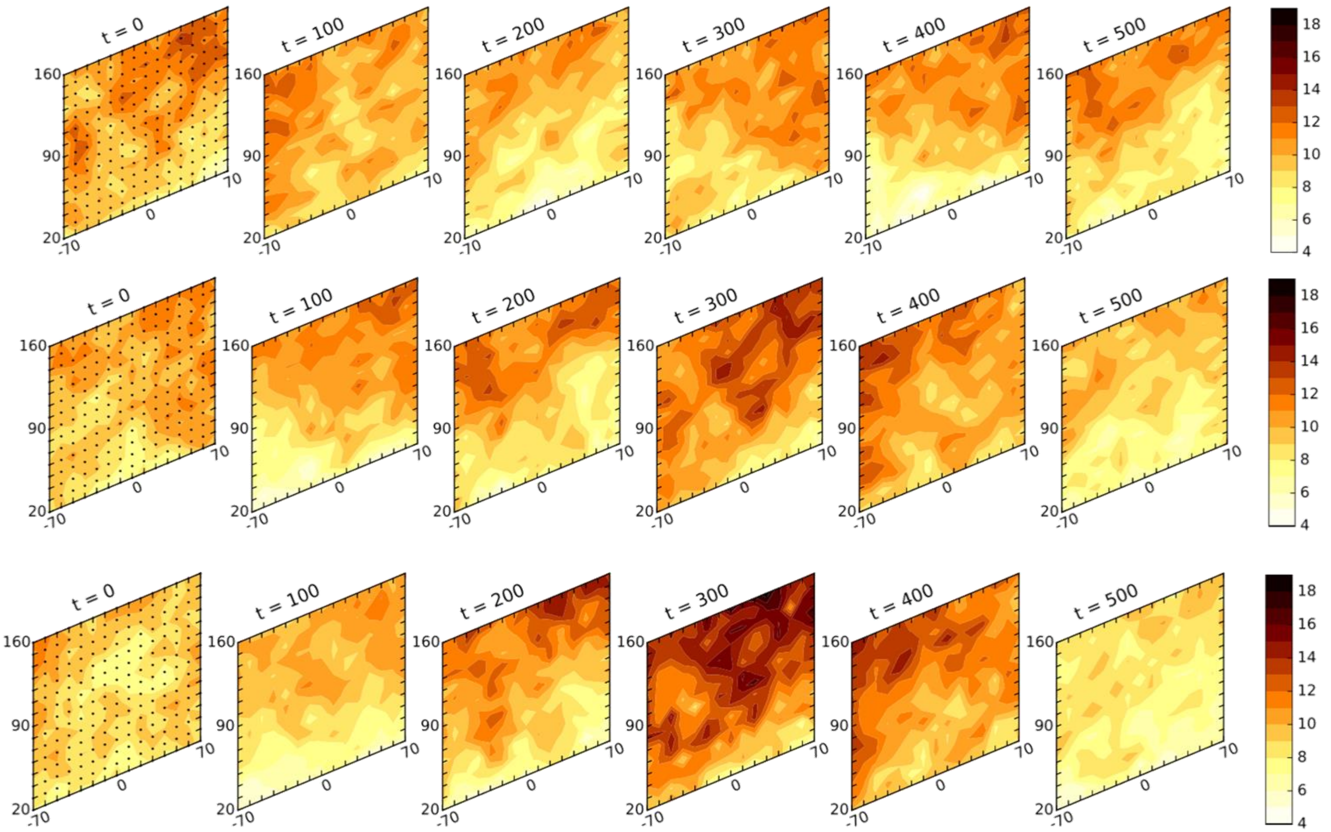


Can easily implement KSEC-TC model in TurbSim

$\rho = 0.0$

$\rho = 0.11$

$\rho = 0.30$



Grid: 140 m x 140 m, 10 m spacing
IEC Parameters: Turbulence class C, 90 m hub height, 10 m/s reference speed

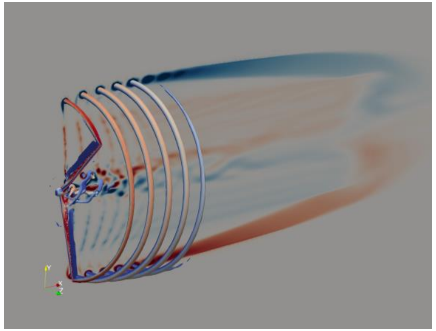
KSEC-TC = Kaimal Spectrum, Exponential Coherence, with Temporal Correlation

Jenni Rinker

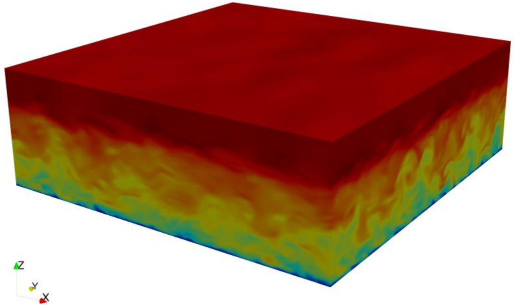
Computational Wind-Plant Modeling – Challenges & Strategy

- **Challenges**
  - Geometry-resolved turbine simulations – O(billion) grid points
  - Arbitrary mesh motion – blade deformations, nacelle-yaw, floating-platform motion
  - Turbulence modeling – DNS is impossible given the range of scales
  - Coupling to mesoscale models
- **Modeling pathway**
  - Acoustically-incompressible Navier-Stokes (N-S) flow equations
  - Hybrid ABL/LES/RANS turbulence models
  - Hybrid structured/unstructured CFD solvers w/ overset-mesh coupling methodology
- **Other considerations**
  - *Open-source* development model
  - Rigorous verification & validation process, robust unit and regression test suite
  - Follow modern software development practices – version control, CI, etc.

Turbine simulations

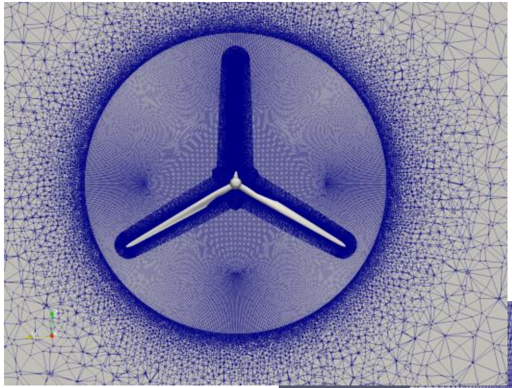


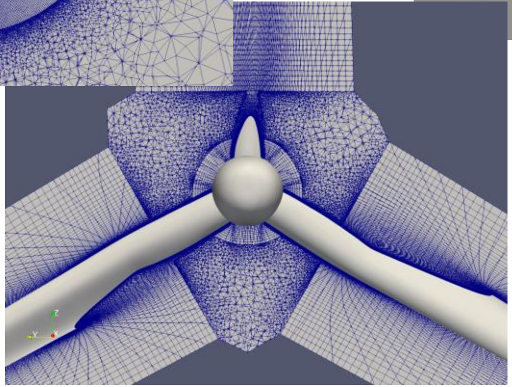
Atmospheric boundary layer simulations

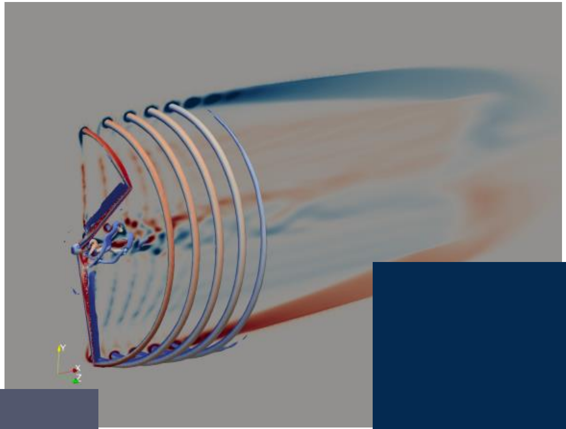


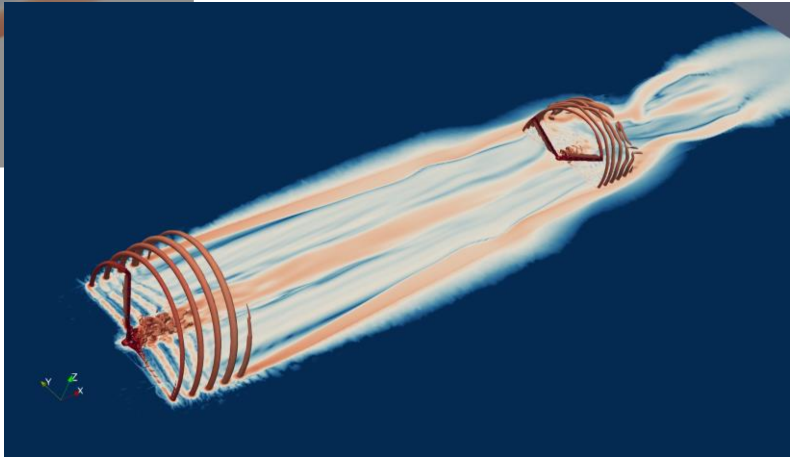
Nalu-Wind – GPU Scaling & Performance

Geometry-resolved turbine simulations in uniform flow









Images: Ananthan & Vijayakumar (NREL)

ExaWind – Primary Application Codes

Nalu-Wind

- **https://github.com/exawind/nalu-wind**
- **Unstructured grid finite-volume discretization**
- **Incompressible N-S solver**
- **Hybrid RANS/LES turbulence models**
- **C++ code built on Trilinos; Kokkos abstractions**

AMR-Wind

- https://github.com/exawind/amr-wind
- Block-structured finite-volume discretizations
- Incompressible N-S solver
- C++ code built AMReX
- Full-functionality on NVIDIA, AMD, Intel GPUs

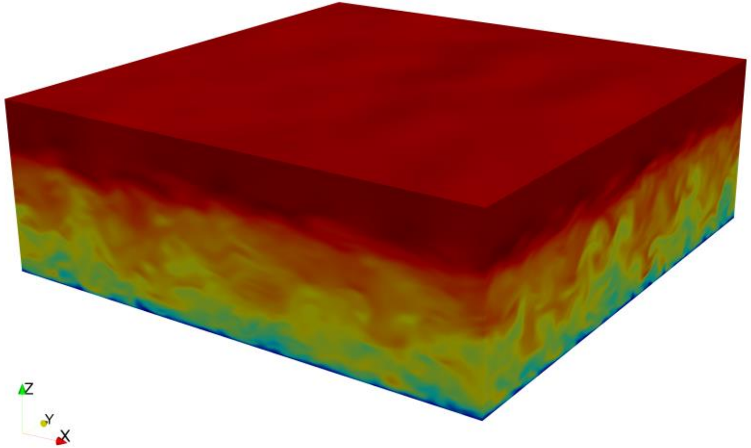
OpenFAST

- https://github.com/openfast/openfast
- Whole-turbine simulation code
- Includes models for blades, control system, drivetrain, tower, etc.

Core ECP Software Technology Integrations

Trilinos, AMReX, *hypre*, kokkos, kokkos-kernels, Alpine-DAV, spack

AMR-Wind – GPU Scaling & Performance

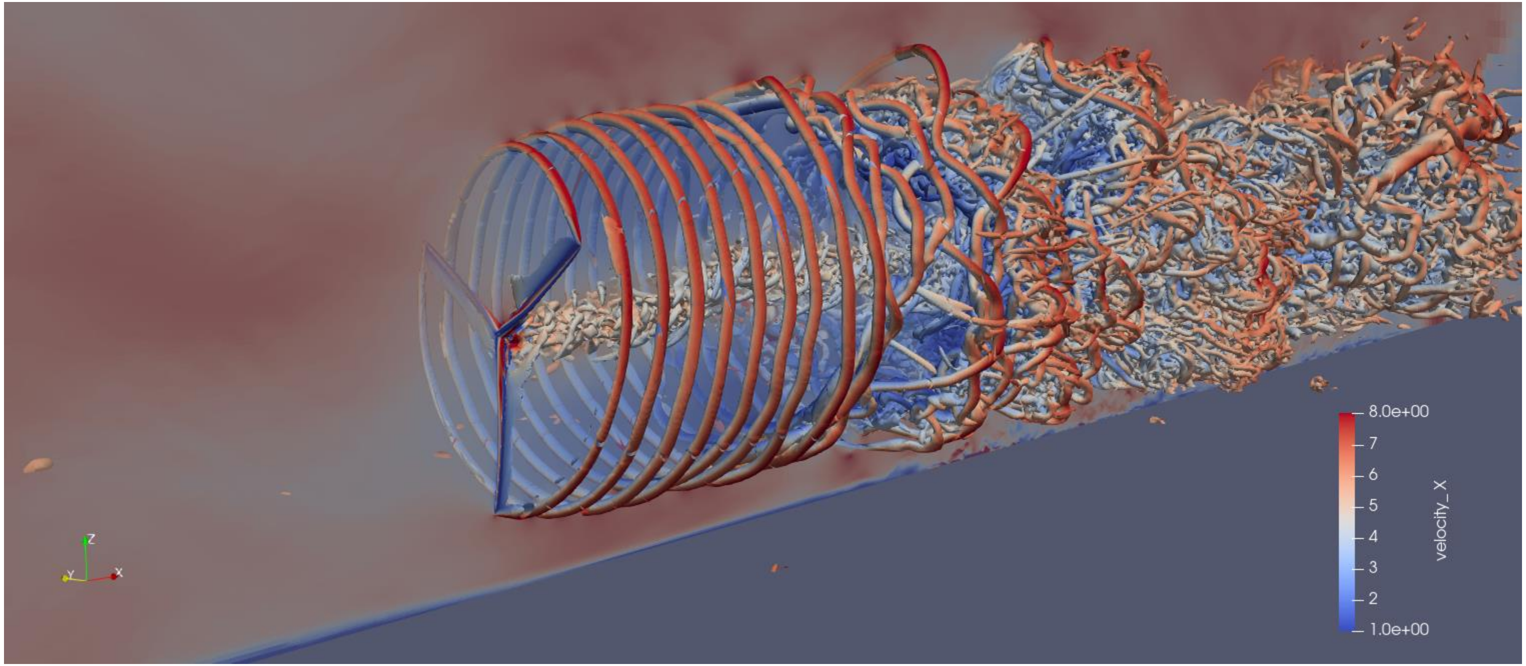


Velocity field in a representative AMR-Wind large-eddy simulation of a 3 x 3 x 1 km^3 domain for a neutrally stable ABL

Atmospheric Boundary Layer (ABL) simulations

- **Key component for wind turbine & wind farm simulations**
- **Structured hex mesh with uniform grid resolution**
- **LES turbulence model with shear-stress wall BC; periodic BC on sides**
- **Strong & weak scaling studies on ORNL Summit**

AMR-Nalu-ExaWind Simulation: IEA Task 29 Rotor

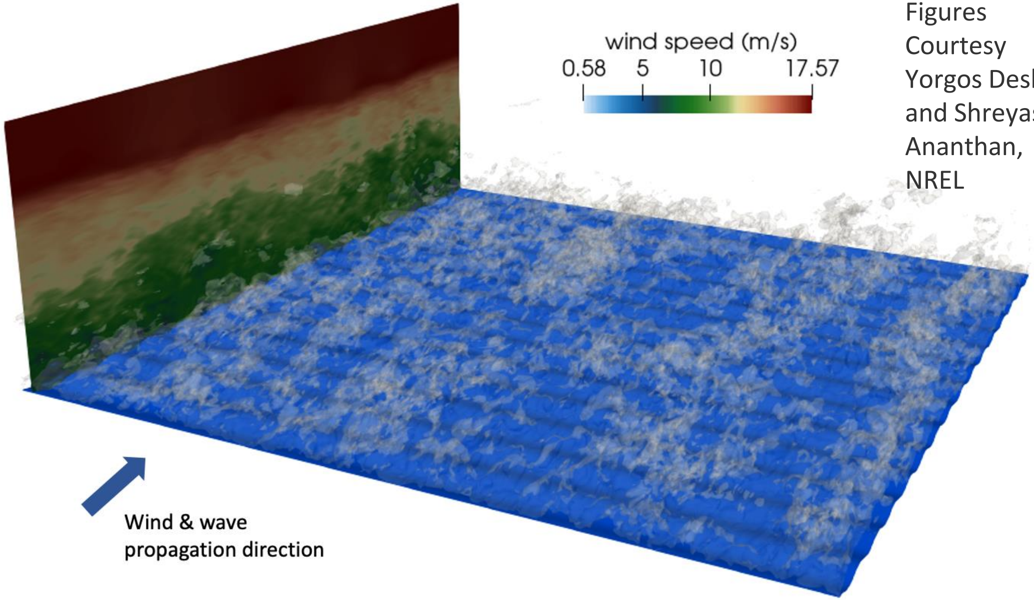


Visualization of the flow field around the 2-MW NM80 wind turbine under turbulent inflow. The isosurfaces highlight vortical structures and the colors indicate streamwise velocity.

Image courtesy of Ganesh Vijayakumar, Shreyas Ananthan and Mike Brazell, NREL

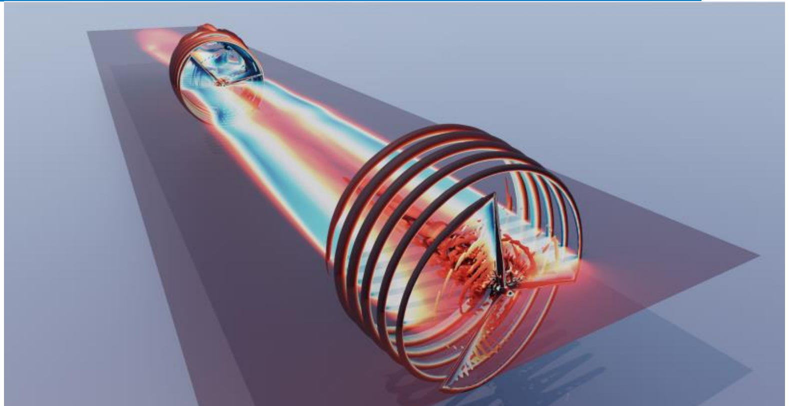
Computational Solutions for Offshore Wind

- The large scales and expensive of hardware will drive greater reliance on high-fidelity computational results
- Design-level capabilities will use AI/ML to capture high-fidelity computational findings

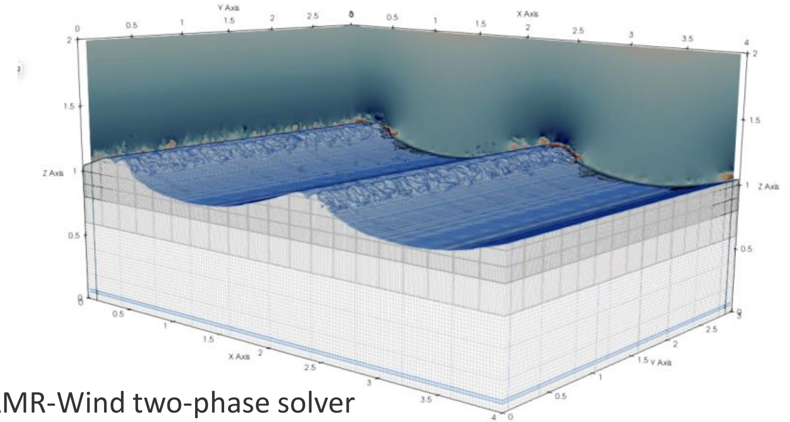


LES of a marine atmospheric boundary layer over idealized, wind following and fast-propagating long waves (swell)

Figures Courtesy Yorgos Deskos and Shreyas Ananthan, NREL



ExaWind simulation of wake impact on downstream rotor



AMR-Wind two-phase solver (air and water) simulates breaking waves

Thank You! Questions?

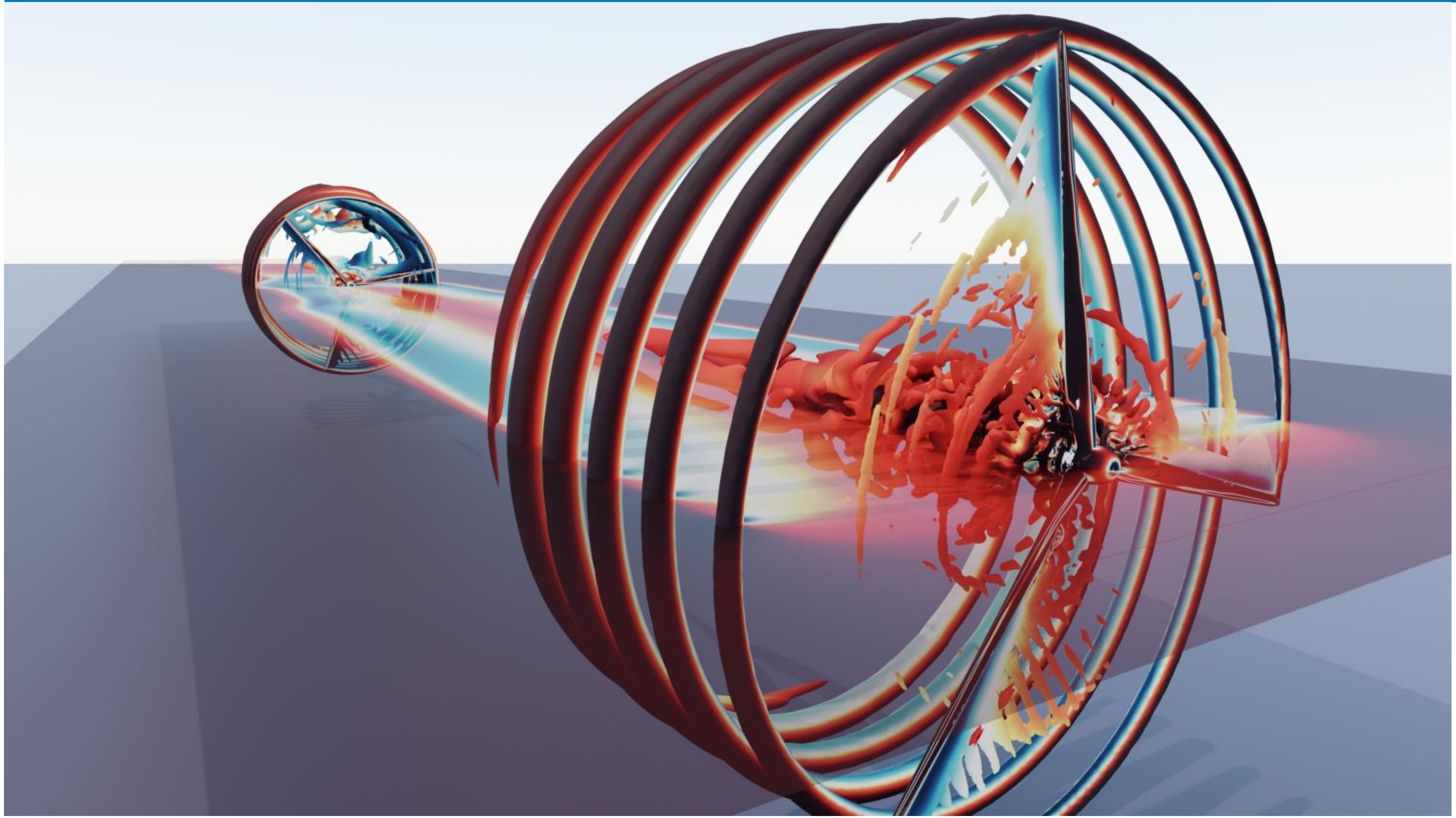


Image: Ananthan, Vijayakumar, Binyahib (NREL)