NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Offshore Wind Technology and Modeling Needs

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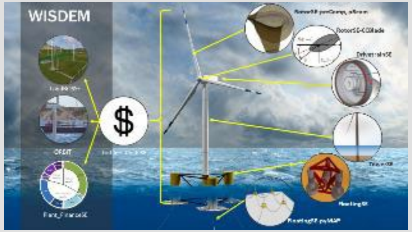
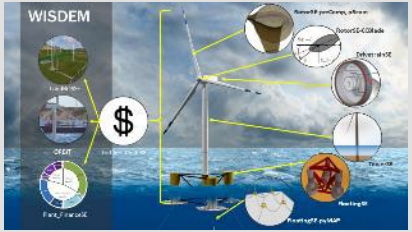
CPUC Emerging Technology Workshop

September 20, 2023

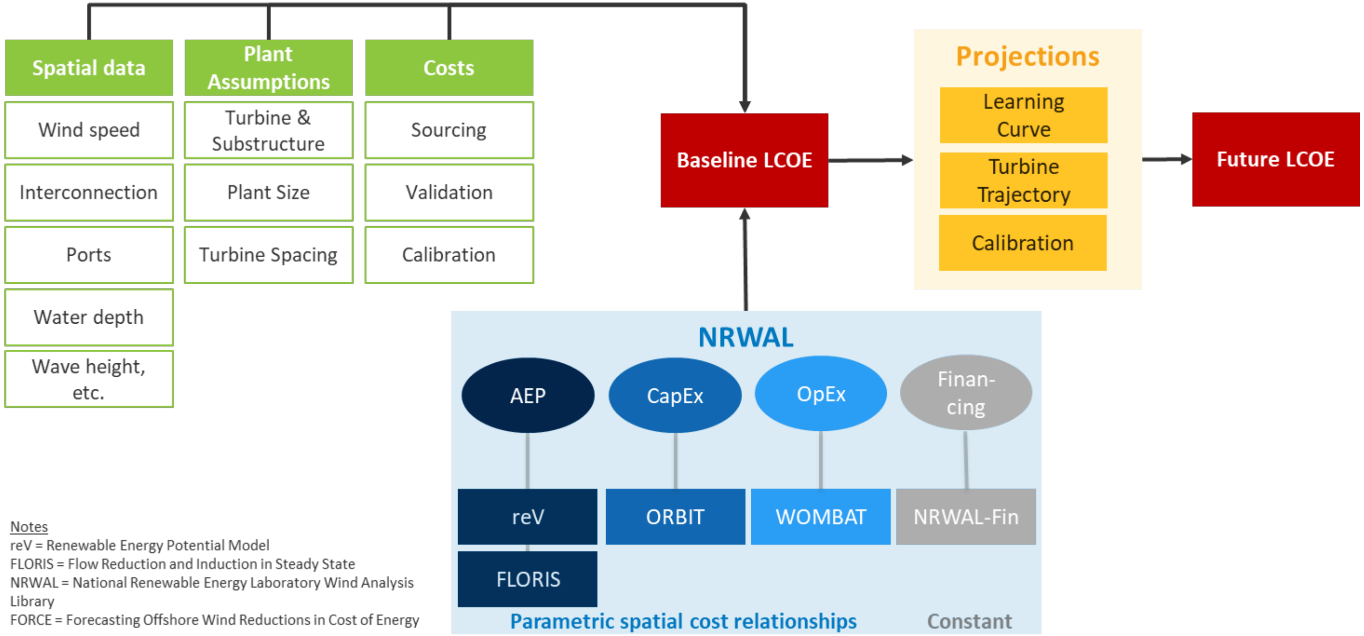
NREL Offshore Wind Modeling Overview

- Cost Modeling Tools
- Metocean Modeling – Wind and Waves
- Single Turbine Performance and Loads Modeling
- Full Wind-Plant Performance and Loads
- Mooring Systems
- Grid Systems Integration and Reliability

NREL/DOE Open-Source Wind Cost Models

Fidelity	Turbine Components	Onshore Plants	Offshore Plants
Regression – Market Based Empirical rules of thumb based on rating, rotor diameter, hub height, etc.	**WISDEM (NREL-CSM), SAM** Simple spreadsheet-style turbine mass and costs 	**SAM** Simple spreadsheet-style balance of station (CapEx) and operations and maintenance (OpEx)	**SAM** Simple spreadsheet-style balance of station (CapEx) and operations and maintenance (OpEx)
Bottom-up Detailed estimation of costs from materials, labor, consumables, tooling, financing, etc.	**WISDEM (major components)** Detailed manufacturing process models 	**LandBOSSE, WOMBAT** Process-based accounting of balance of station (CapEx) and operations and maintenance (OpEx)	**ORBIT, WOMBAT** Process-based accounting of balance of station (CapEx) and operations and maintenance (OpEx)

Bottom-up Cost Modeling Approach



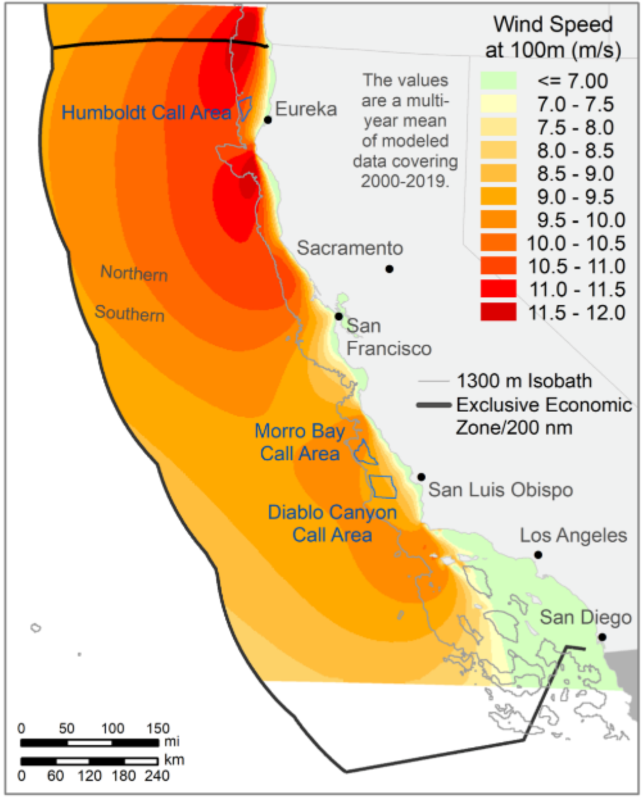
Notes
reV = Renewable Energy Potential Model
FLORIS = Flow Reduction and Induction in Steady State
NRWAL = National Renewable Energy Laboratory Wind Analysis Library
FORCE = Forecasting Offshore Wind Reductions in Cost of Energy

Image by NREL

Cost Modeling Needs

- Higher resolution on temporal scale for cost reductions
- Tradeoffs between industrialization/standardization and turbine upscaling
- More granularity on future costs of subcomponents
- Floating wind components and validation

Weather Research and Forecasting Model for Wind Resource, Forecasting and Extreme Event Predictions



Optis et al. 2020

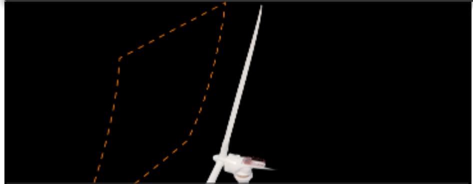
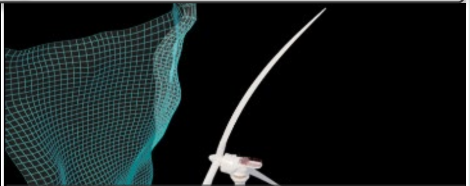
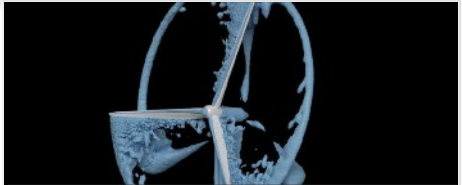
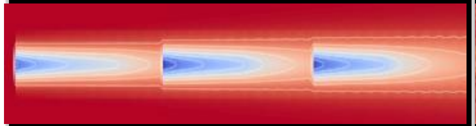
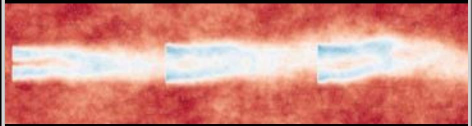
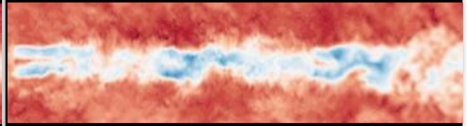
WRF setup was chosen for California CA20 dataset based on validation with best observations available in 2020:

1) CA ocean surface buoys (4-m above the water)
2) Four coastal radars
3) Three floating lidars in the Mid-Atlantic

- CA20 data show a large positive bias using the MYNN Planetary Boundary Layer (PBL) set-up compared to the lidar observations at all considered heights (+0.6 m s^{-1} at Morro Bay, +1.9 m s^{-1} at Humboldt). Windspeeds were over predicted!
- MYNN set-up is valid in most other regions, why not CA?
- More research is needed to understand the physics causing the California wind bias in WRF because we need to be able to trust the models offshore.

NREL/DOE Performance and Loads Modeling Tool

Model Fidelity / Computational Intensity →

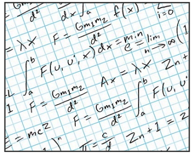
Application	Design Exploration	Detailed Design	Highly Resolving
Single Turbine Performance and Loads	**WISDEM, RAFT** Multidisciplinary design optimization and cost modeling	**OpenFAST** Turbine loads analysis, detailed turbine design, IEC standards	**ExaWind/SOWFA** Understand physics, final turbine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

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

Engineering Tools Enable Technology Advancement

Standards

Theory

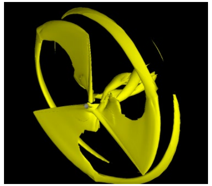


Technology Innovations

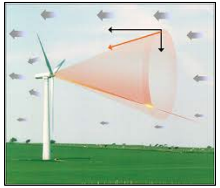
Engineering Tools

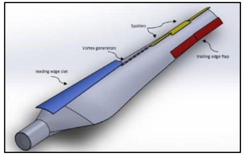
Advanced Wind Technology

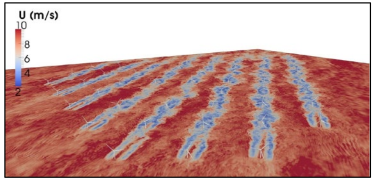
Test Data

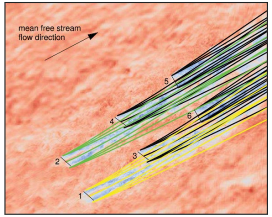


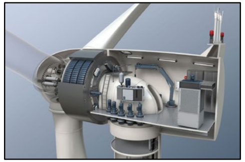
Computational Solutions

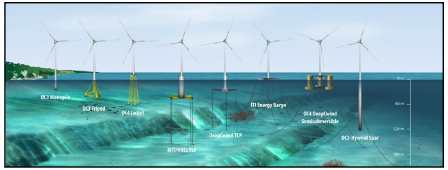






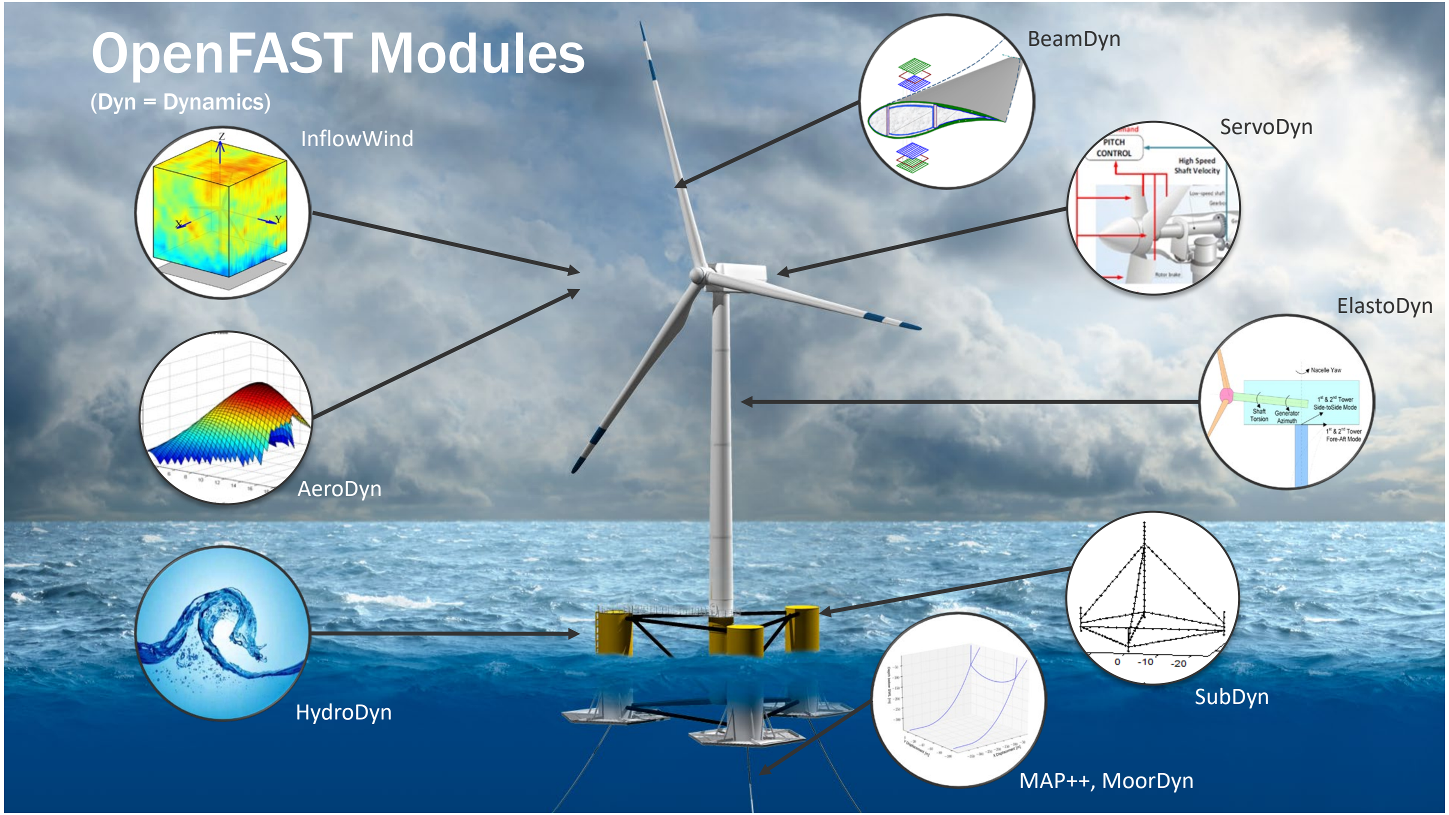






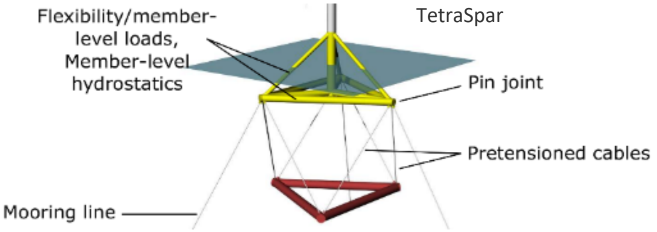
OpenFAST – Primary Engineering Model

Used to develop 80% to the original full-scale floating wind prototypes

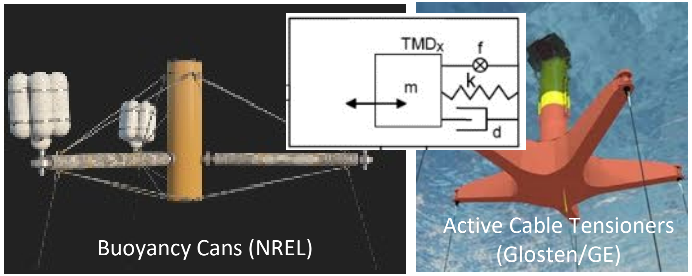


Recent/Ongoing Modeling Improvements

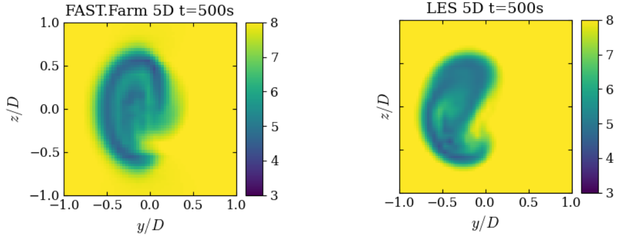
Substructure Flexibility and Member-Level Loads in OpenFAST



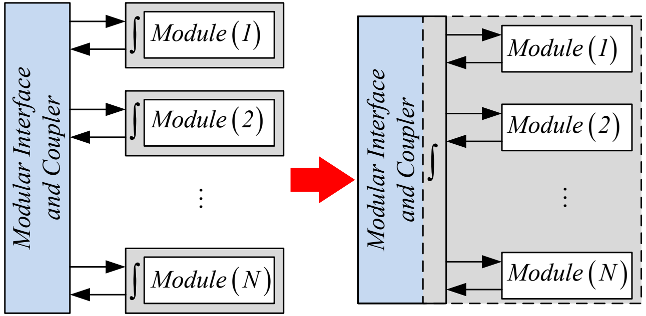
Novel Floater-Based Controls in OpenFAST



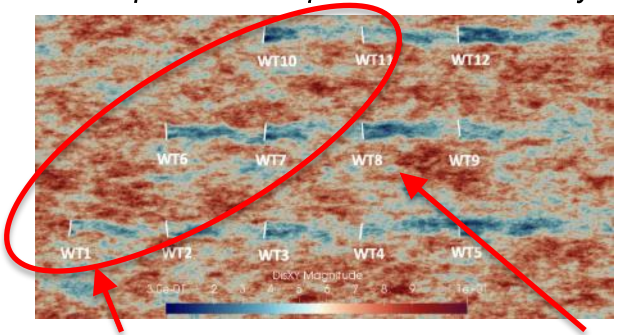
Curled Wake in FAST.Farm for Wake-Steering



Tight-Coupling in OpenFAST for Improved Computational Performance



Simplified Turbine Modeling in FAST.Farm for Improved Computational Efficiency

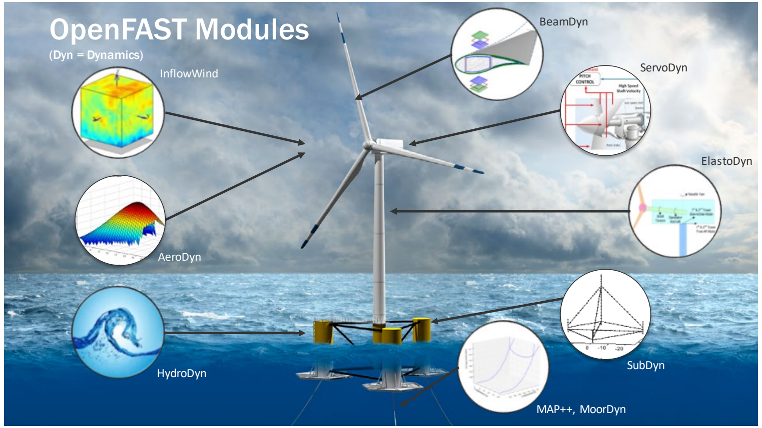


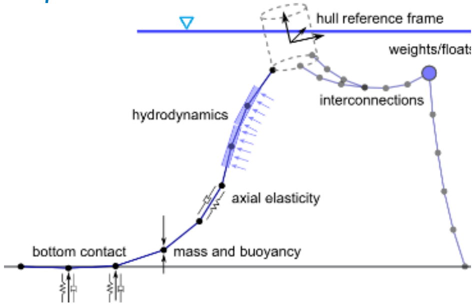
Simplified OpenFAST models with wakes and control

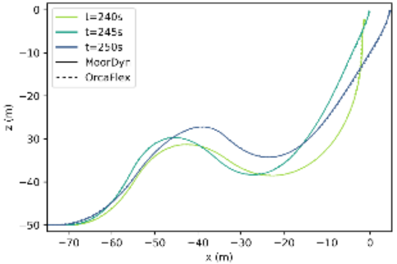
Full OpenFAST models with wakes, control, and structural loads

Mooring Design and Modeling is a Major Focus

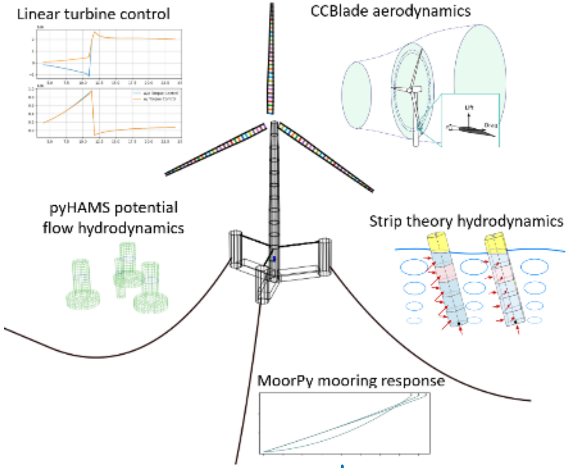
MoorDyn
For dynamics and loads analysis (in OpenFAST)

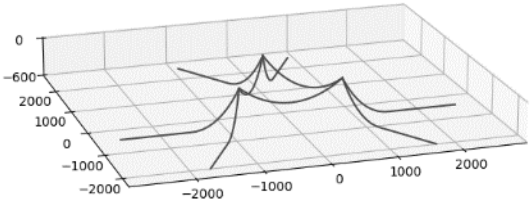


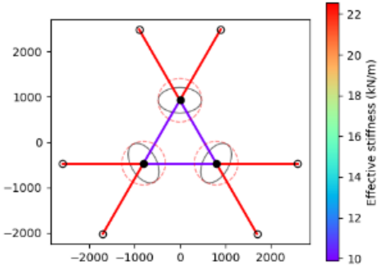




MoorPy
For rapid design and optimization (in RAFT)

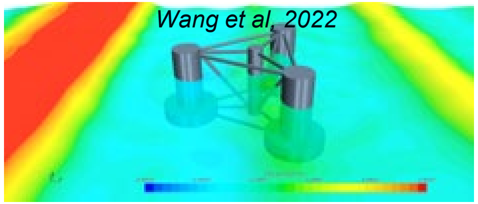


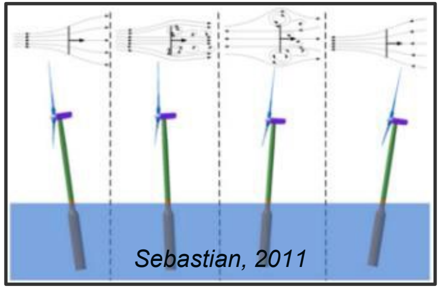


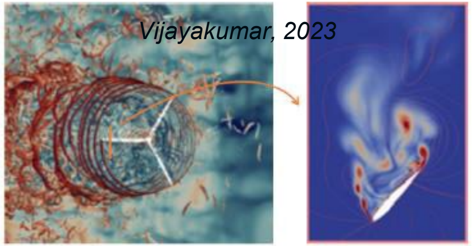


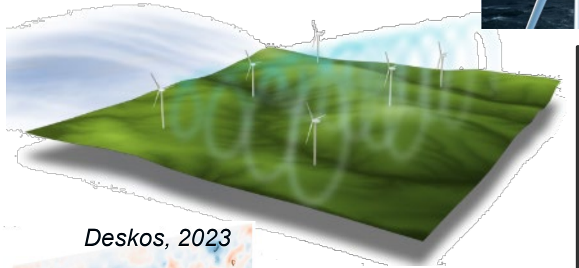
Future Areas for Offshore Wind Modeling

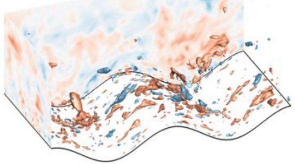
- Viscous hydrodynamics
- Steep and breaking waves
- Floater motion-induced aerodynamics
- Combined rotational augmentation and unsteady airfoil aerodynamics
- High Reynolds number
- Stall- and vortex-induced vibration
- Air-sea interaction
- Atmospheric stability
- Tropical cyclones
- Blockage / deep array effects
- Cluster wakes

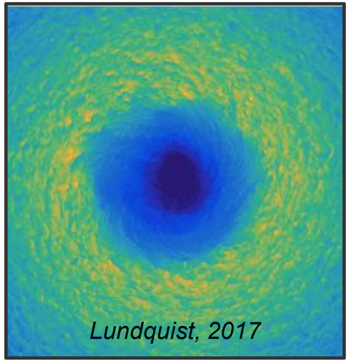


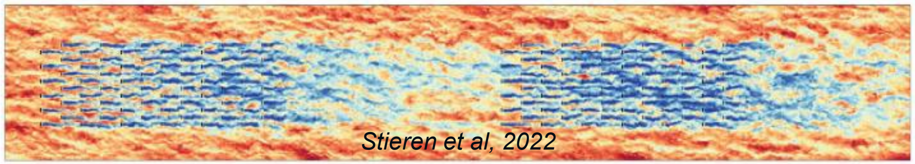












Key Takeaways – Modeling Needs

- **Economic models**
  - Time dependency for cost reductions
  - Future costs of subcomponents
  - Tradeoffs between industrialization/standardization and turbine upscaling
  - Floating wind components
- **Metocean**
  - Better understanding of physics
  - Coupled wind/wave models
  - Extremes
- **Multi-fidelity Performance and Loads Models**
  - Accurate behavior of floating systems
  - Mooring – deepwater, steep slopes, taut systems, TLP
- **Code validation** with field data is needed in all areas
- **Grid modeling** and capacity expansion tools are important.

Thank you for your attention!

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Photo Credit : Dennis Schroeder-NREL