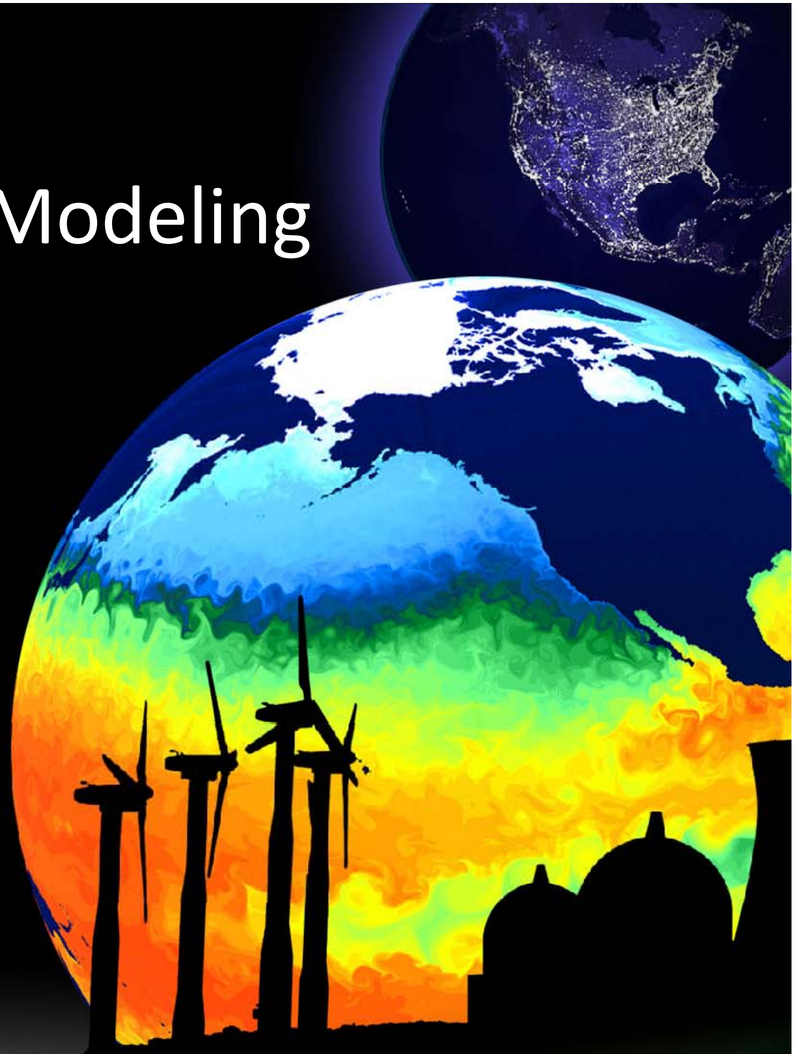
# WindBlade:
# Coupled Turbine/Atmosphere Modeling



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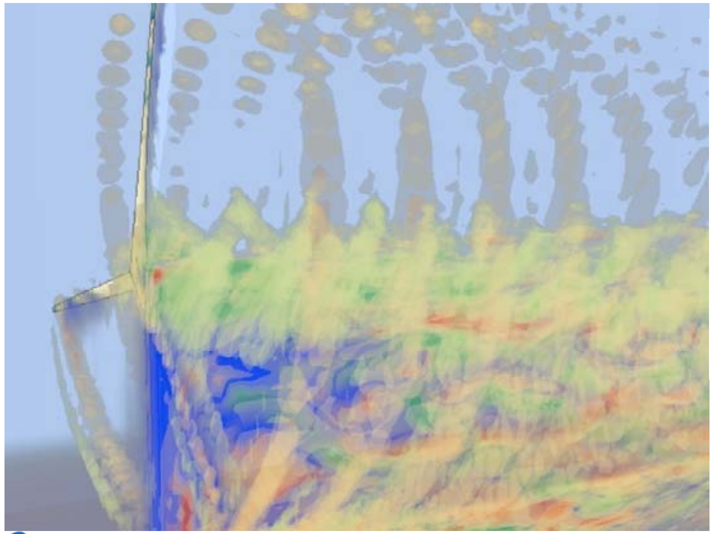
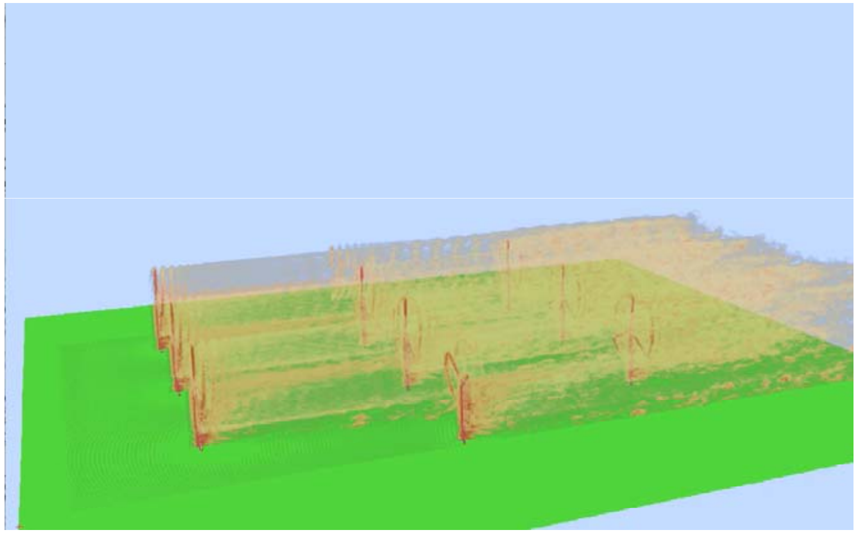
Work supported by LANL's LDRD program

# WindBlade: LANL's Turbine and Plant Simulation Code

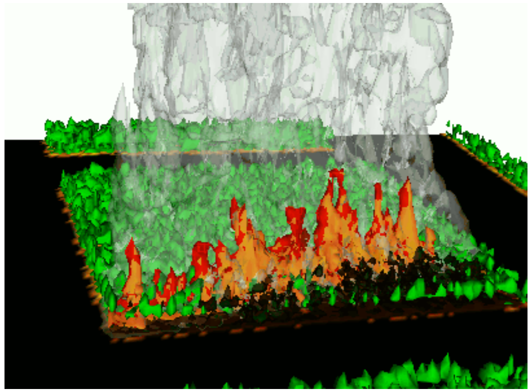
- Couples R&D 100-winning HIGRAD/FIRETEC with LANL's new turbine/wind interaction modeling technique, **WindBlade** (*patent and copyright pending*)
- Provides capability to study realistic wind interactions with rotating turbines
- Lagrangian tracking scheme that **accounts for 2-way feedback between winds and moving solid objects**
- Resolves complex environments: topography, unsteady winds, severe weather, solar heating/unstable mixing, low-level jets, and stable boundary layers

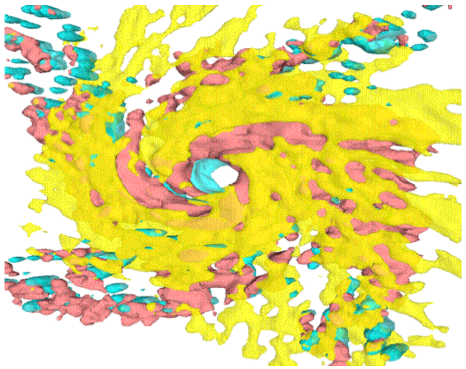


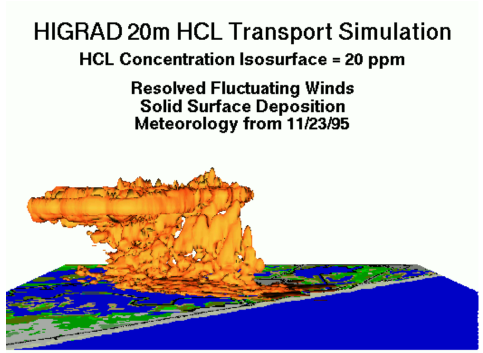


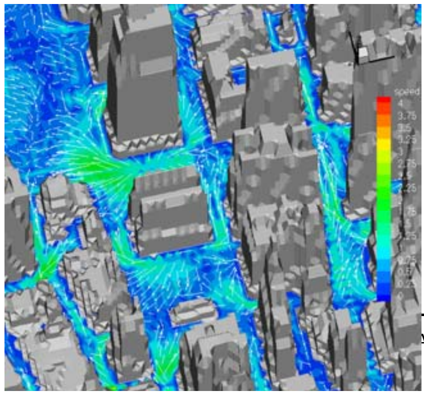
# WindBlade-an Extension of Past Successes,HIGRAD/FIRETEC

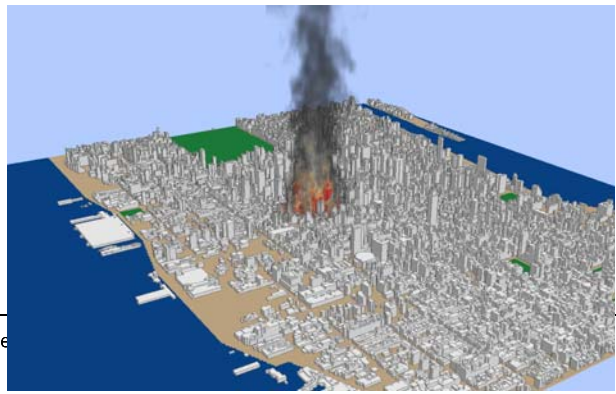
- HIGRAD/FIRETEC developed at LANL since 1994
- ~$16 M invested in development, validation, and application of HIGRAD/FIRETEC
- Utilized for more than 10 M CPU hours of calculations
- Test bed for state-of-the-art numerical techniques
- Wide range of applications
- R&D 100 winner
- Proven HPC agility and ability to take full advantage of new architectures as they are developed (illustrated by current porting to hybrid machines for 30 times speed up)

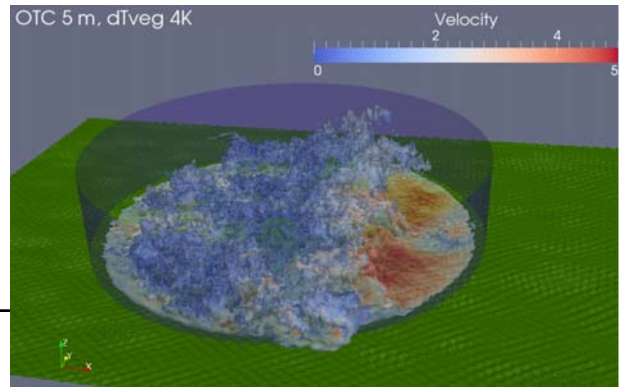








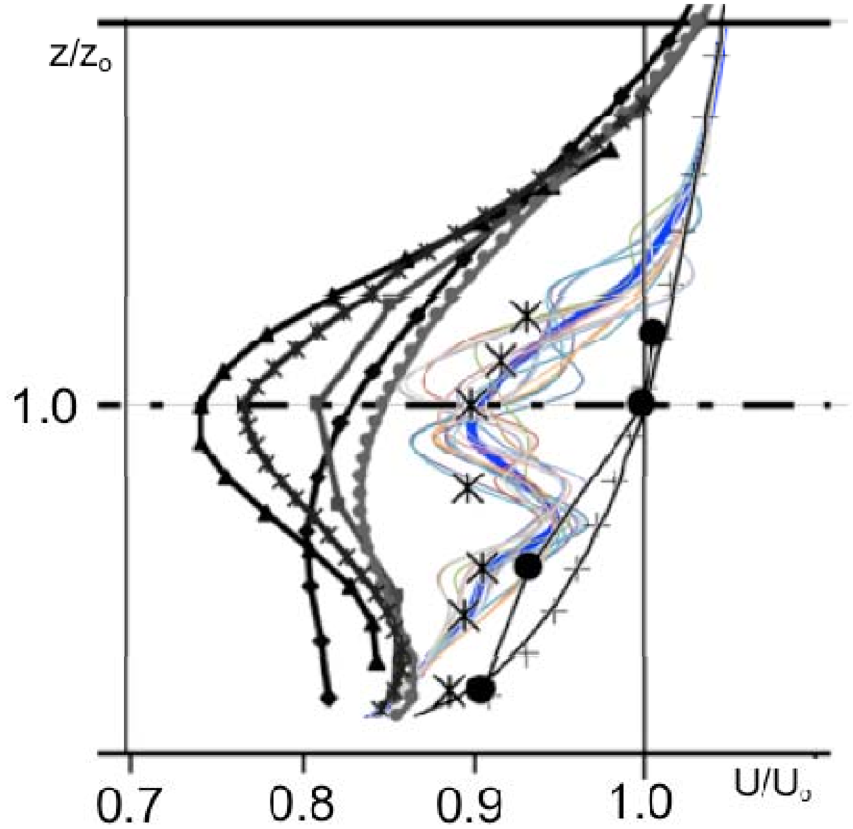


# Scope of WindBlade Development under LDRD

- Coupling NREL's Turbsim for unsteady boundary conditions
- Implementing basic Pitch and Yaw control algorithms
- Exploring atmospheric factors affecting:
  - Power generation
  - Interaction between multiple turbines
  - Initial exploration of factors affecting turbine-array-performance optimization
  - Dynamic loads transmitted to the blade root
- Implementing Aeroelastic, fluid-structure interaction (FSI) (allowing flexing blades)
- Comparison with small scale experiments
- Exploration of basic Influences of topographic and vegetative features
- Examination of implications of resolution and model simplification (will include Mathew Barone at SNL)
- Continual collaborative efforts towards validation against field data
  - Neil Kelley (NREL)
  - Julie Lundquist (University of Colorado, NREL)
  - Greg Poulos (V-Bar, LLC )
  - Eugene Tackle (Iowa State university)
  - Others if interested

# Preliminary validation exercises

Normalized Height (1.0 = hub height)

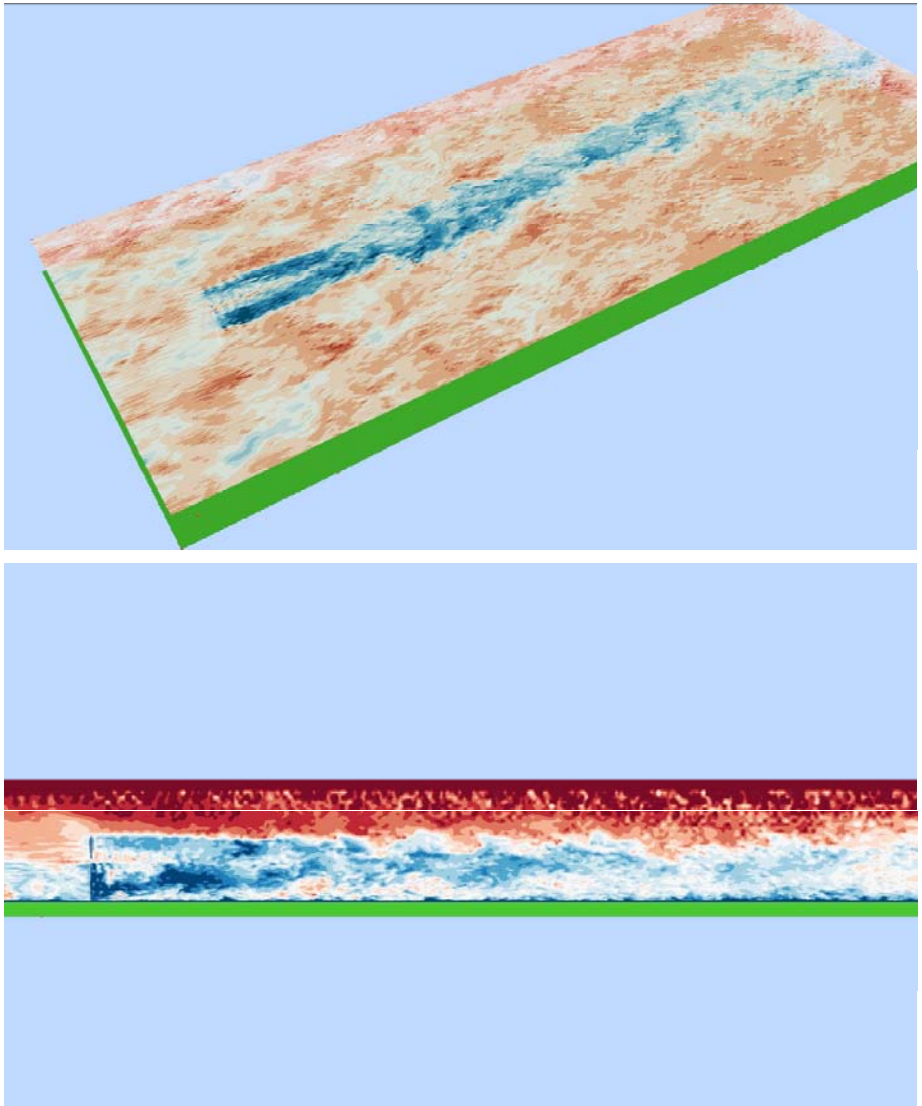



Normalized Streamwise Velocity (1.0 = Hub-height free stream)

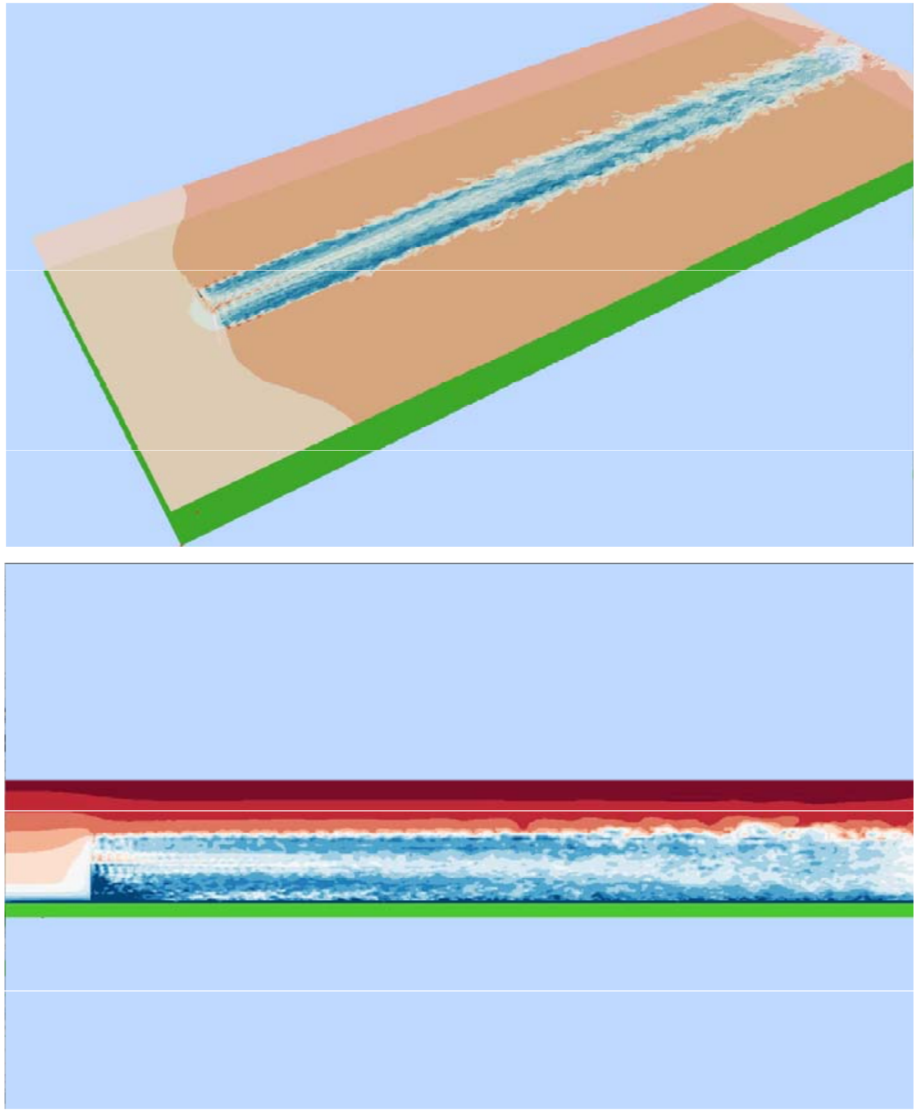
WindBlade turbine wake simulation (colors) compared with measurements (black +'s) and other model results (grey/black curves) from Rados *et al.*

# Significance of turbulence to wake recovery

Visualizing streamwise velocity in vertical and horizontal slices

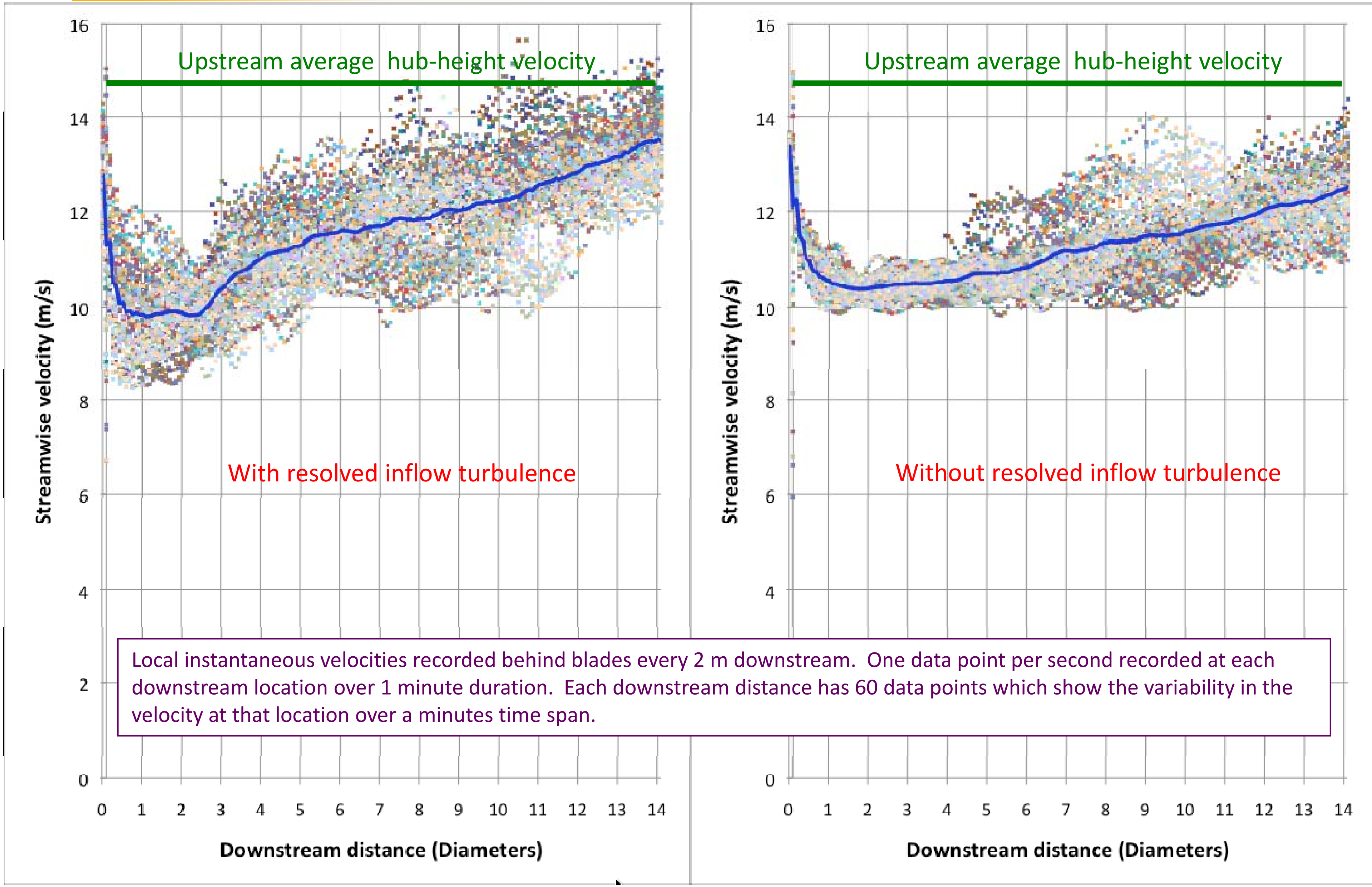


TurbSim LLJ simulation



Laminar LLJ simulation

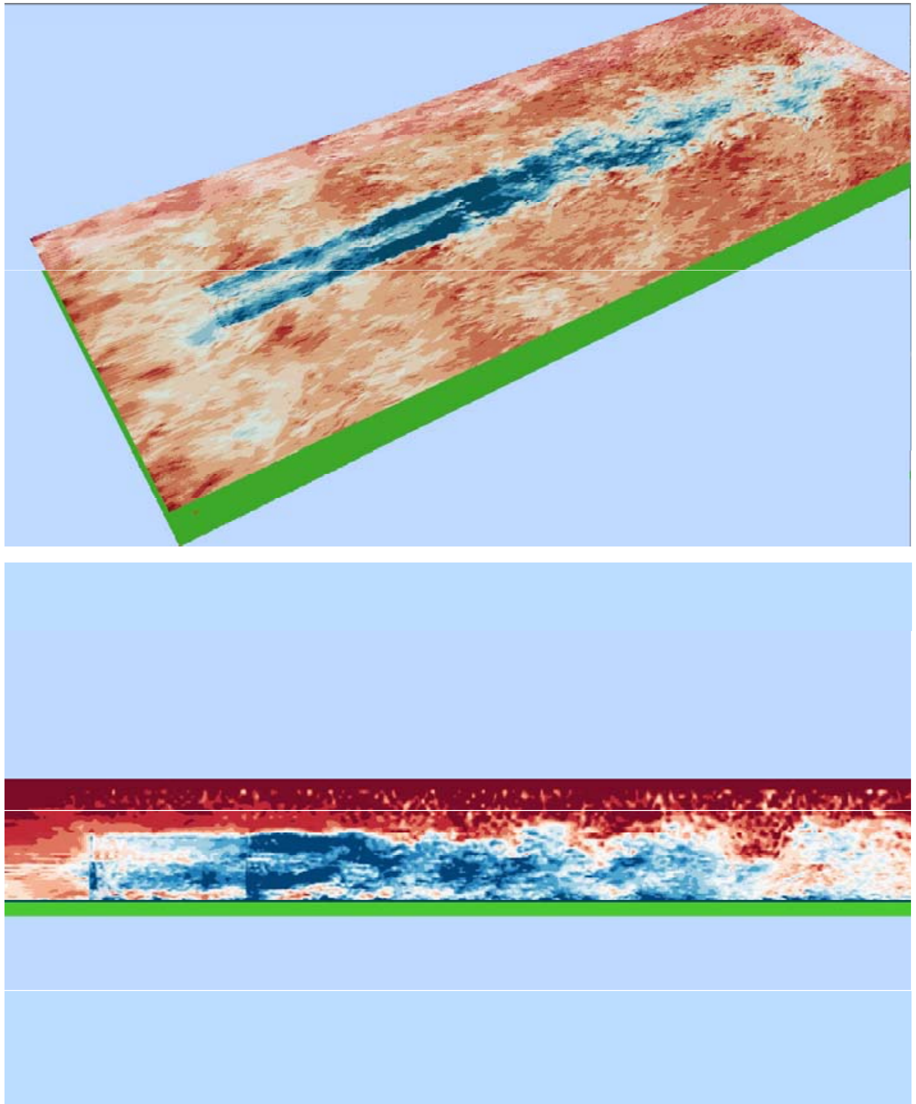
# Wake velocities for single turbine simulations



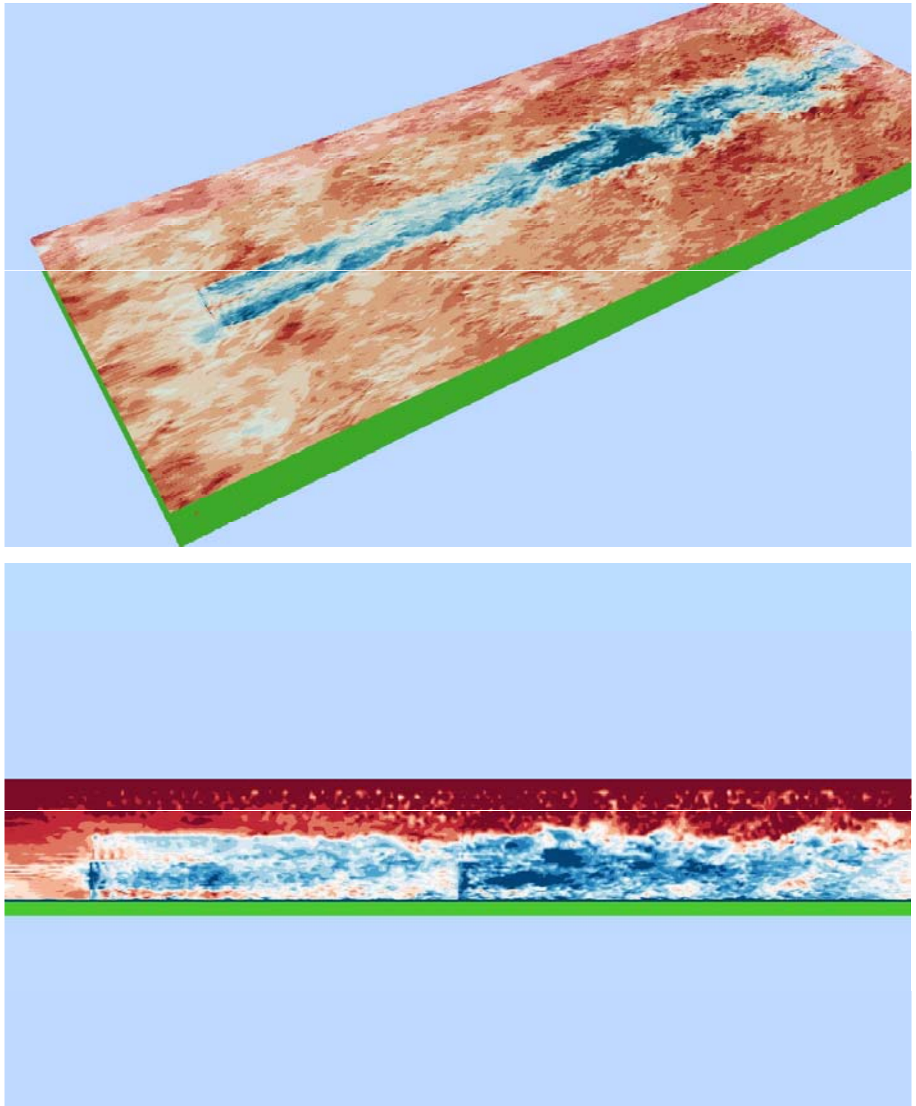

Local instantaneous velocities recorded behind blades every 2 m downstream. One data point per second recorded at each downstream location over 1 minute duration. Each downstream distance has 60 data points which show the variability in the velocity at that location over a minutes time span.

# Influence of a turbine spacing (3D and 7D spacing)

Visualizing streamwise velocity in vertical and horizontal slices

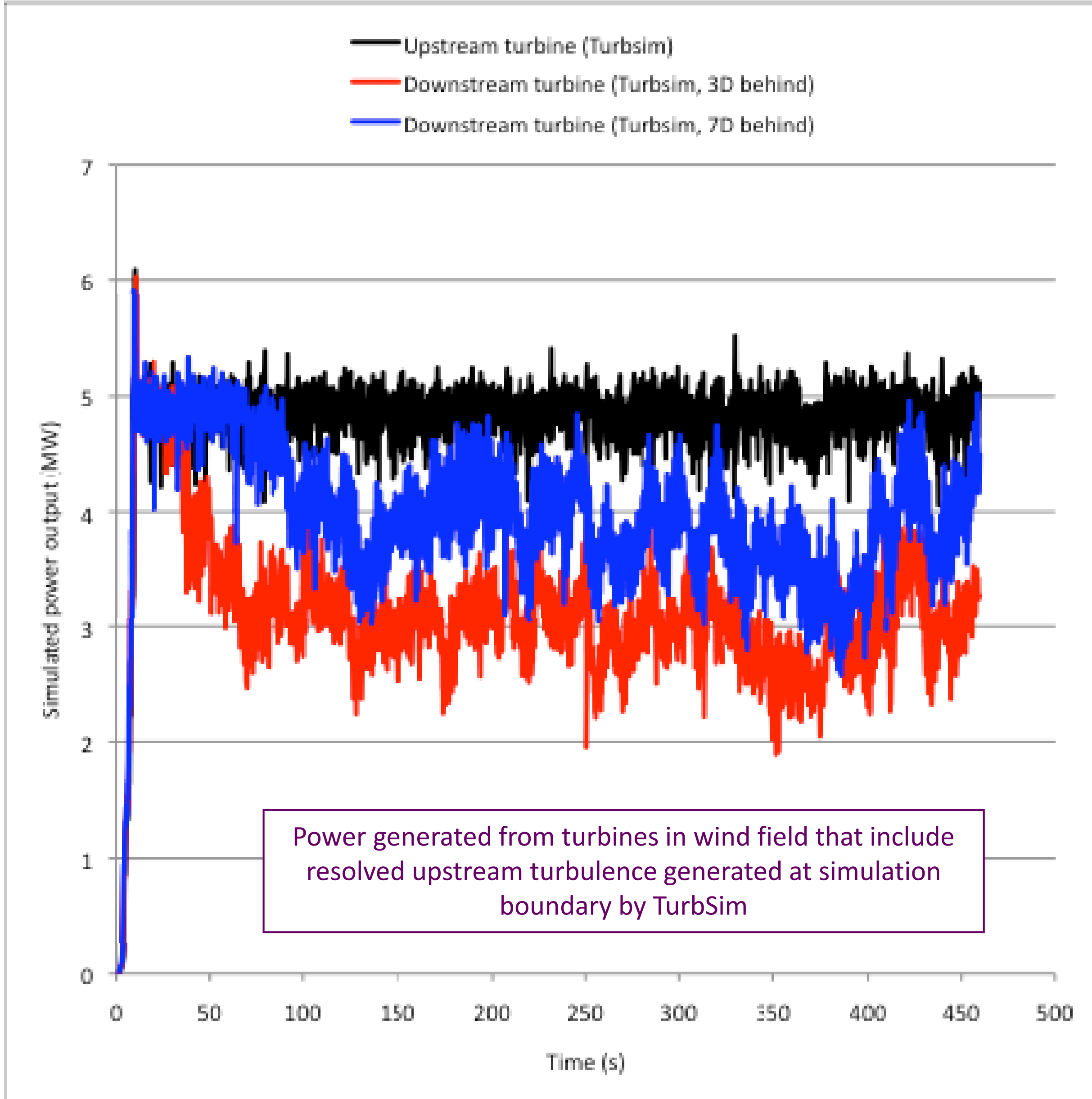


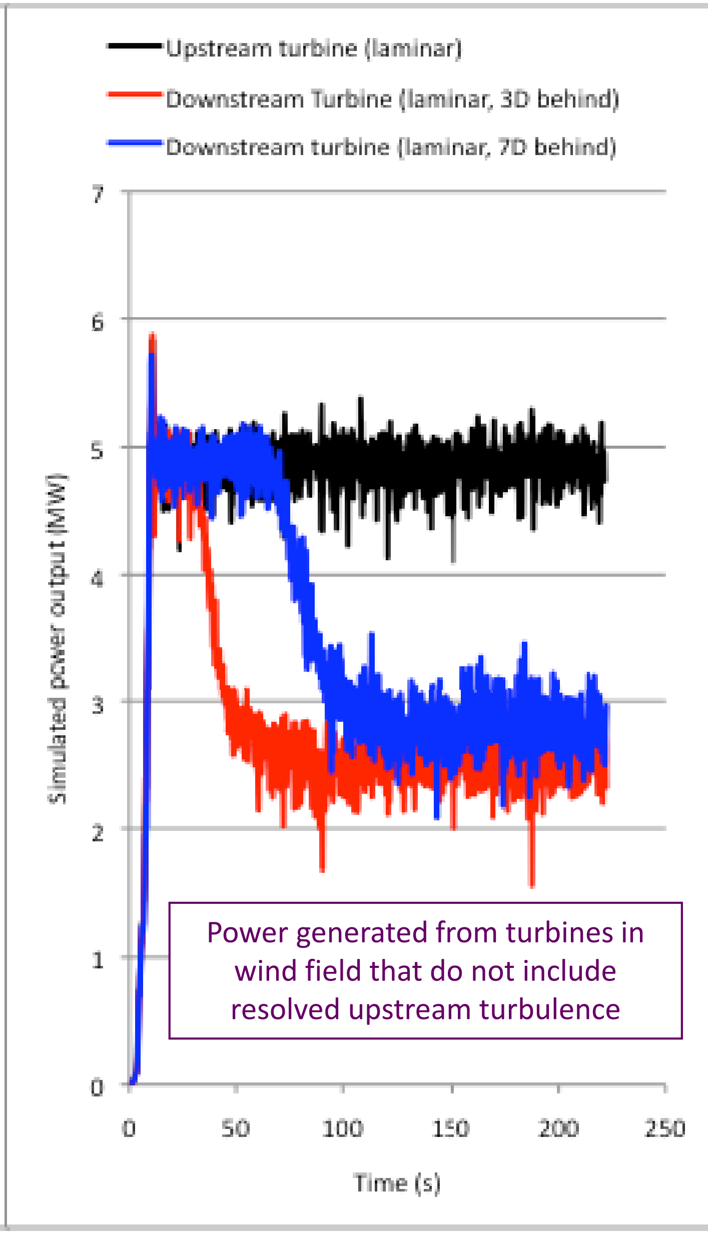
3D separation



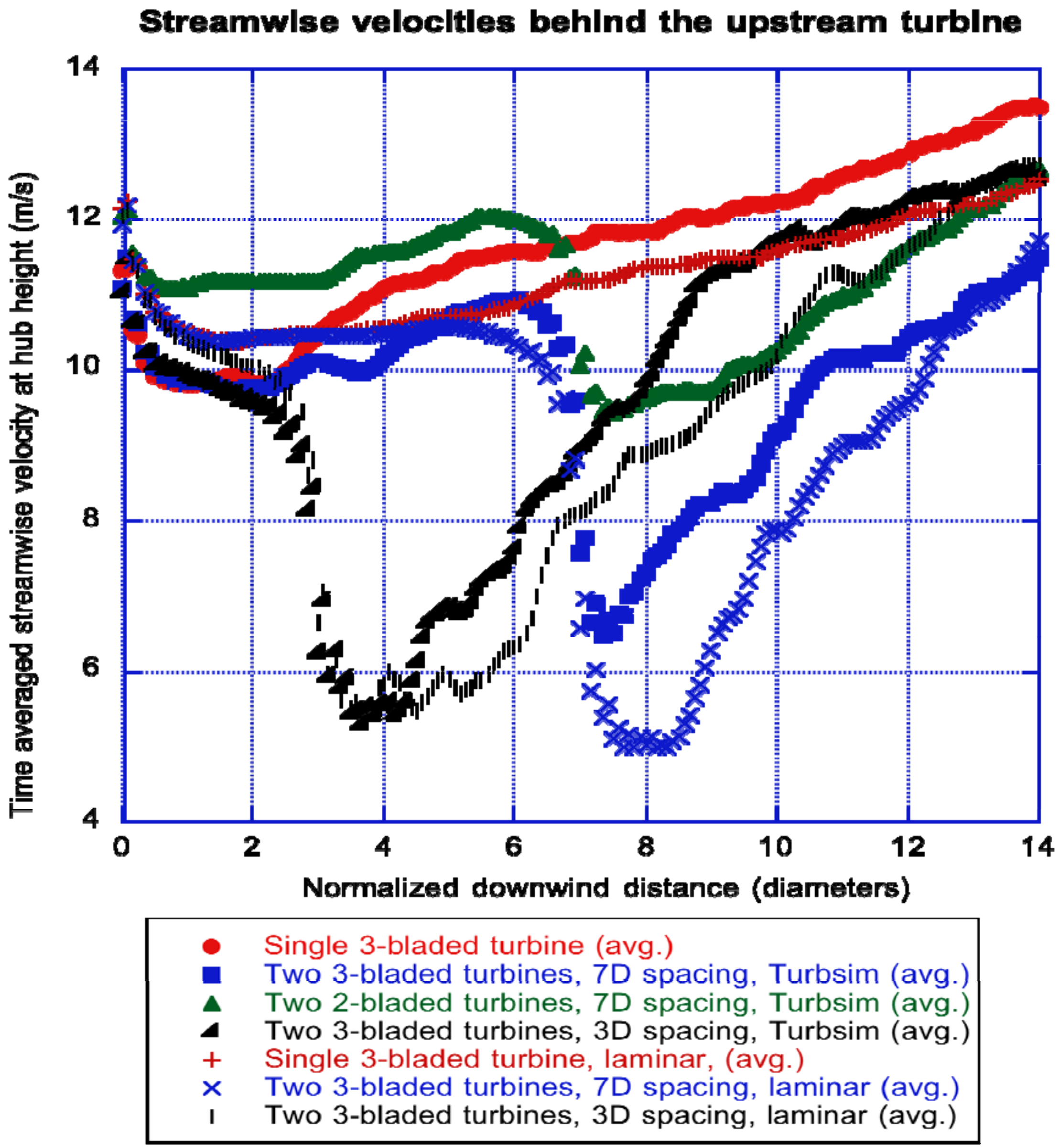
7D separation

# Power output from two turbines, the significance of upstream turbulence

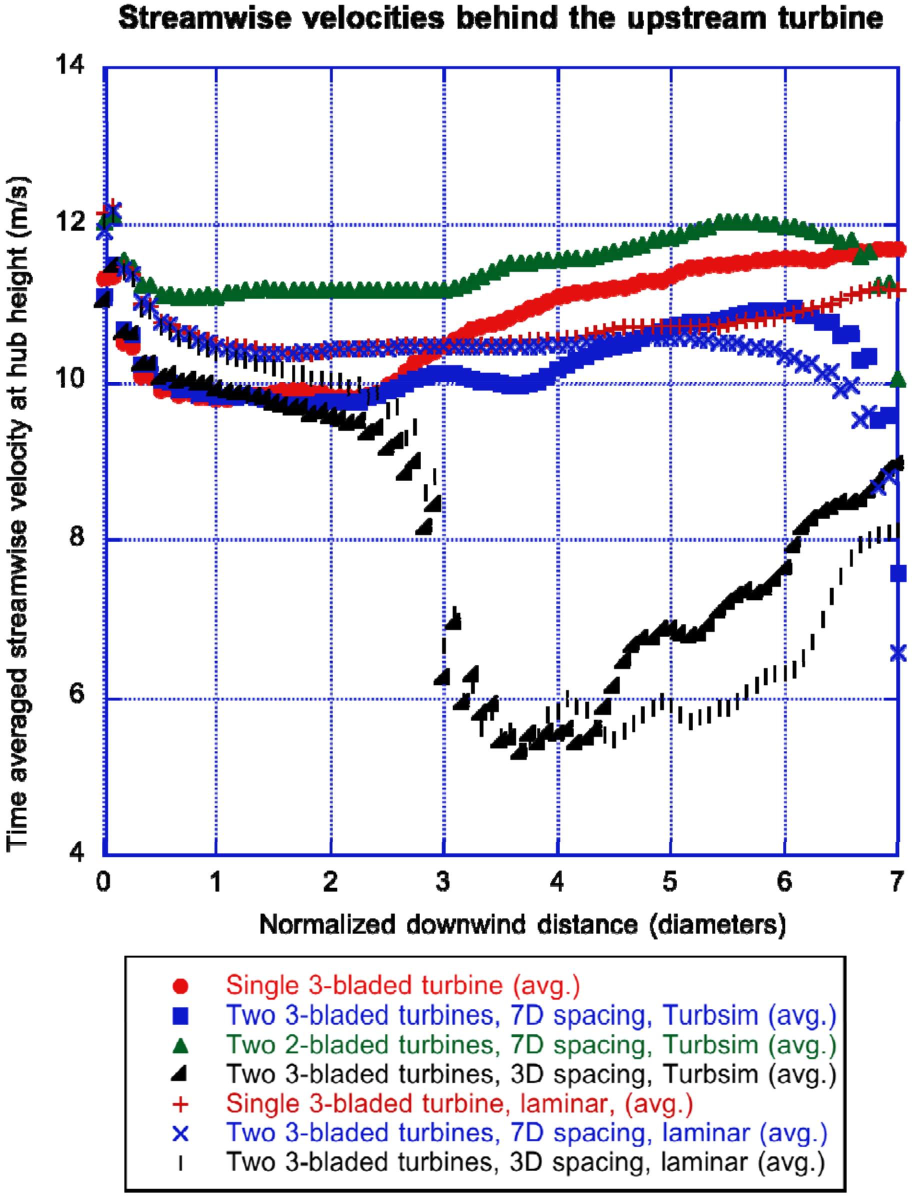


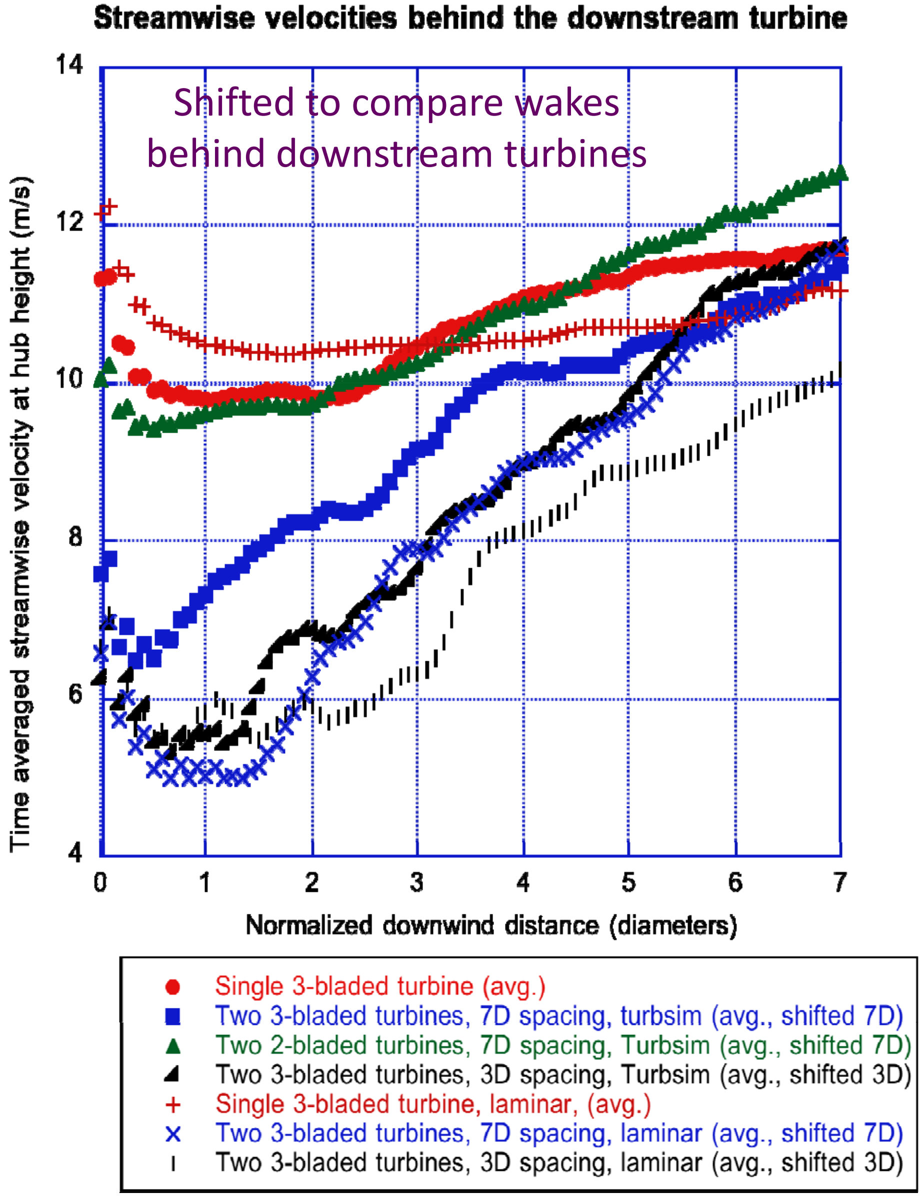



# Wake velocities measured from upstream turbines

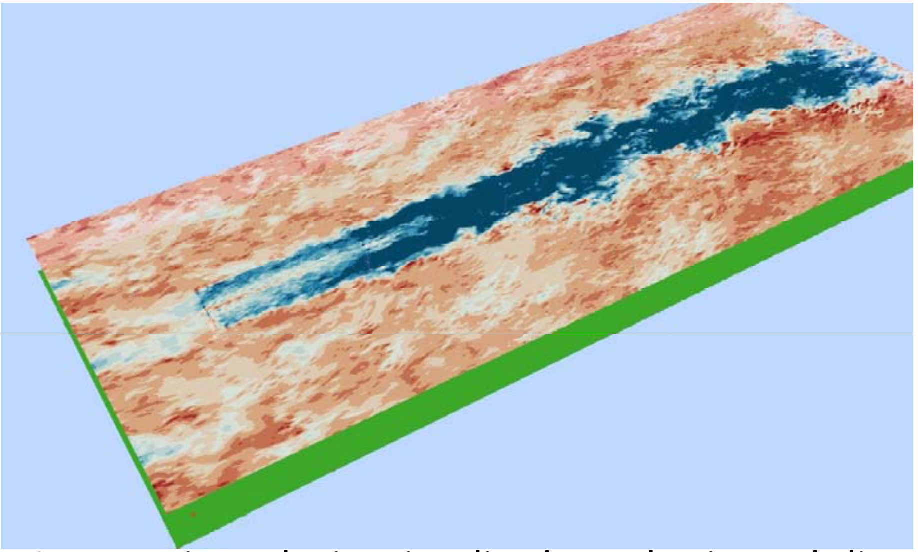


# Wake velocities measured from upstream and downstream turbines

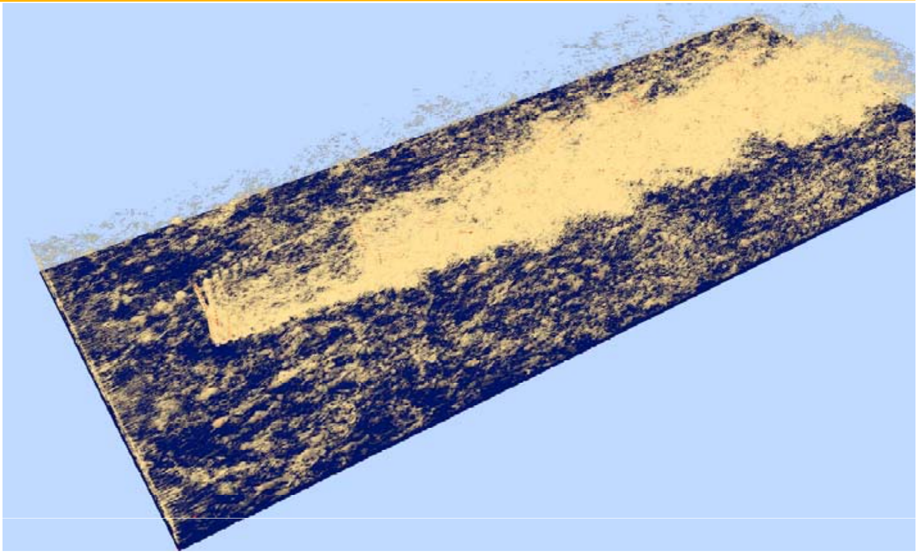


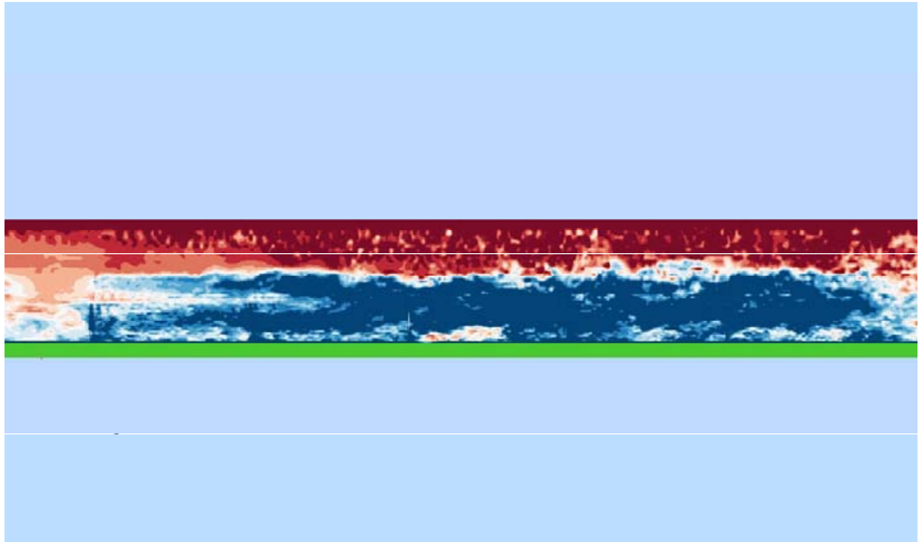
# HPC turbine/wind interaction



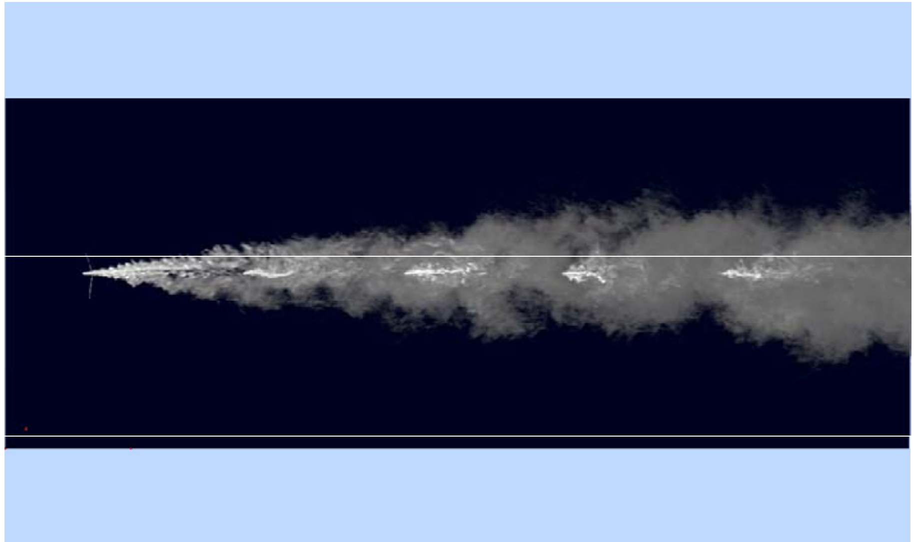
Streamwise velocity visualized on a horizontal slice



Vorticity

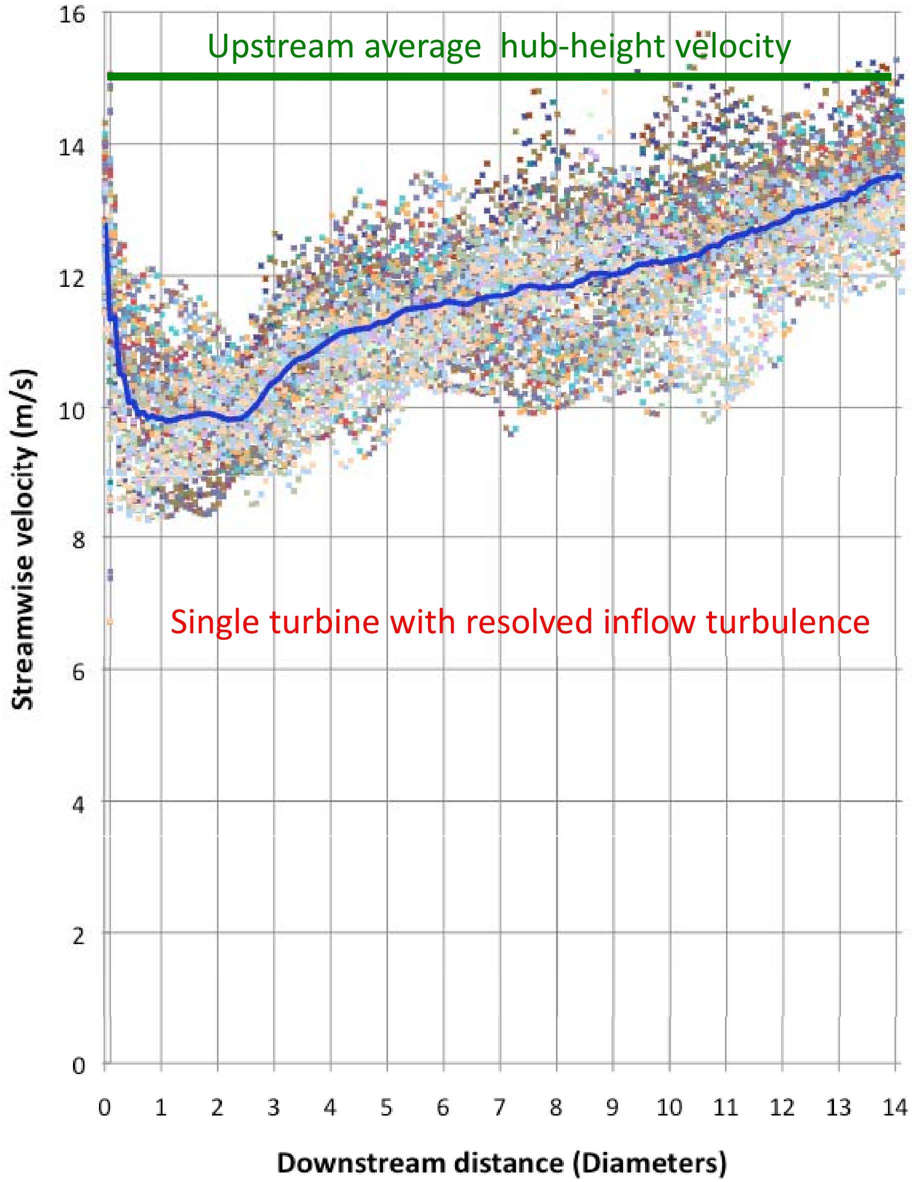


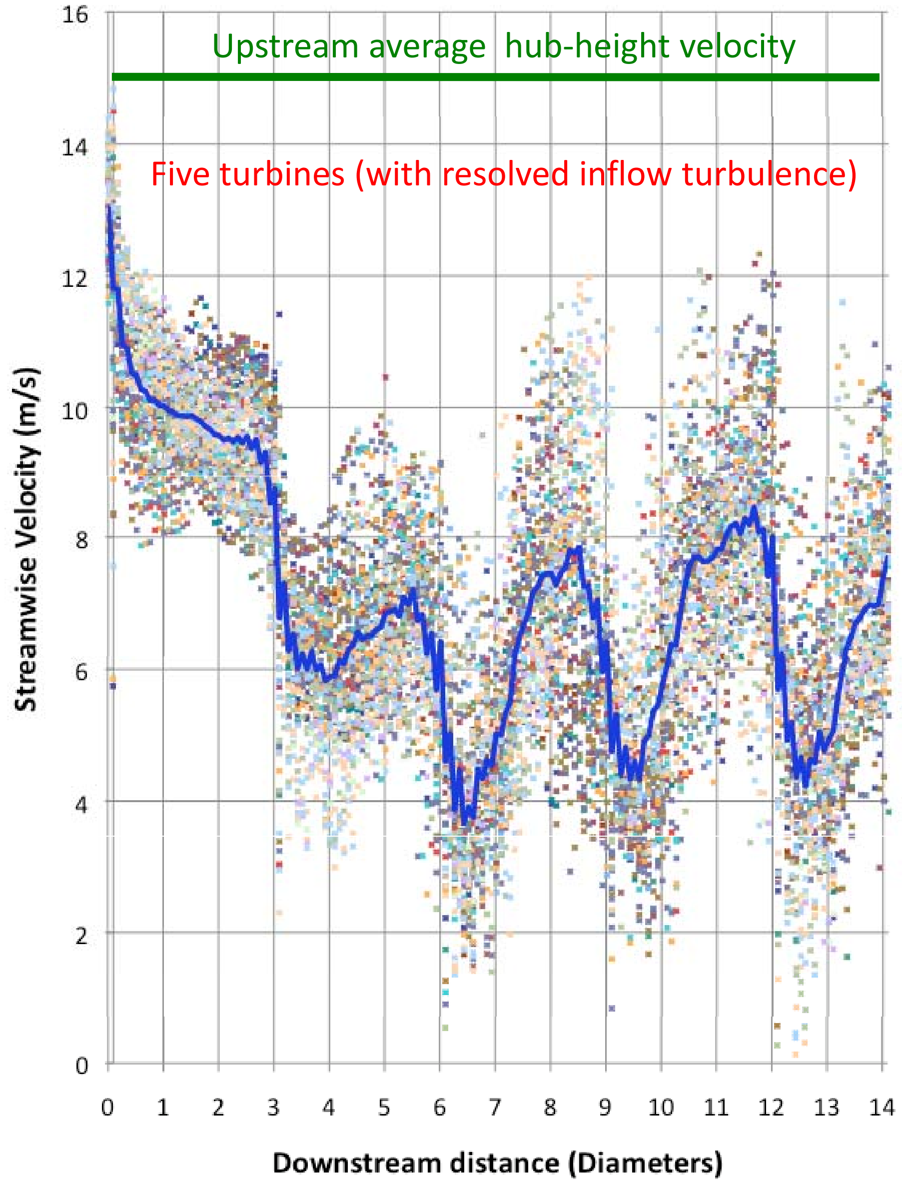
Streamwise velocity visualized on a horizontal slice



Turbulent mixing visualized with emitted tracer

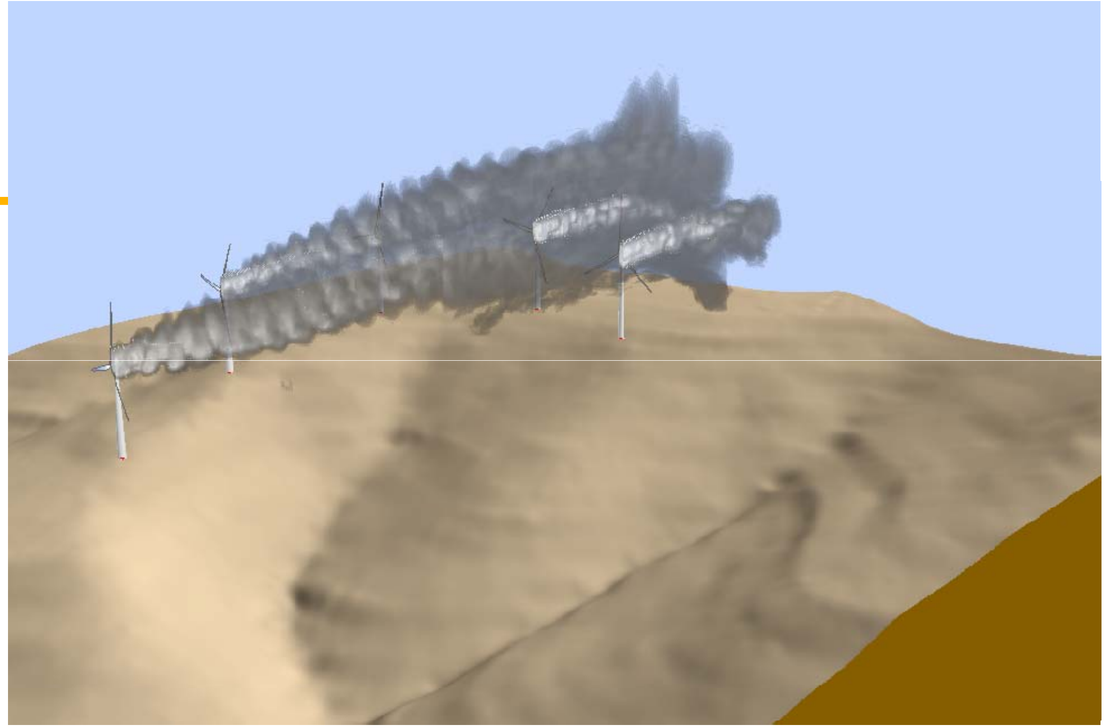
# Wake velocities for single vs. multiple turbine simulations

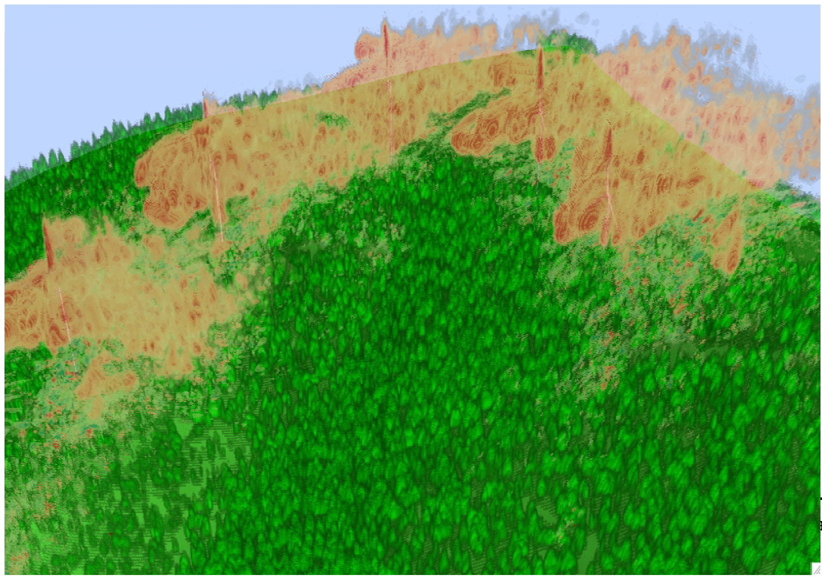


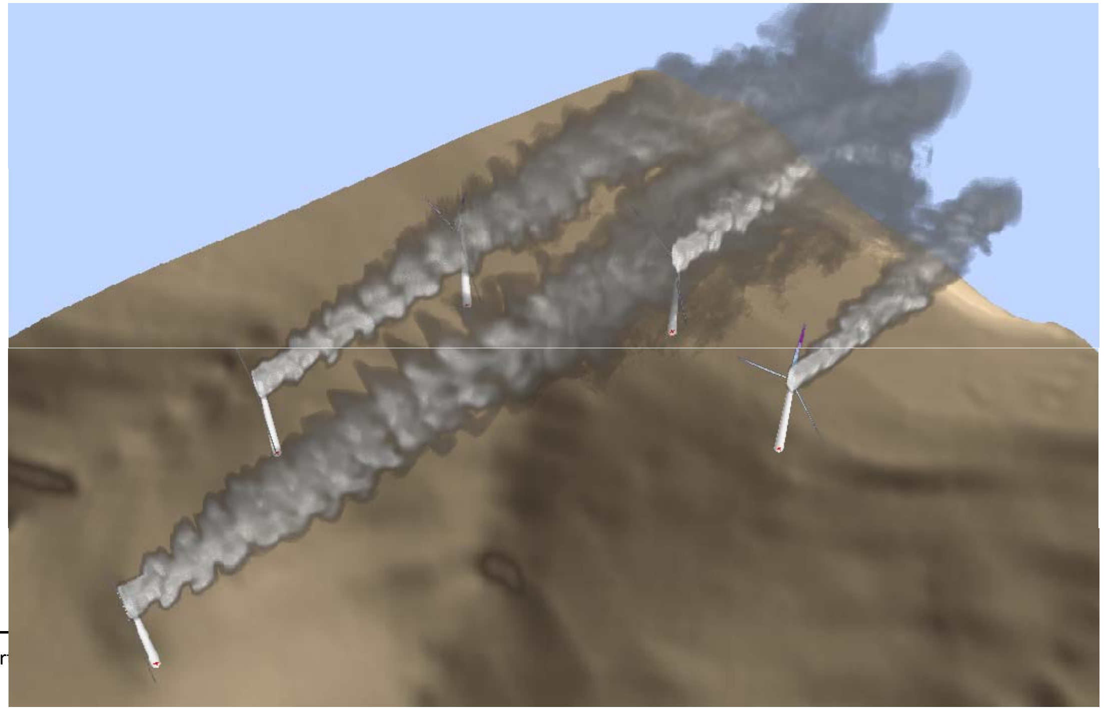



# Topography

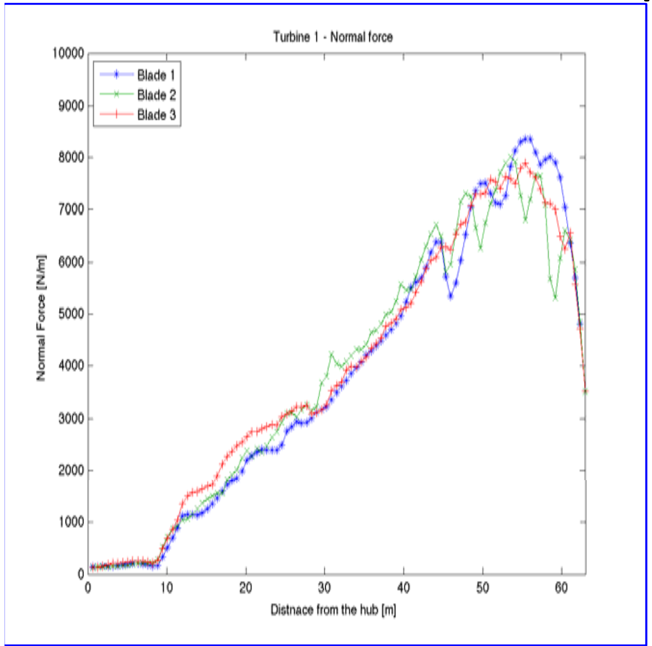
- Implementation of Windblade on a hypothetical site near Las Vegas, NM.
- Use of automatic yaw control algorithm to adjust for the influence of terrain on wind field
- Realistic heterogeneous vegetation is present in this simulation.

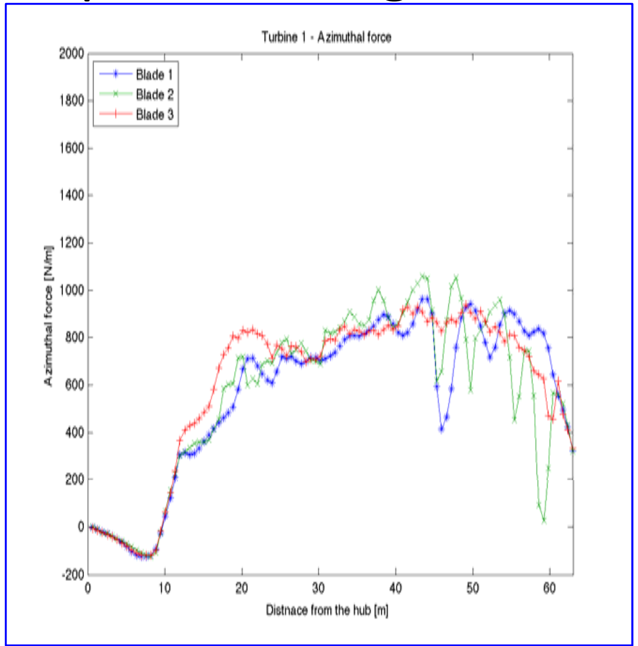


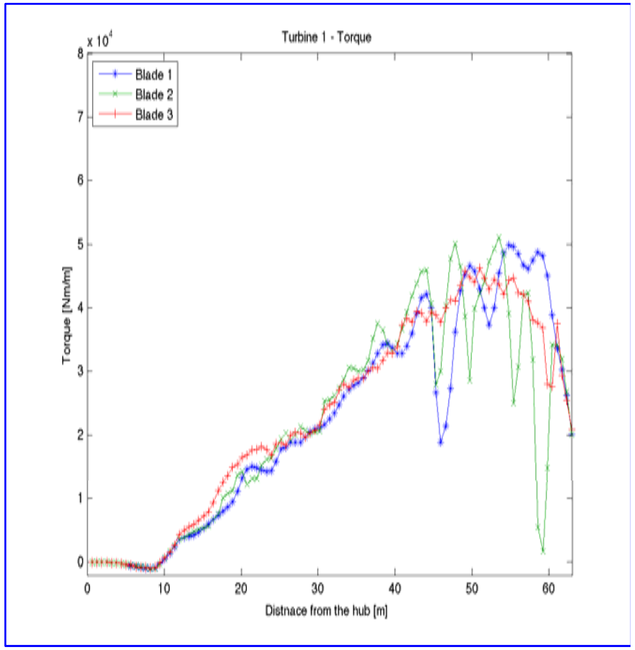




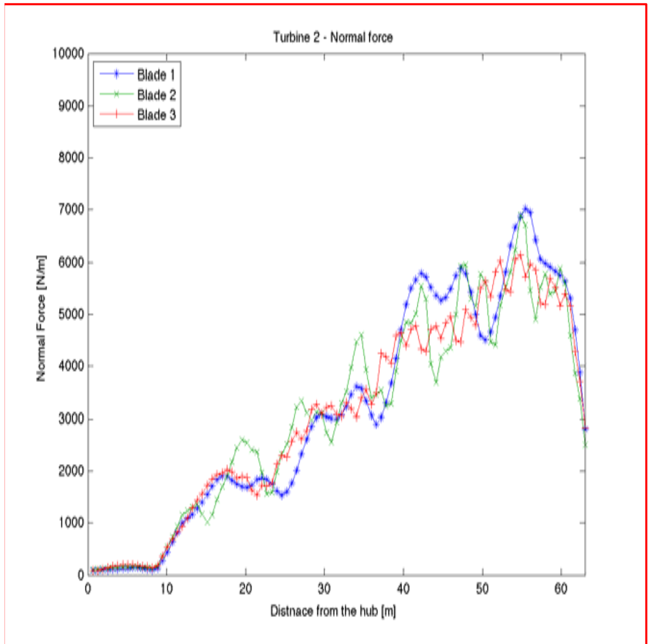
# Blade loads and torque per unit length for 2 turbines

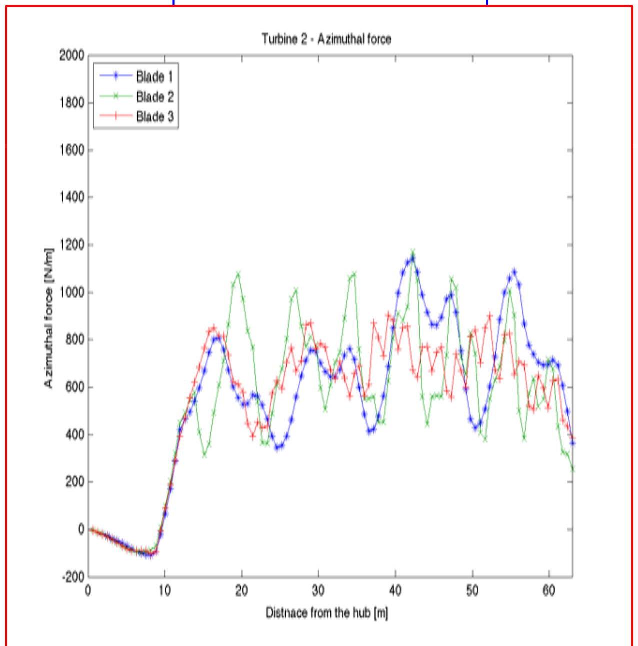


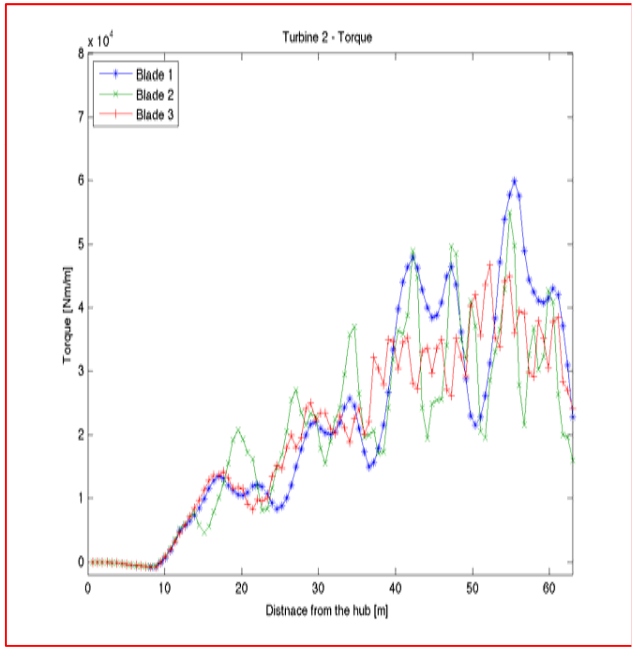




Upstream Turbine




7D Downstream Turbine

# Opportunities beyond this LDRD project

Opportunities for capability advancement:

- Leveraging order of magnitude computational acceleration of HIGRAD/FIRETEC
- Inclusion of marine atmospheric boundary layer (leveraging HIGRAD hurricane-intensification research for air/sea interaction)
- Coupling effects of wave mechanics
- Translation of forces into gearbox
- Coupling to CFD blade-design codes
- HPC-based transformational hydrodynamic/aerodynamic model

(These tasks would be done in partnership with research institutions possessing relevant expertise, including: SNL, NREL, universities)

Providing for the community:

- Inexpensive method of exploring influences of off-shore environments on turbine and turbine array designs as well as reliability
  - Off-shore atmospheric boundary layer
  - Larger turbine designs
  - Influence of coupled wave interaction
  - Gear box loadings and failure mechanisms
- Providing guidance for observation strategies
- Providing explanations for observed phenomena
- Opportunity for optimization of wind farm configurations for off shore, great plains, and complex topographic settings

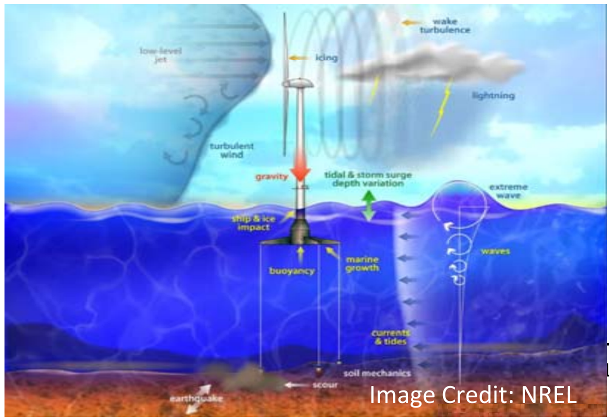


Image Credit: NREL