

Wind Farm and Wake Modeling at NREL



**IEA Task 23: Offshore
Wind Farms: Wake
Effects**

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Critical Elements for 20% Scenario

Improved Performance

- 10% reduction in capital cost
- 15% increase in capacity factor
- Address Wind Farm underperformance

Mitigate Risk

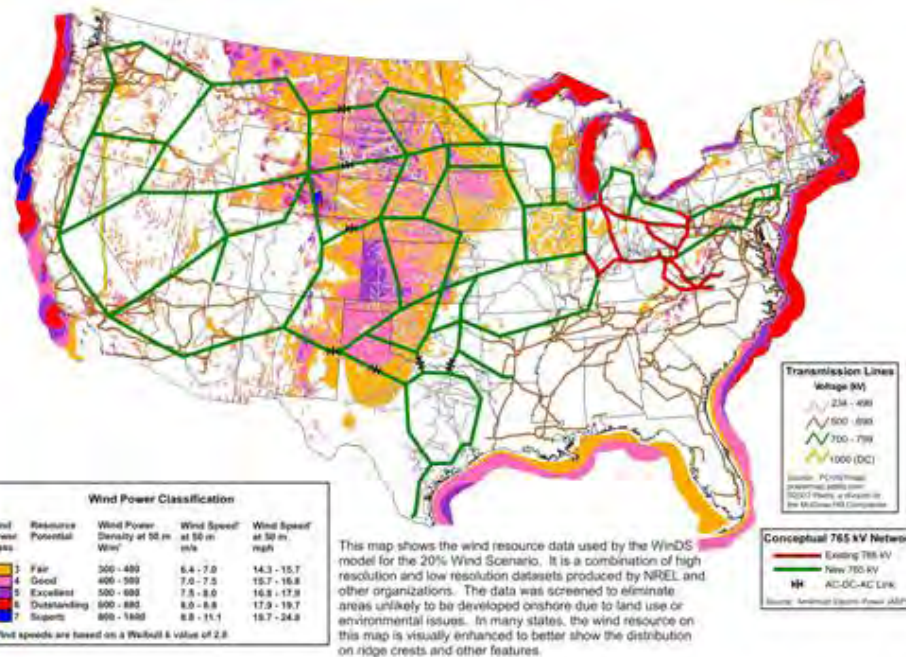
- Reduce O&M costs by 35%
- Foster the confidence to support continued 20% per year growth in installation rates from now until 2018

Enhanced Transmission System (AEP)

- \$60 billion cost estimate over 20 yrs
- 19,000 mi of line
- Supports 200-400 GW addition

Policy, Communication & Outreach

Infrastructure Development

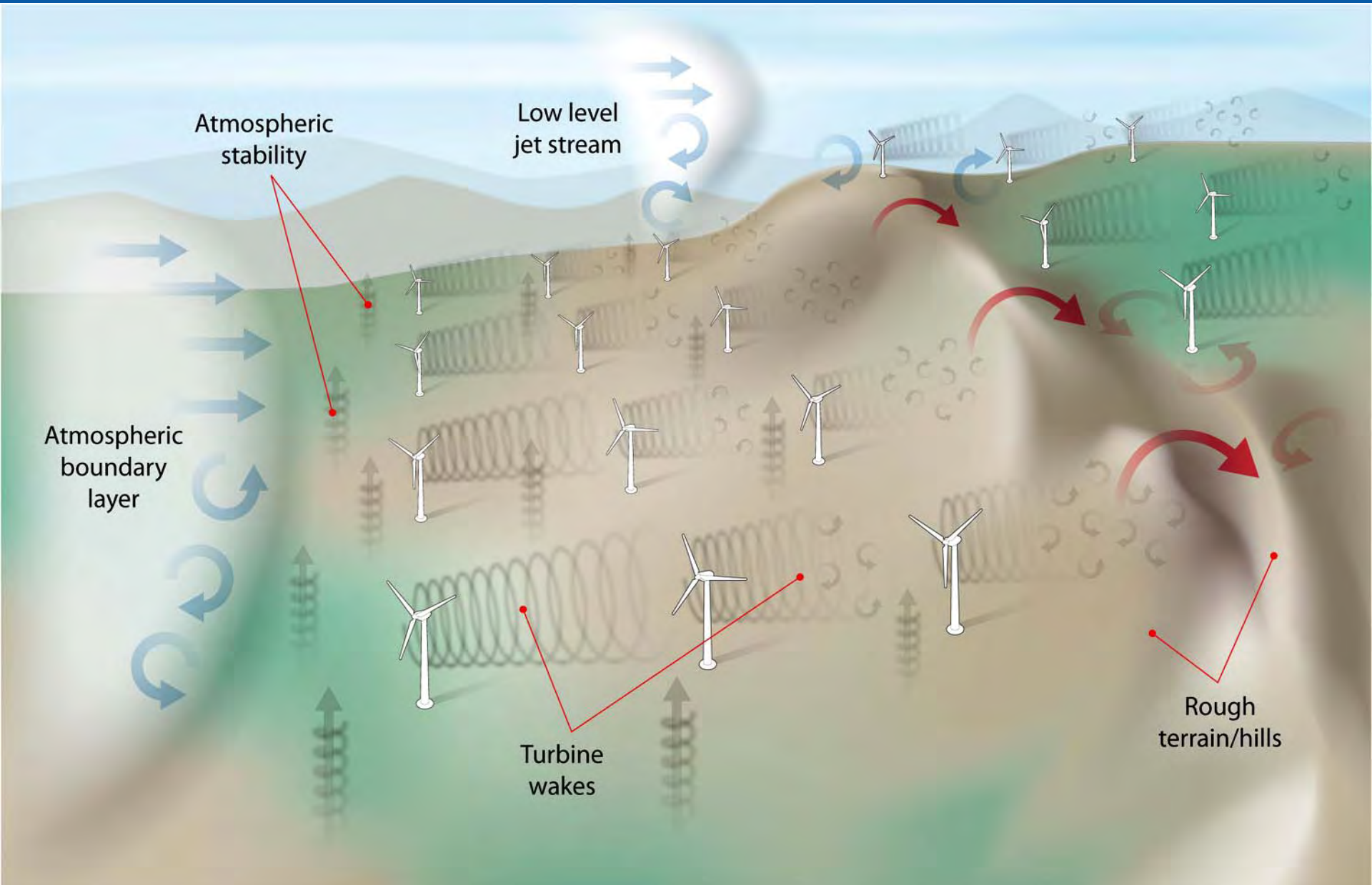


Offshore

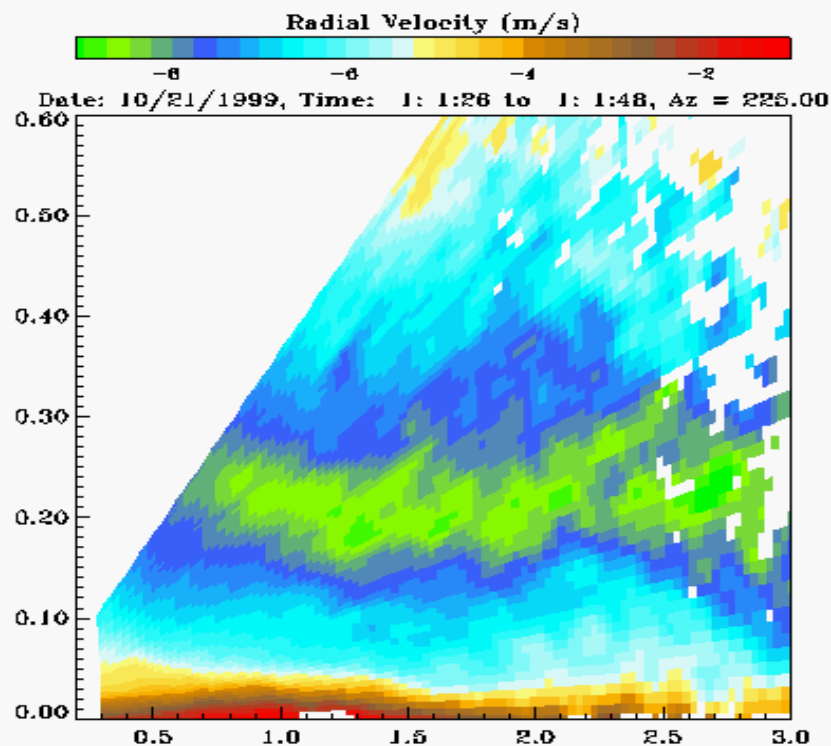
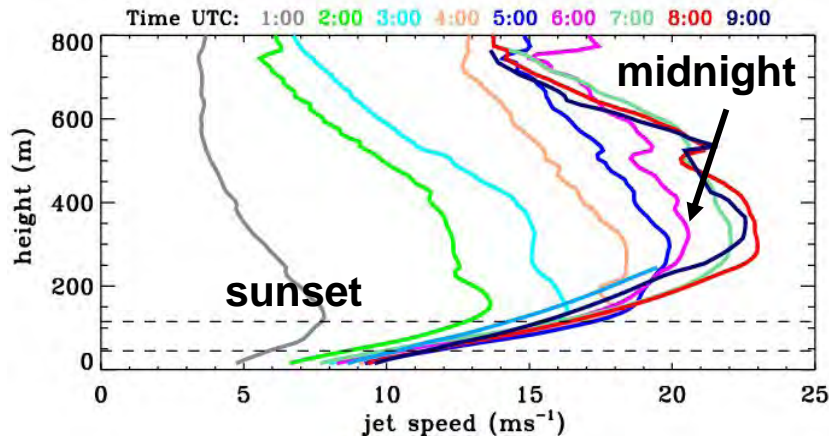


Picture used by permission of Uni-Fly A/S

Onshore

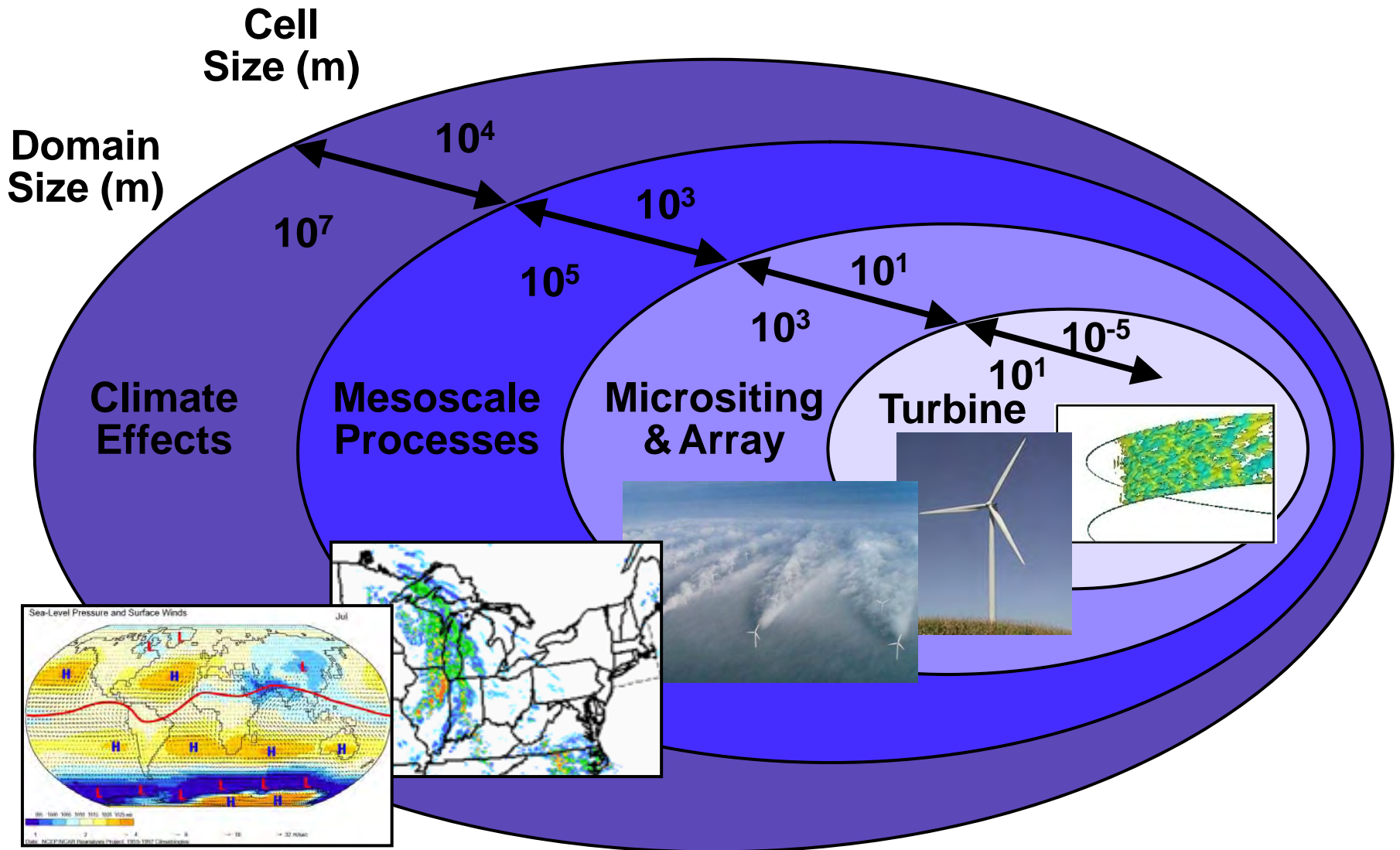


Planetary Boundary Layer (PBL)



- Turbine, wind farm, PBL; similar dimensional scales
- Farm / inflow interactions not quantified
- Characterization & prediction remain an issue
- Detailed inflow information required for turbine design and optimized control
- Diurnal variation
- Growing concerns include:
 - Quality of the downwind resource
 - Microclimatology changes
 - Agriculture impacts
 - Permitting

Computational Modeling Scales



Wind Farm Modeling Tools

Engineering Models

- Linear or Semi-Linear
- WAsP, WindFarmer, openWind, etc

Computational Fluid Dynamics (CFD)

- Reynolds Averaged Navier Stokes (RANS)
 - Turbulence modeled
 - MetoDyn, Ventos, WindSim, RaptorNL – Mainly resource assesment
 - Fast
- Detached Eddy Simulation (DES)
 - Hybrid RANS/LES
- Large Eddy Simulation (LES)
 - Most turbulence calculated
 - Expensive
- Direct Numerical Simulation (DNS)

Industry

Research

NREL's modeling approach

Computational Fluid Dynamics

- Mostly Large Eddy Simulation
- Some Reynolds Averaged Navier Stokes for comparison
- Fluent (\$) Open▽FOAM
- OpenFOAM
 - <http://www.opencfd.co.uk>
 - Developing atmospheric modules
 - Easier for collaboration

Focus on atmospheric interaction

- Atmospheric stability
- Surface roughness effects
- Partnering with National Center for Atmospheric Research (NCAR) – also have PBL LES code



CFD Approach

Precursor Simulation

- Unsteady inlet condition for turbine simulation
- Slightly smaller domain (in length)
- 3 different runs
 - Unstable, stable and neutral PBL
 - Can be reused for many turbine configurations
- Researching roughness elements

Main turbine simulation (to date)

- Two turbines
 - 100m diameter -100m hub-height
 - Scaled V80 power curves (Hansen Upwind WP8.1)
 - Simplified BEM – radial variation of momentum extraction

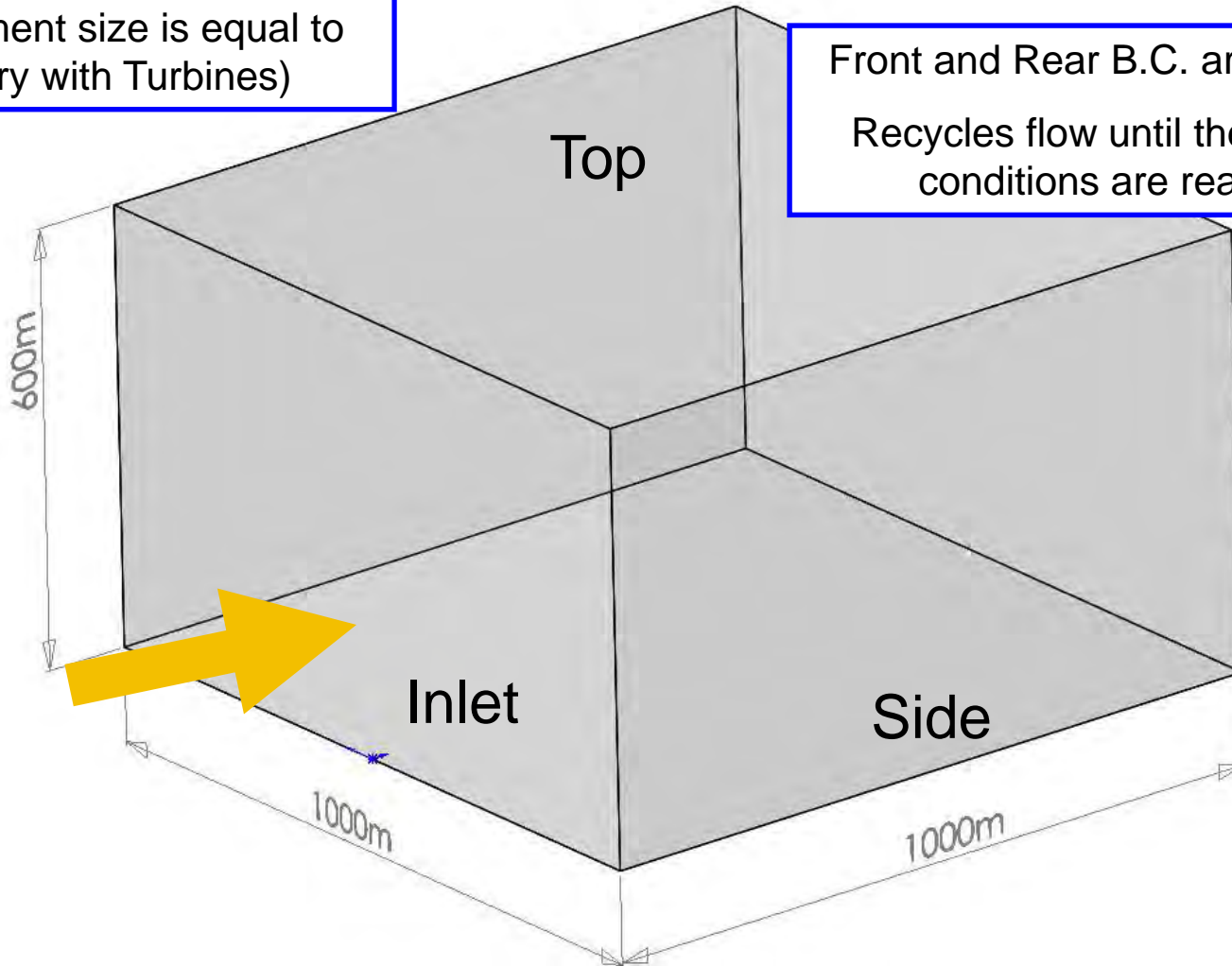
Very coarse grids

- ~200K cells
- Preliminary scoping exercises
- Further refinement required!

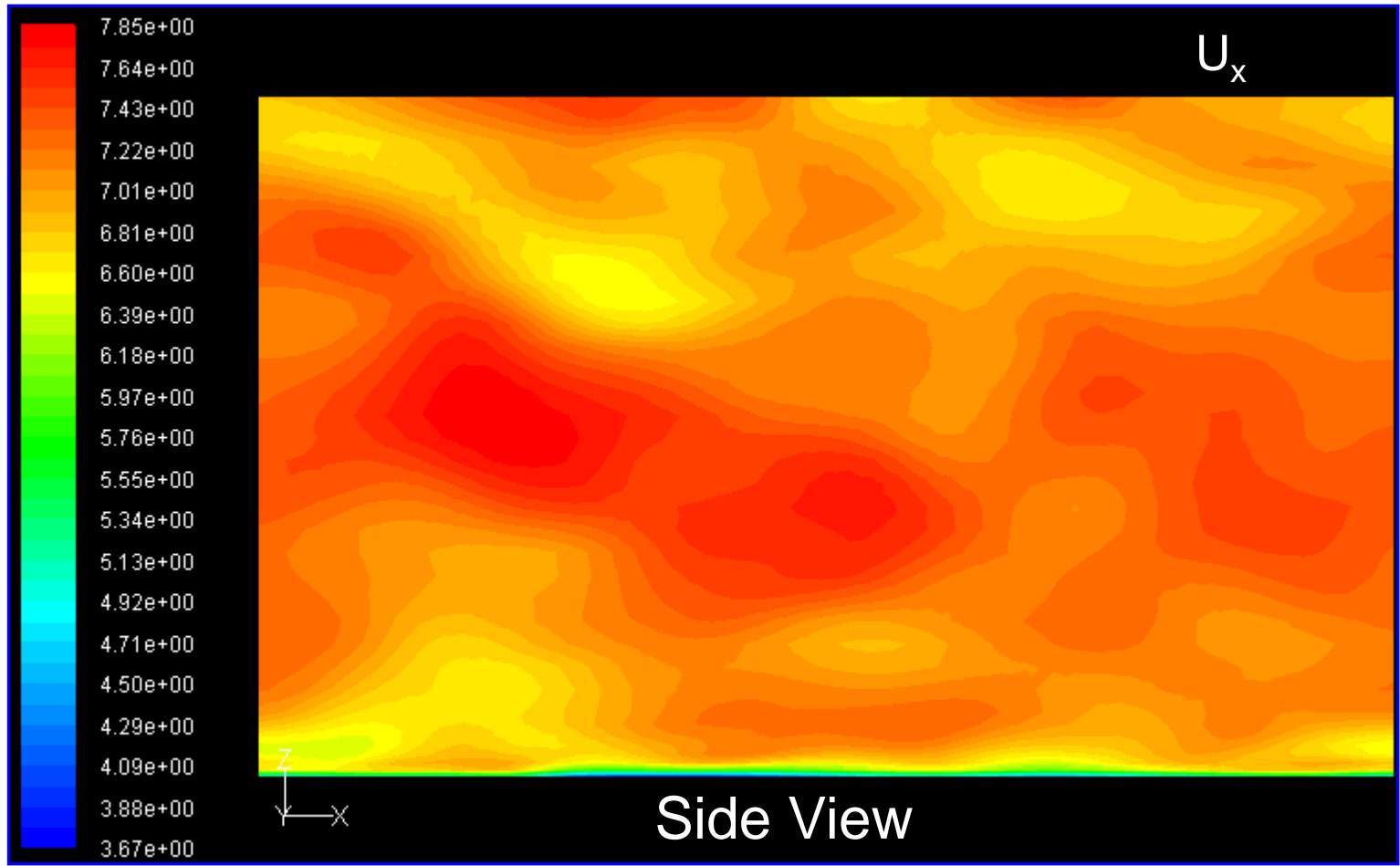
Precursor Simulation

Mesh Element size is equal to geometry with Turbines)

Front and Rear B.C. are Periodic
Recycles flow until the desired conditions are reached

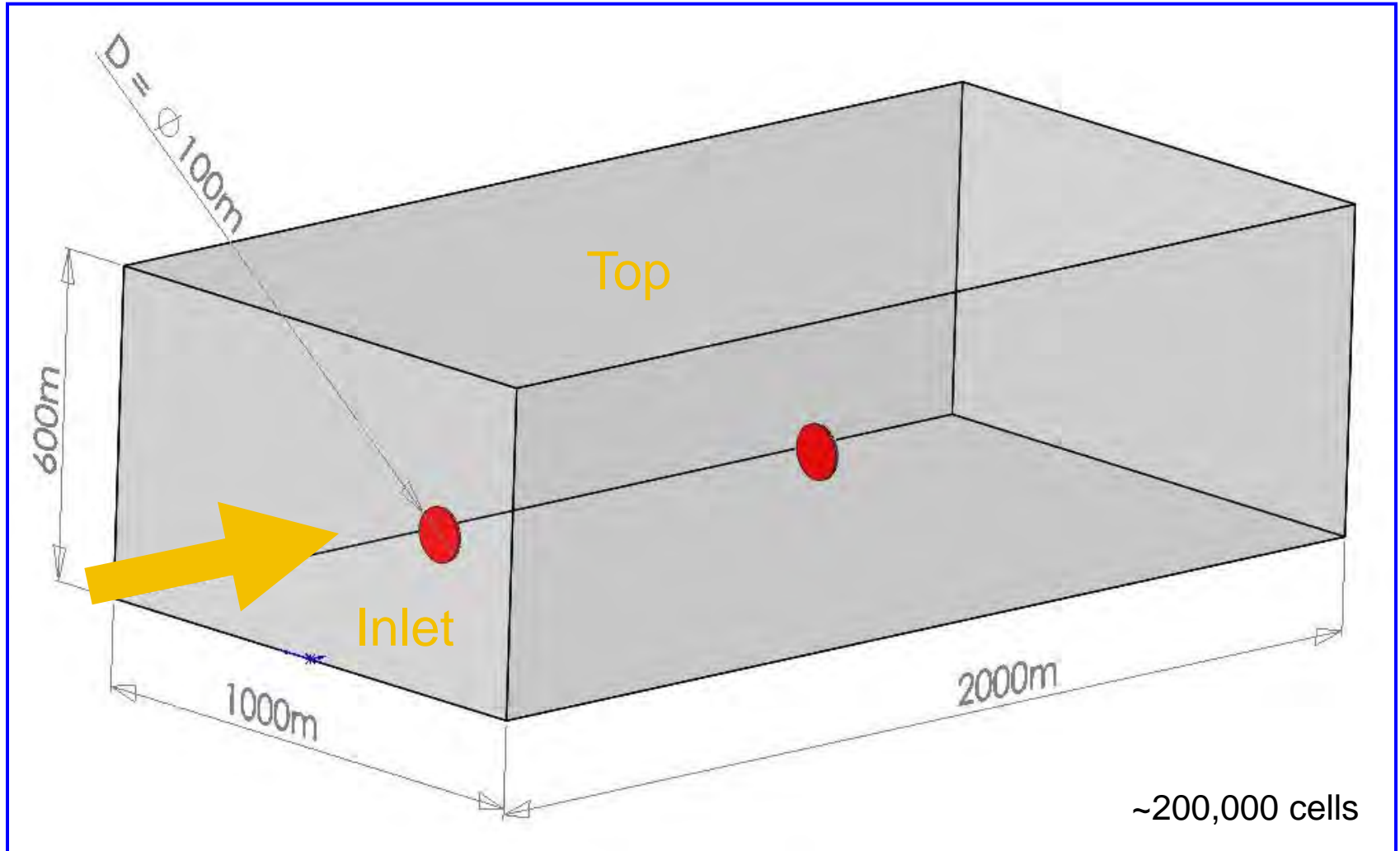


Precursor Simulation

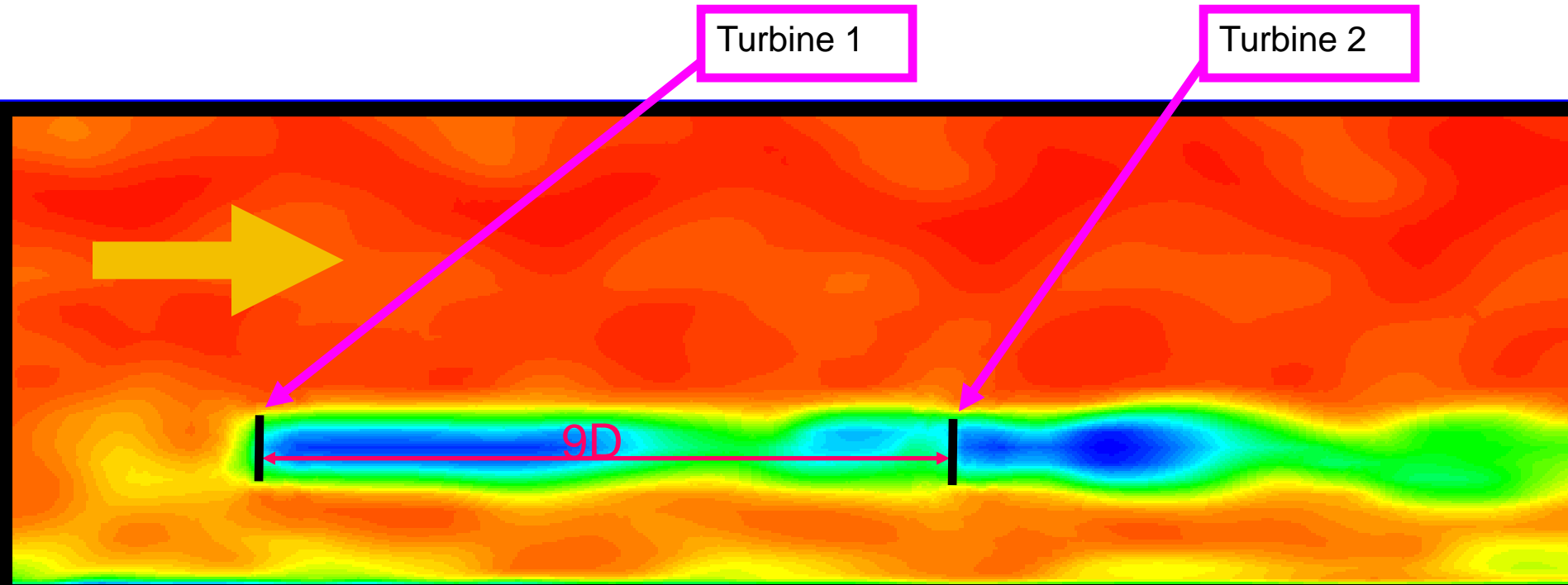


Preliminary

Computational Domain



Full Turbine Simulation

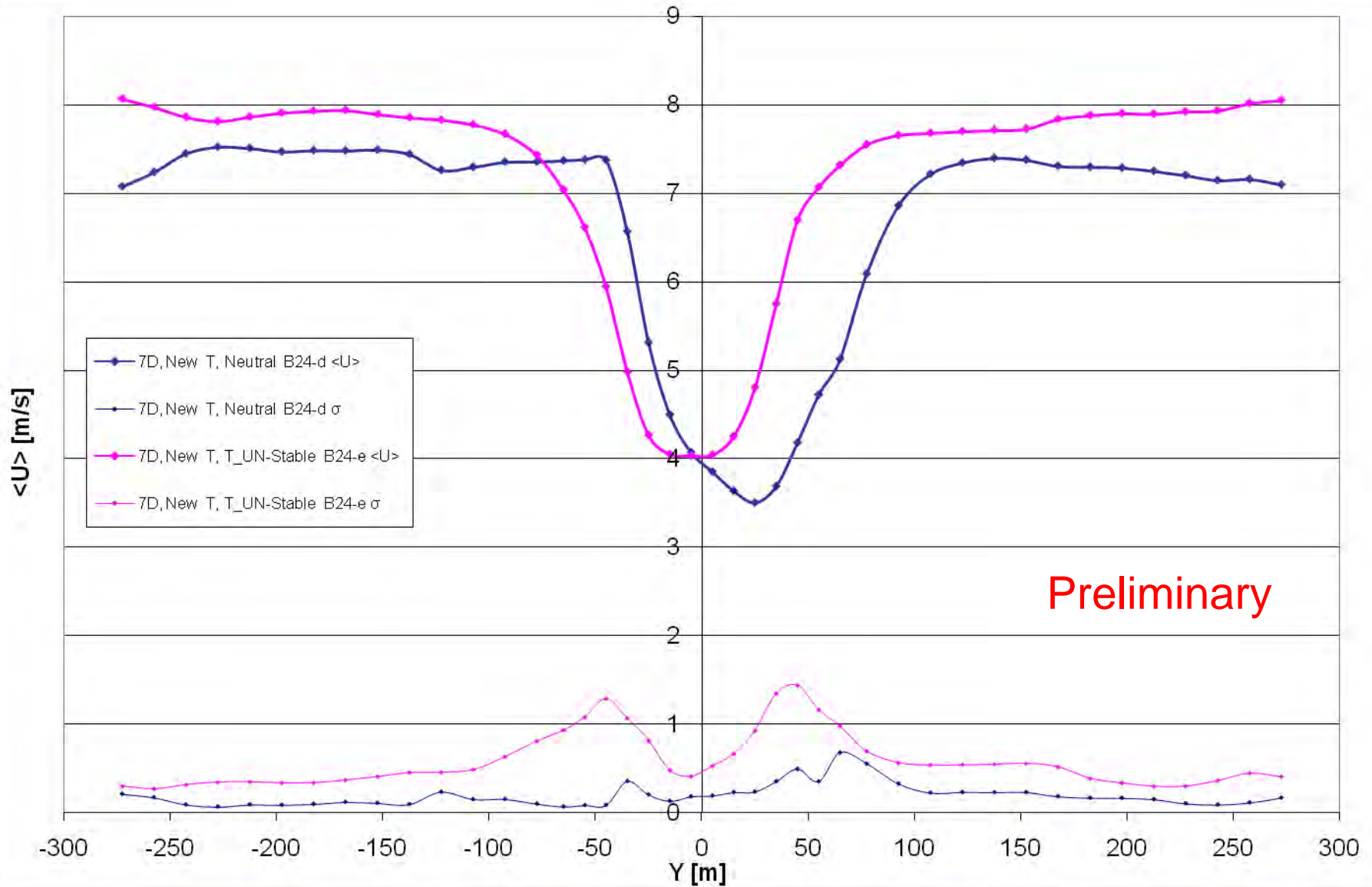


Side
View

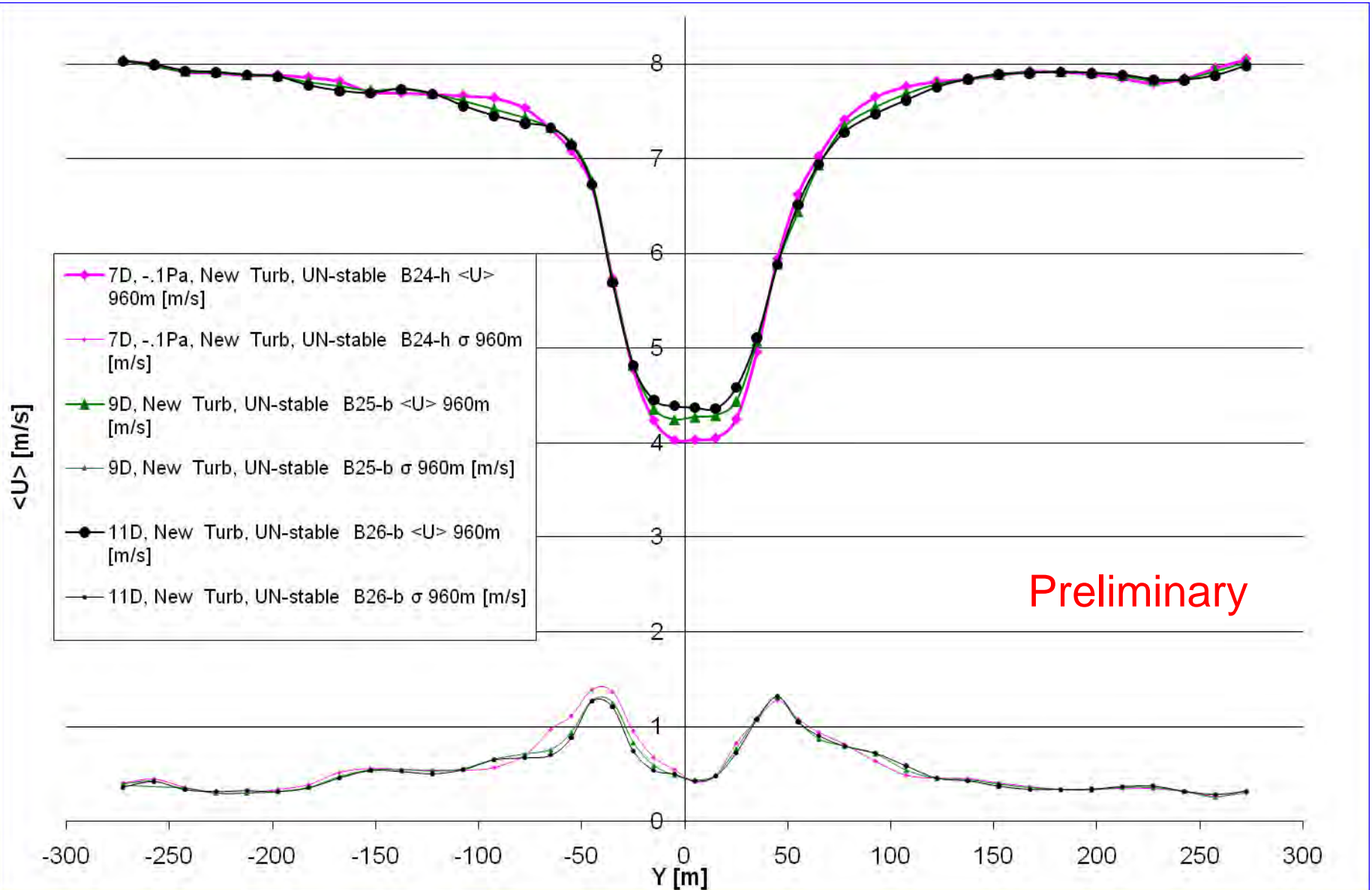
Preliminary

Contours of V_x
Range: 2.5-8.0 m/s

Velocity Deficit - Stability Effect

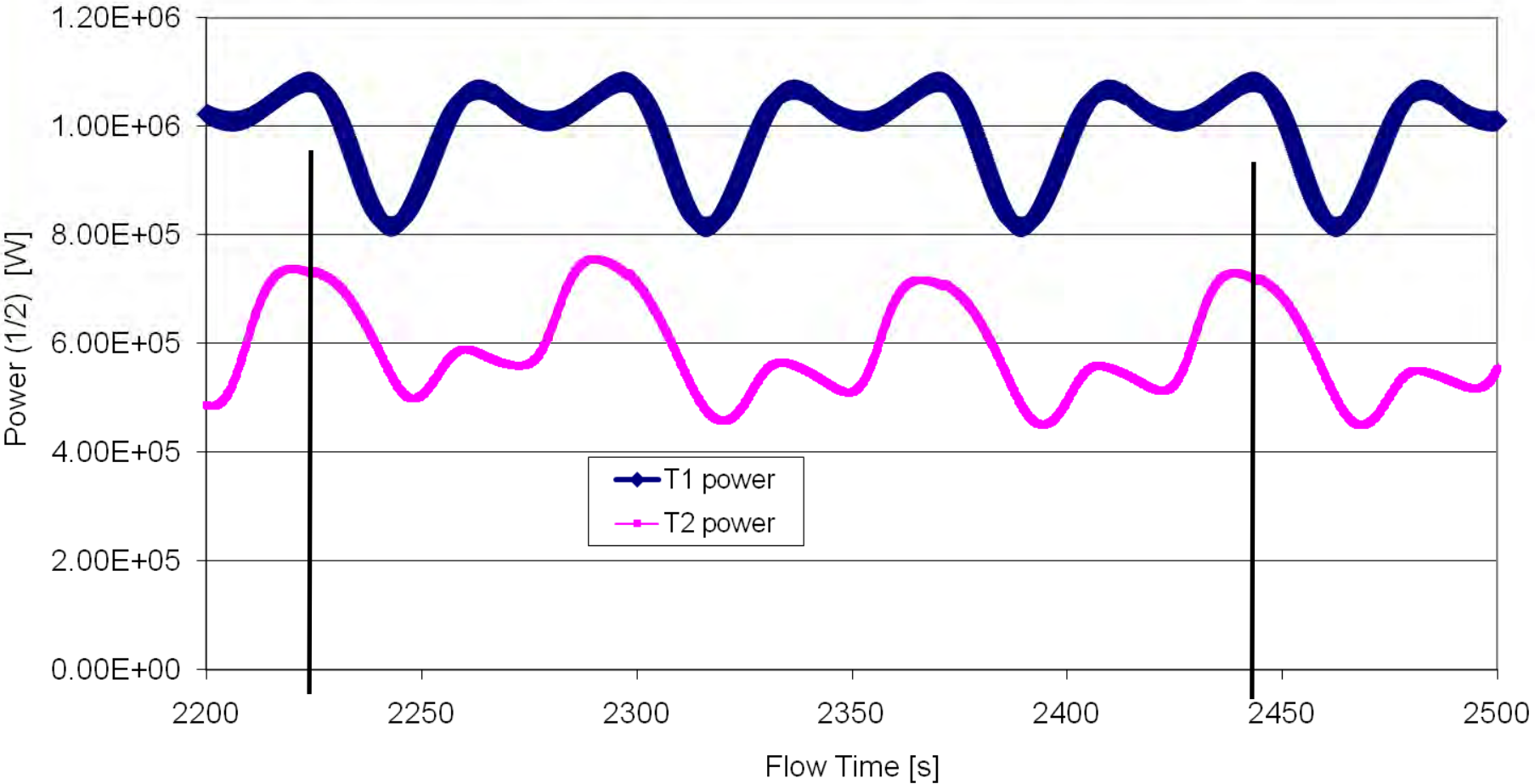


Velocity Deficit – Spacing Effect



Relative Turbine Power

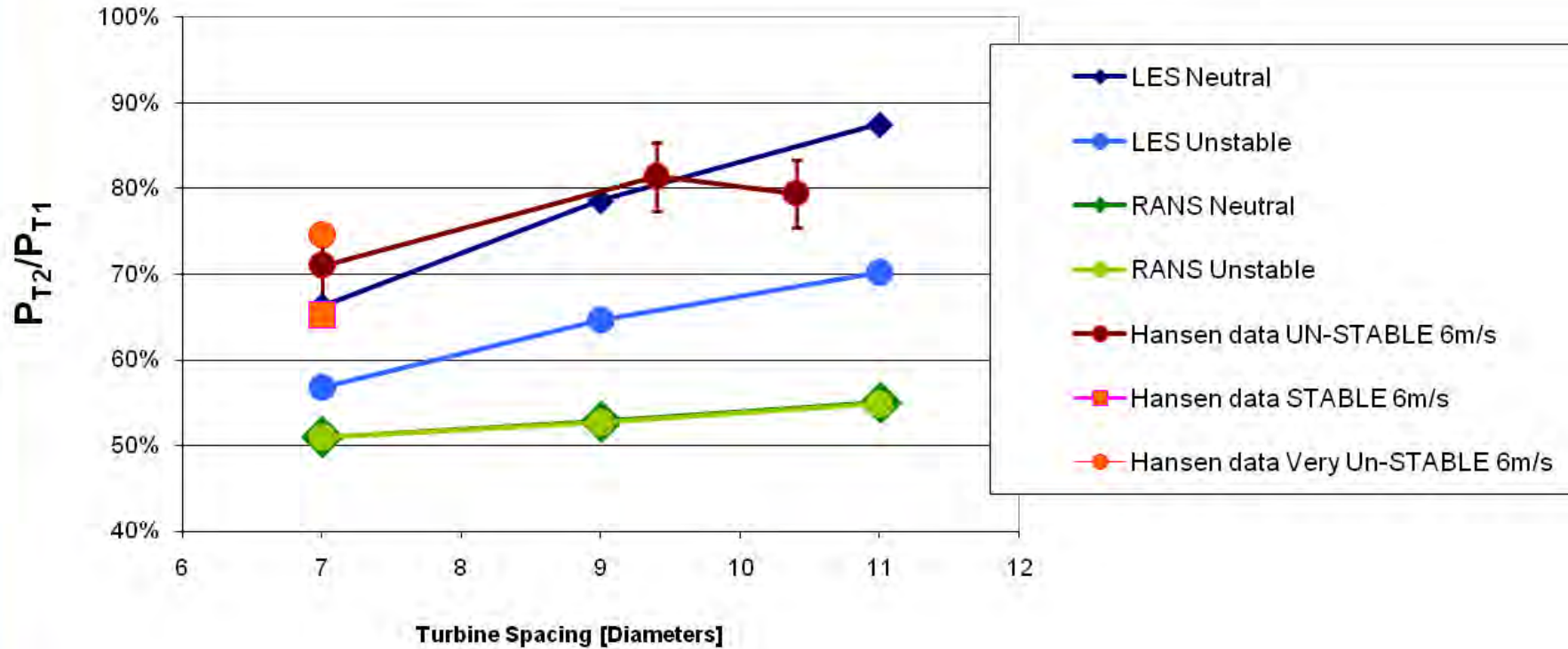
Turbine Power vs. Flow Time



Preliminary

Relative Turbine Power

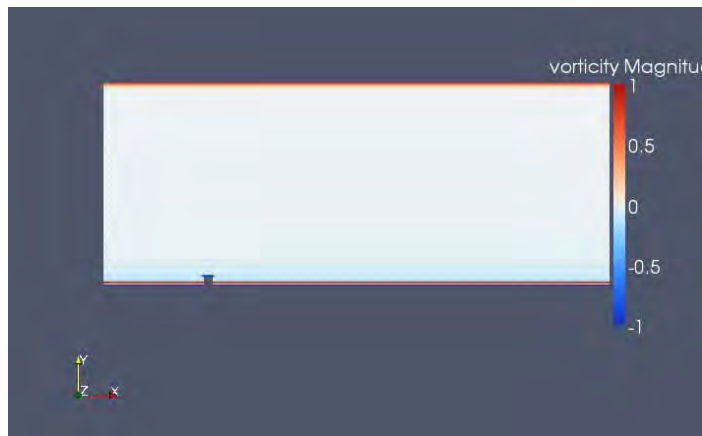
Power Deficit vs. Turbine Spacing



Preliminary

Surface roughness

- What is the correct way to simulate surface roughness?
 - Want to match spectra and turbulent statistics of atmosphere in precursor simulation



- How well is wind farm itself represented as increased roughness?
 - Atmospheric scientists have been exploring this for forest canopies

Impact of vegetation on flow over hills

QuickTime™ and a
BMP decompressor
are needed to see this picture.

Specified roughness

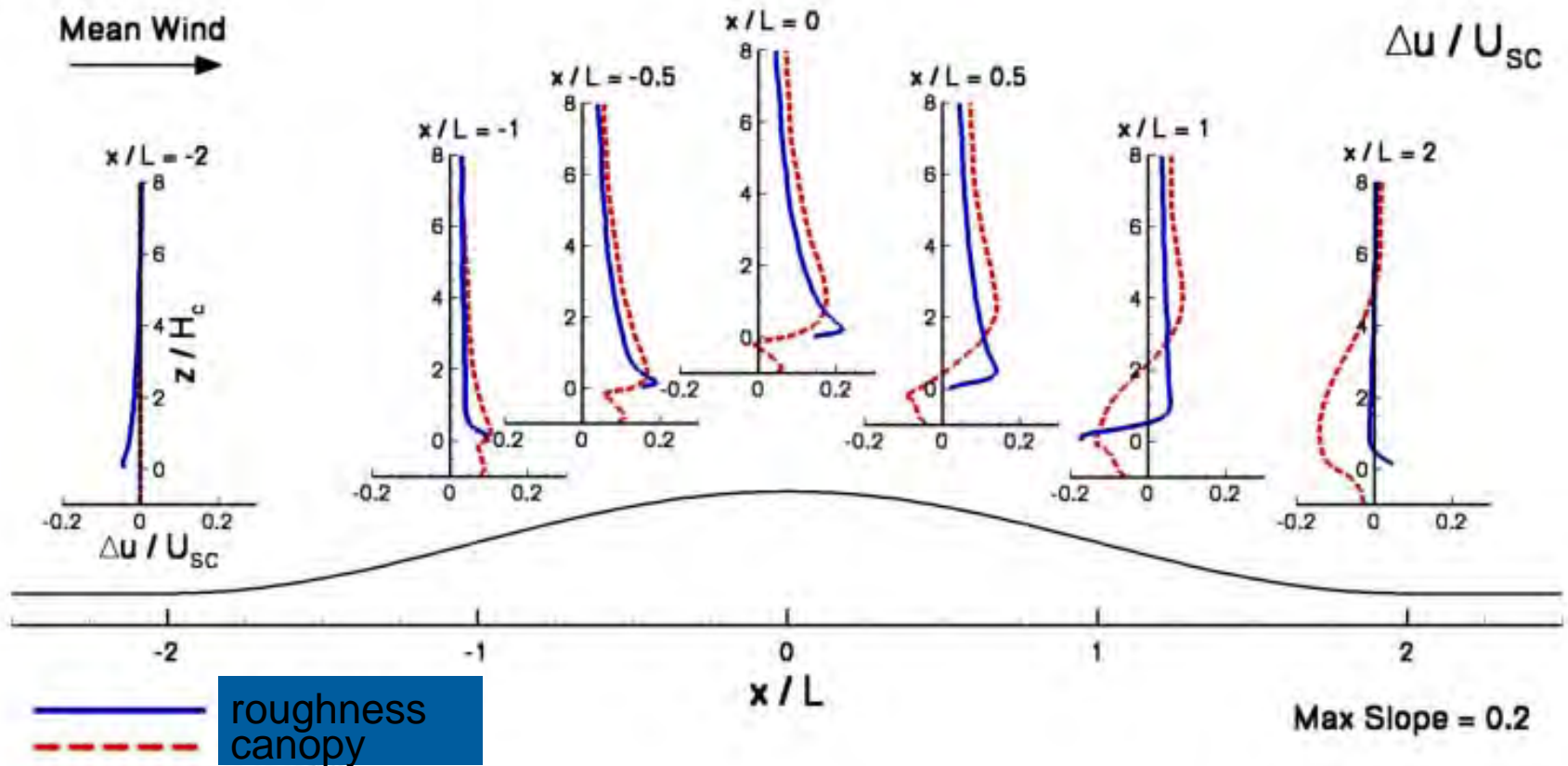
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Resolved canopy

Patton et al. 2006

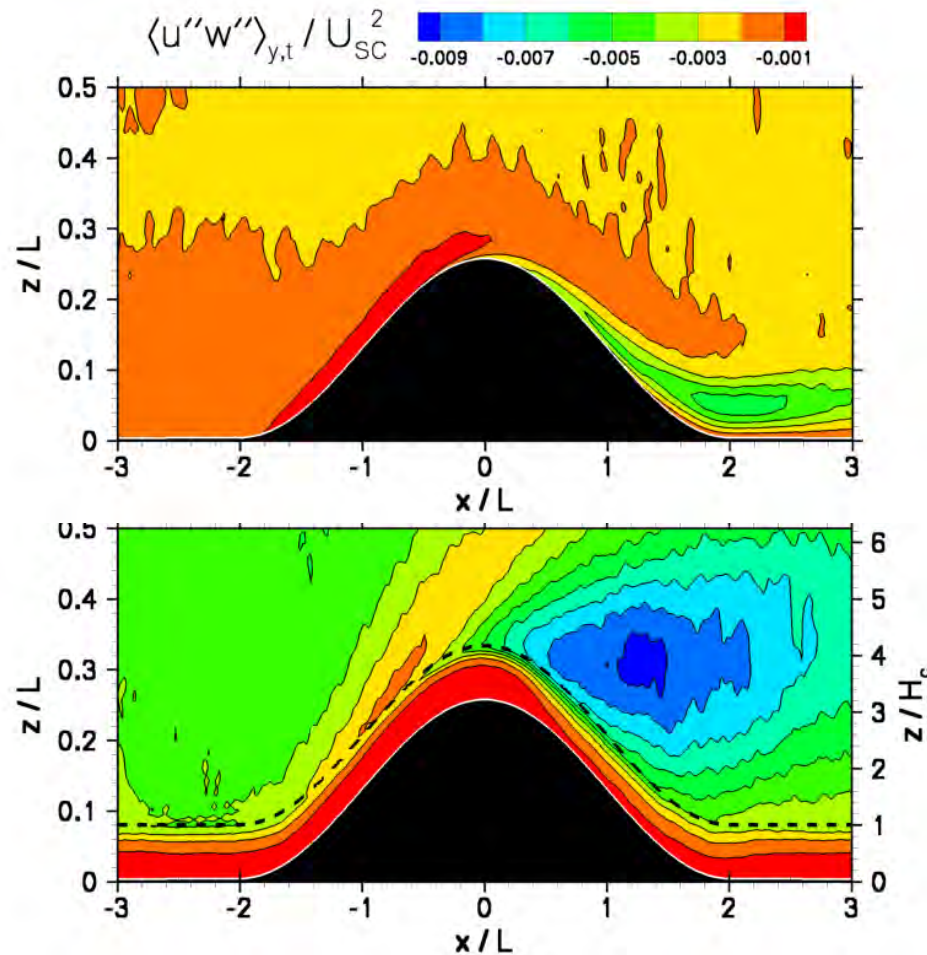
Impact of vegetation on flow over hills

Normalized Mean Streamwise Velocity Perturbation



Impact of vegetation on flow over hills

Normalized momentum flux

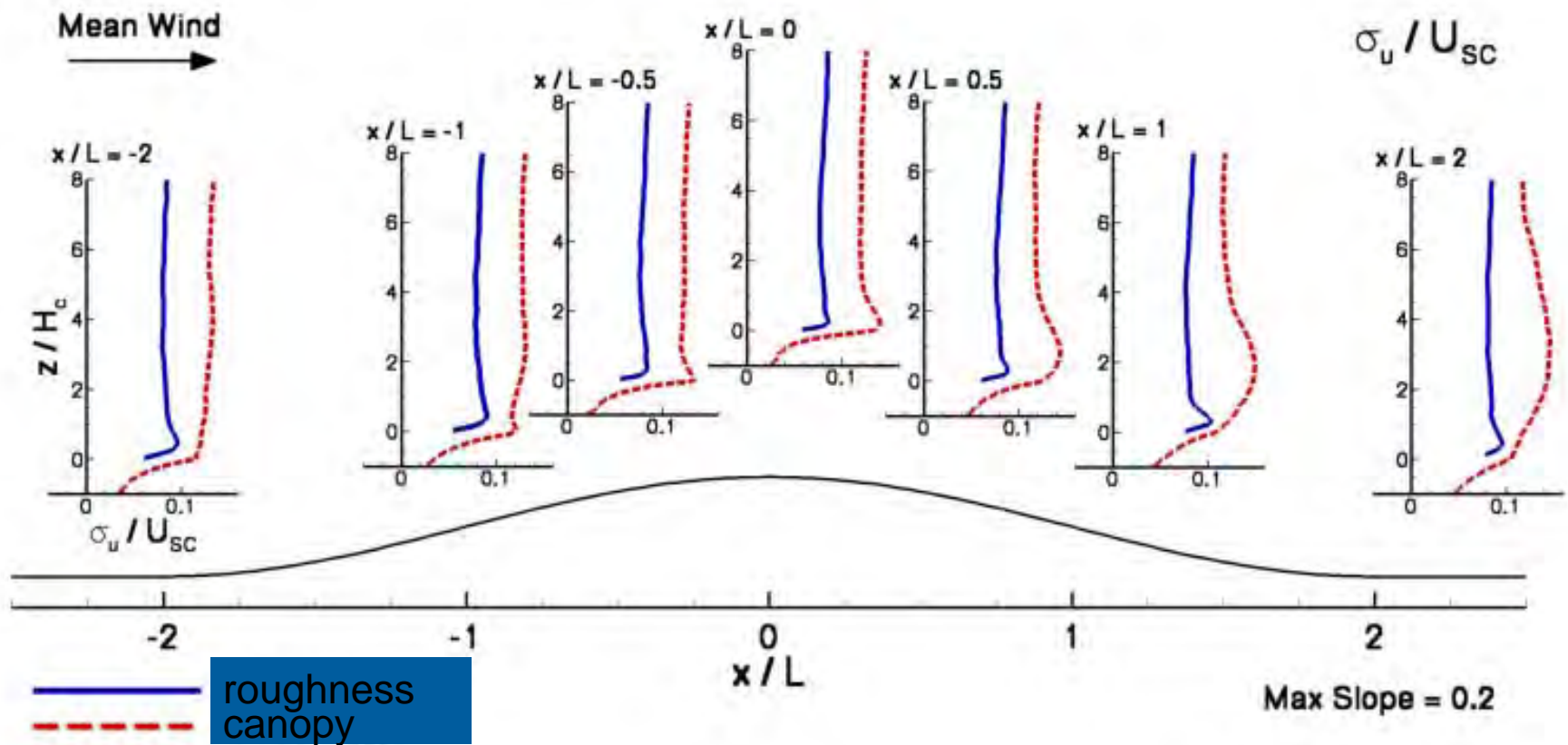


Surface roughness

Resolved canopy

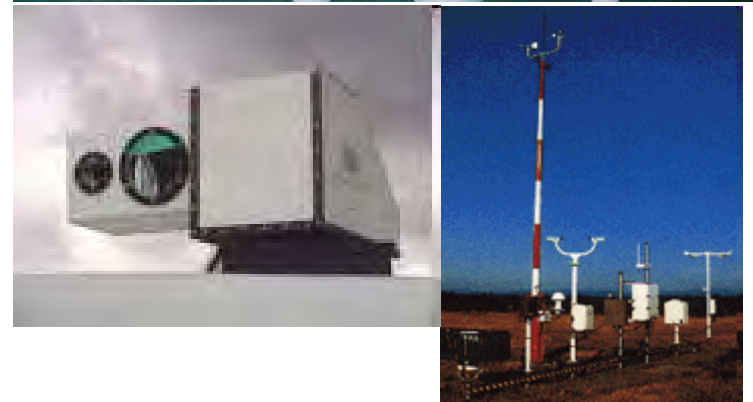
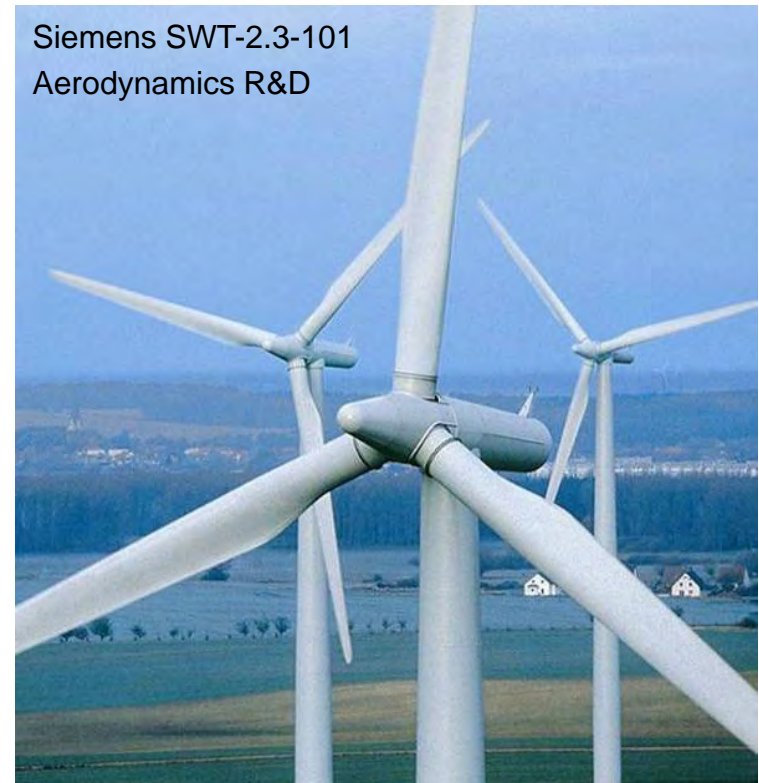
Specified roughness vs. canopy

Normalized Streamwise Velocity Fluctuations



Future Plans

- **CFD**
 - **Finer grids and longer simulations**
 - 1000s CPU's
 - Does OpenFOAM Scale?
 - NCAR LES code with turbines
 - **Parameterized models for RANS, WAsP type simulations**
- **Experiments**
 - **Siemens 2.3 MW turbine at NWTC**
 - Summer 2010
 - Fully instrumented – similar to DANAERO
 - Wake
 - Inflow
 - Blade aerodynamics
 - **Wind farm measurements**
 - Summer 2012
 - 3-5 fully instrumented turbines
 - Expanded Ponnequin wind farm
 - Other locations, terrain types etc.
- **Continued collaboration with government labs, industry, universities and international partners**





NREL

National Renewable Energy Laboratory

Innovation for Our Energy Future



Questions?

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