Wind and marine turbine modelling at Heriot-Watt

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Introduction :: motivation and goals

- Cost/benefit analysis: energy yield estimation for layout optimisation

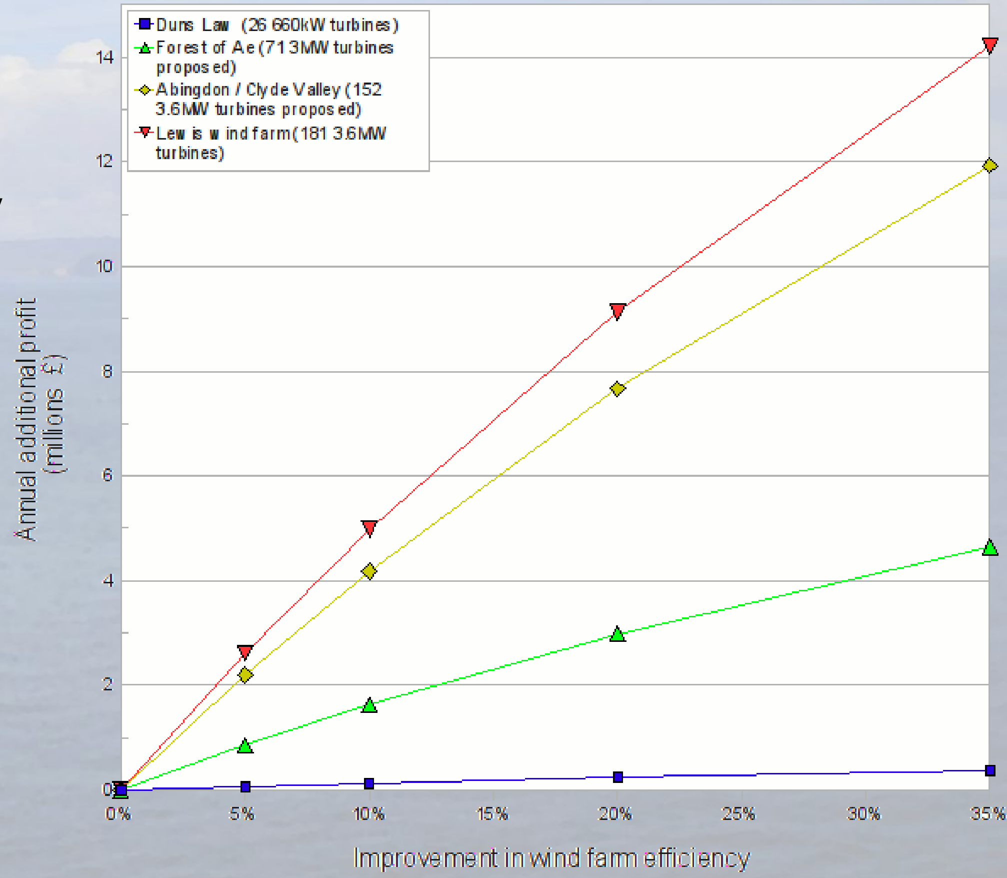
- Downstream effects:
  - environmental impact assessment
  - farm developments
  - wake modelling over large distances

- Second-by-second performance data for each turbine

Introduction :: farm configuration

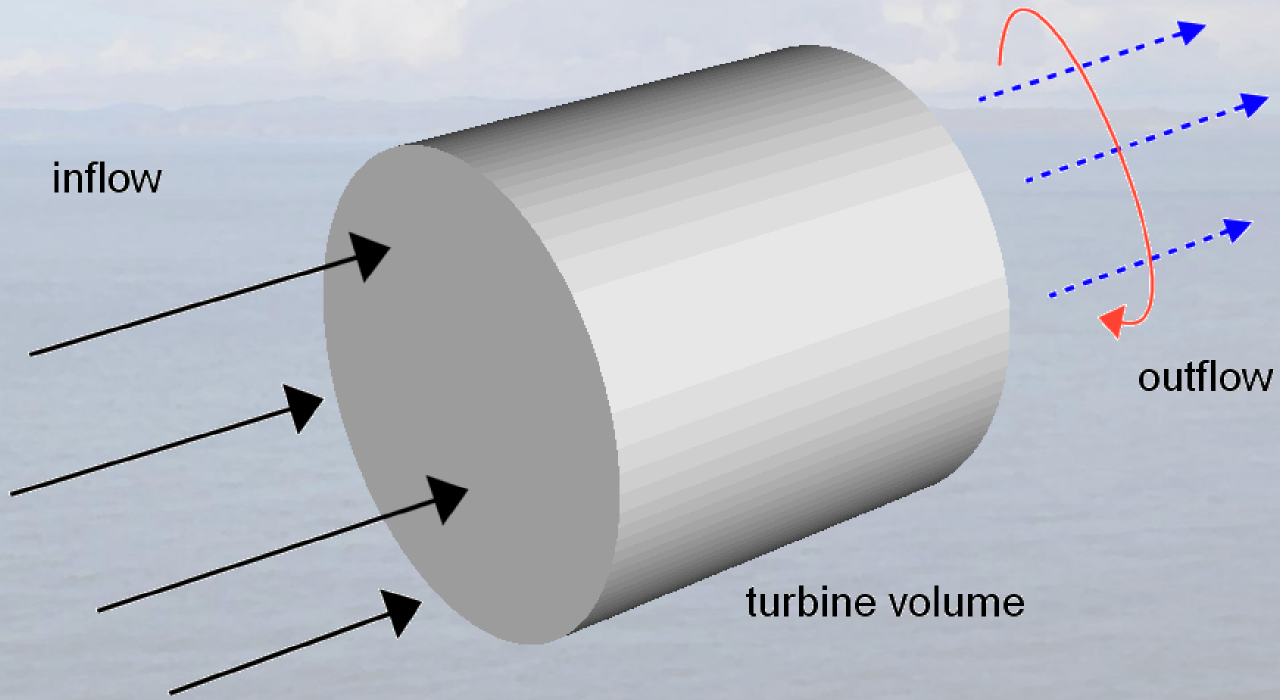
- Wind farm utilisation is on average 30% of rated power
- Graph shows % efficiency increase v. annual savings for farm
- Accurate farm modelling allows for better planning
- And for marine turbine farms?

Improvement in wind farm efficiency vs. annual additional profit



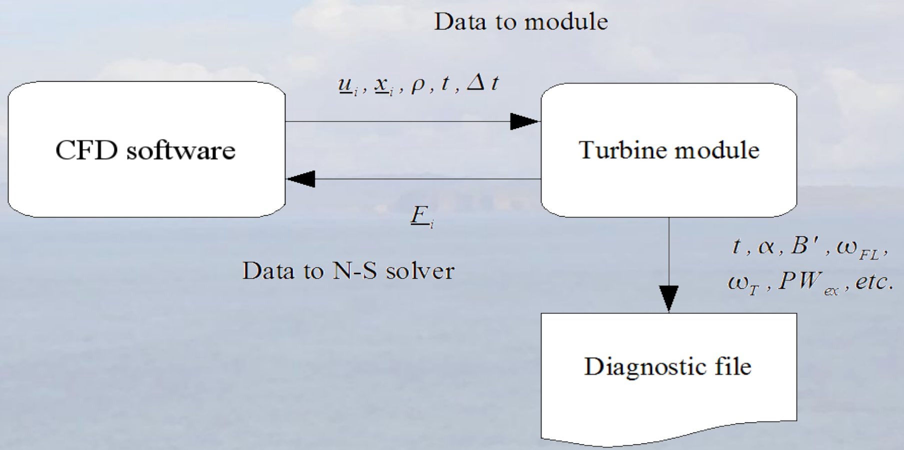
Theory :: model overview

- Cylindrical volume in which body forces act – no boundary conditions
- Uses hybridised blade-element theory



Theory :: model overview (2)

Turbine module uses state-of-the-art computational fluid dynamics (CFD) software to model turbulent flow.

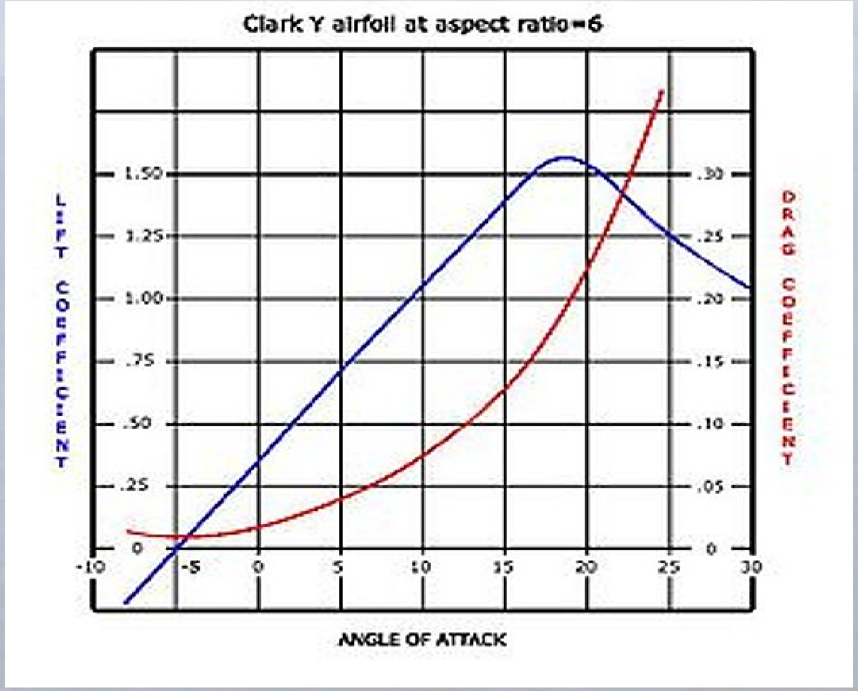


- Turbulence is modelled by large-eddy simulation
- Bathymetry and bottom drag can be added
- Free surfaces are possible
- Large simulations – scalable to thousands of cores

Theory :: parameterisation

To parameterise the turbine, need:

- Blade geometry and weight distribution
- Lift/drag coefficient graphs



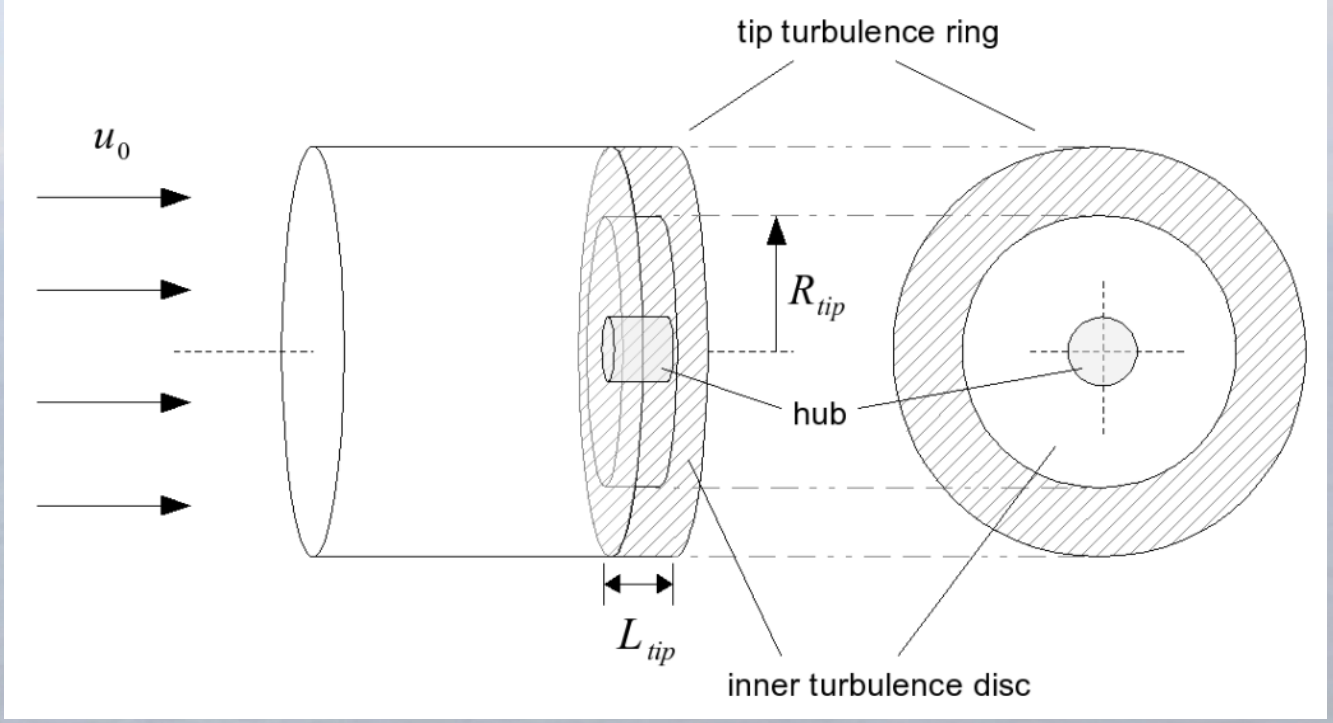
Theory :: turbulence

Generated at end of turbine volume, divided into three sections:

1. **Tip**

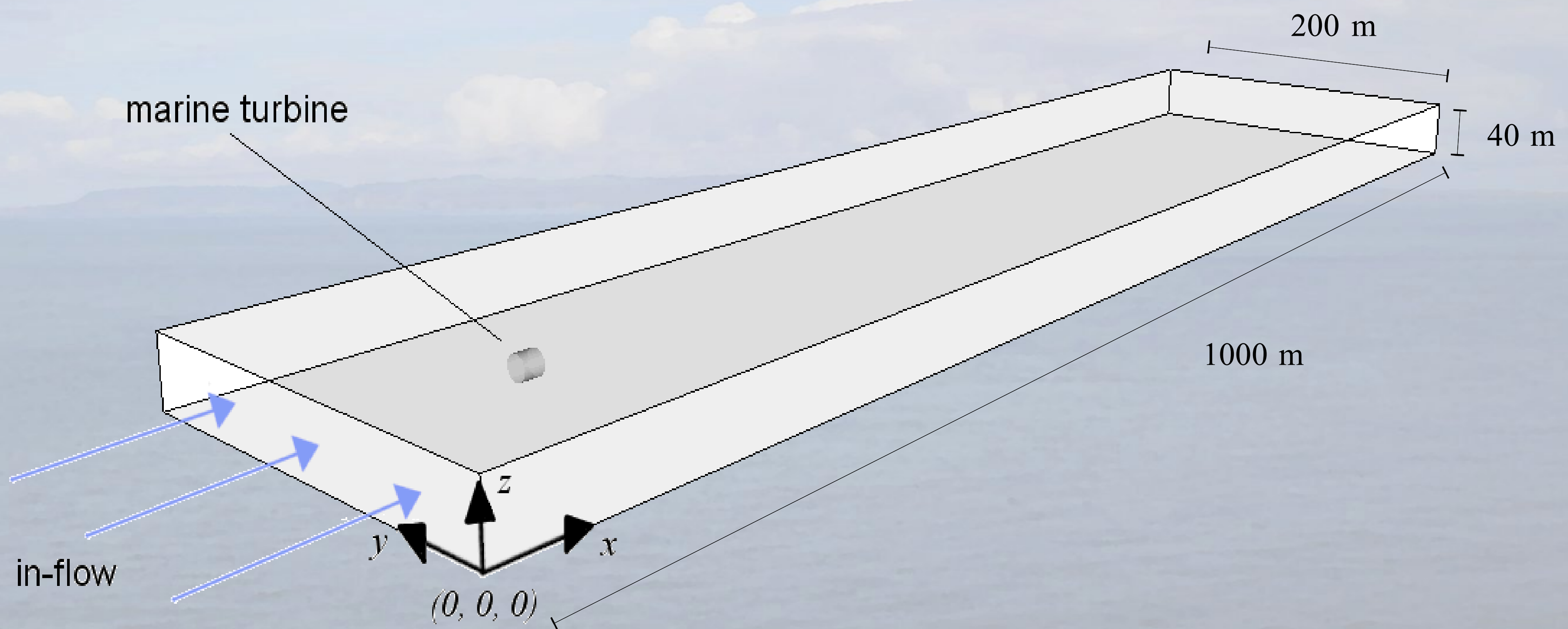
2. **Inner section**

3. **Hub**

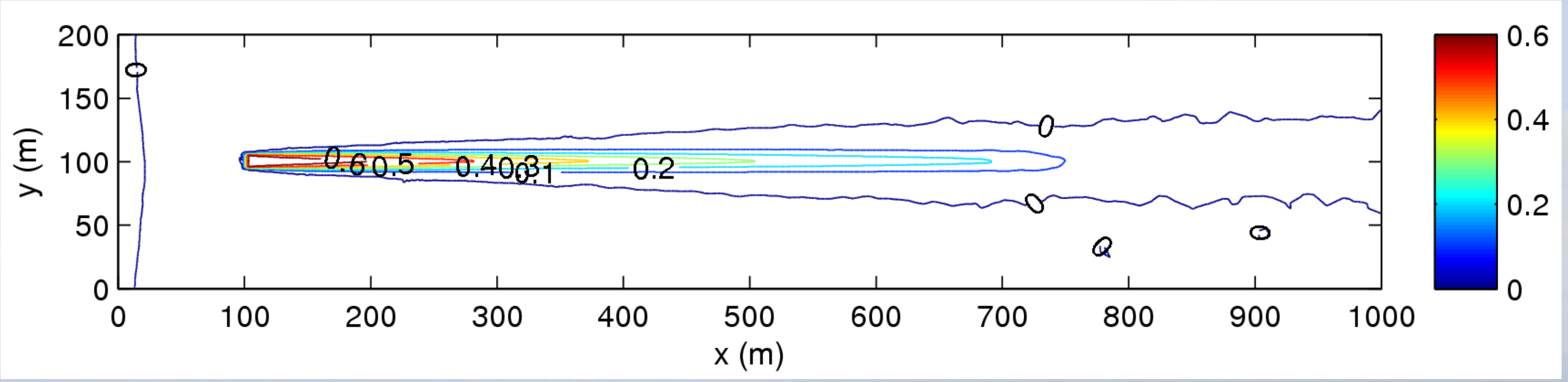


Marine :: water channel

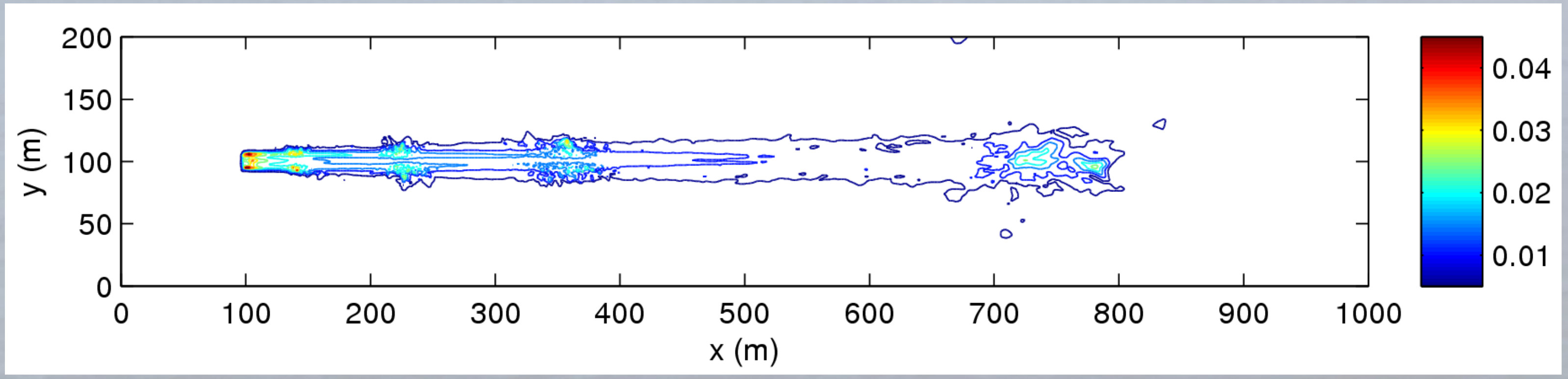
Marine Current Turbine Ltd – Seaflow (300 kW)



Marine :: velocity profile



Turbulence intensity slice calculated over 45 minutes



Marine :: videos

- Bottom drag vertical slice (solid slice here / contours here)
- Bottom drag case horizontal slice (click here)

Validation work

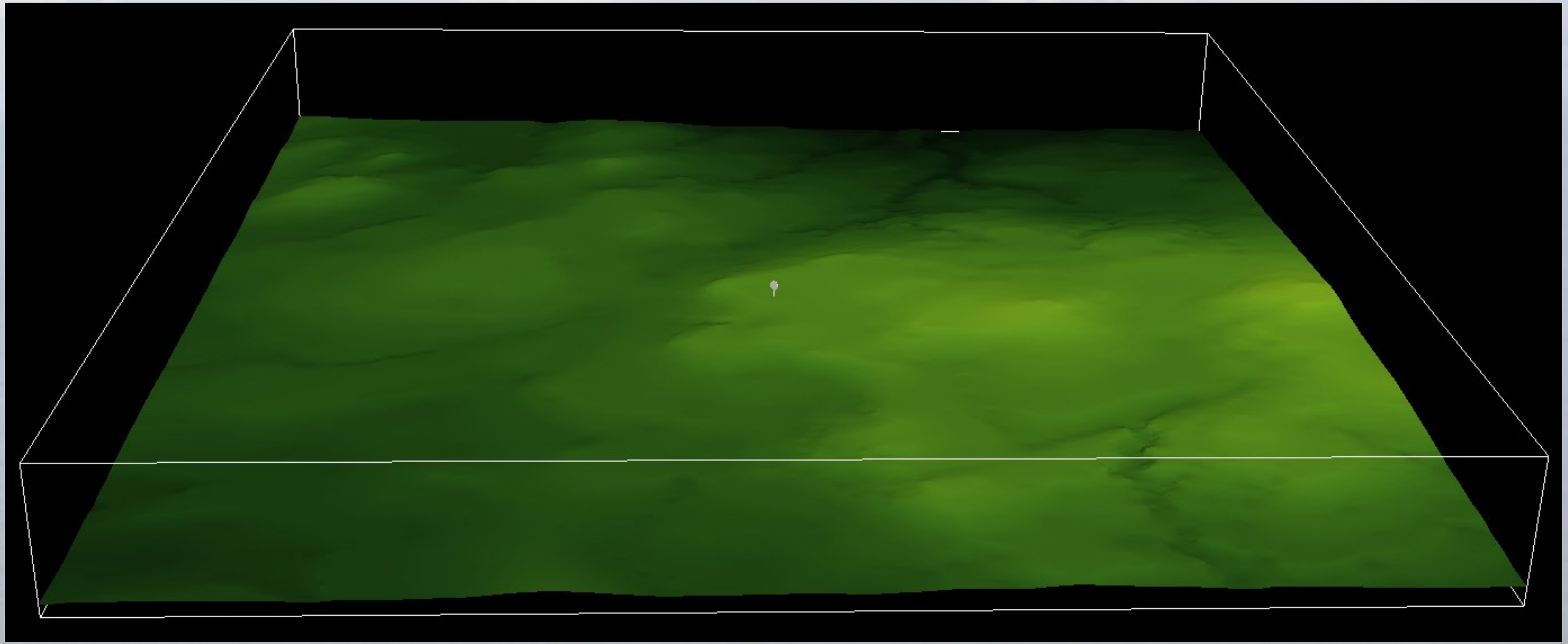
Validation with wind turbines

Joint project with energy company to validate model against real data.

- Site selected with turbine in-situ
- LIDAR site measurements provided for wake comparison
- Ordinance Survey (OS) data used for terrain modelling
- Ground features (trees, grass etc.) added as boundary conditions
- Realistic wind profiles as boundary conditions

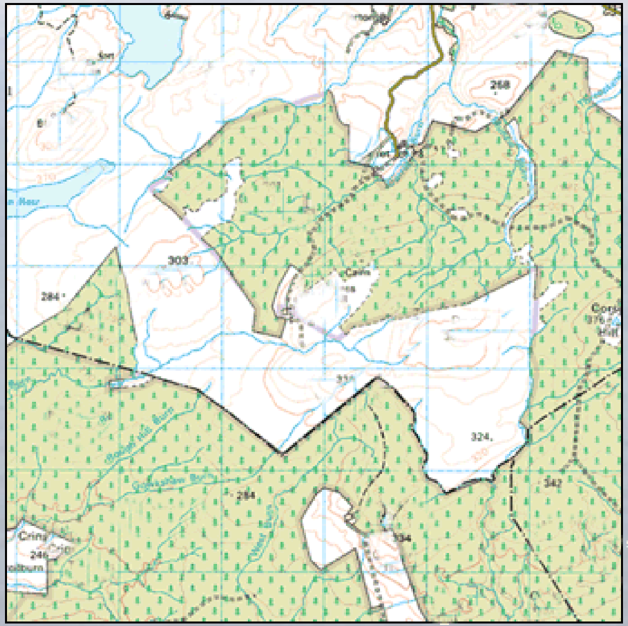
Model overview

- Large simulation domain – 6km x 6km x 750m
- Southwesterly wind at 8 m/s peak (~6 m/s at hub height)
- 950kW turbine at centre of domain, 50m hub height



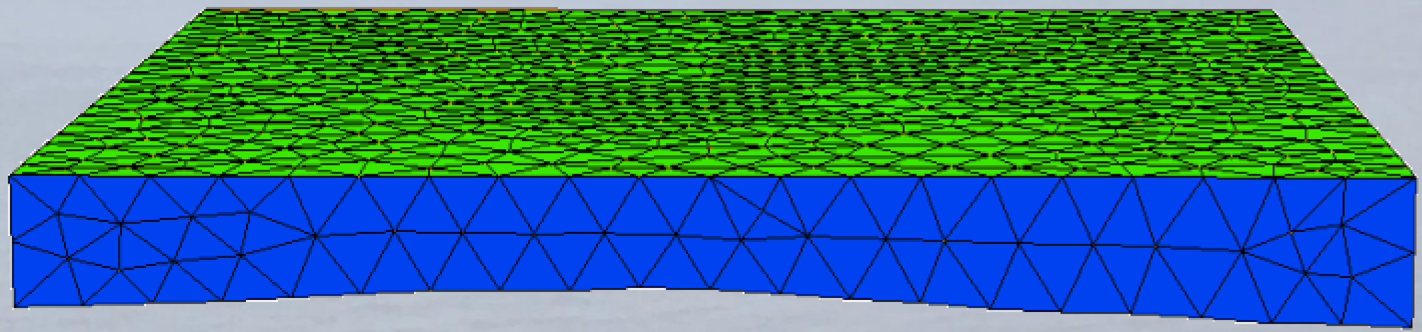
Specification :: ground features

- OS map data provides data on locations of trees, grass, water, etc.
- Graymap overlay converted to drag coefficients, zero-mean displacements and roughness lengths.



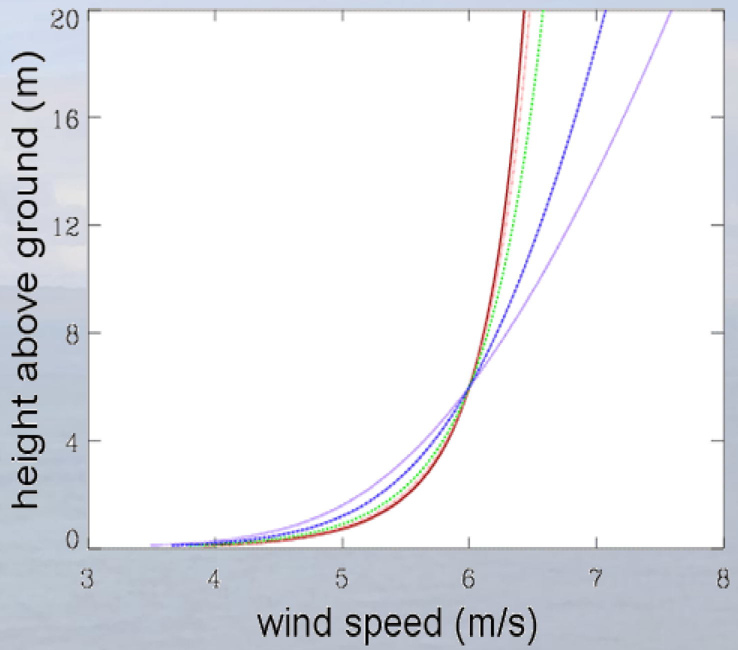
Specification :: land relief

- OS contour data at 10m intervals
- Used to generate height grid
- Finite-element mesh fitted to height grid
- Bottom surface locked to preserve topography



Specification :: boundary conditions

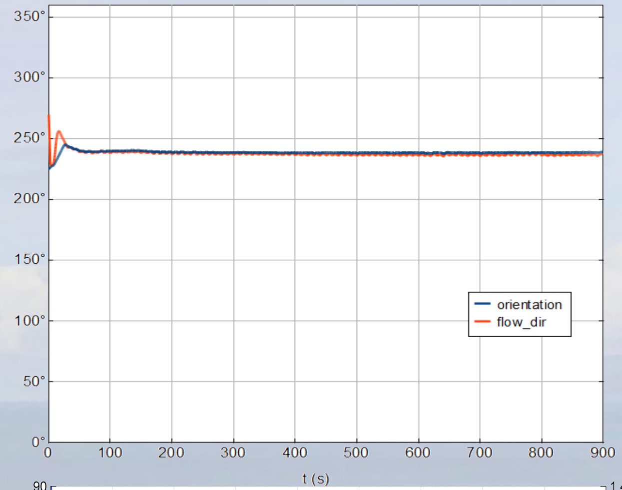
- Log wind speed profile set at boundaries
- Specified wind direction
- In future will use Synthetic Eddy Method with LIDAR turbulence measurements – fully turbulent boundary conditions

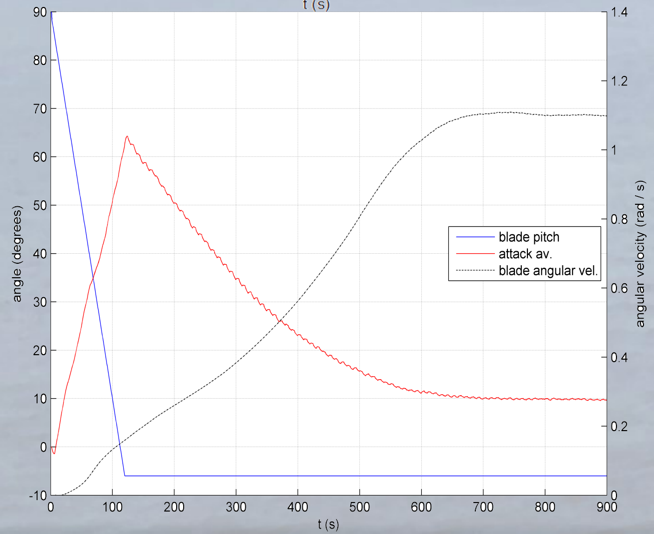


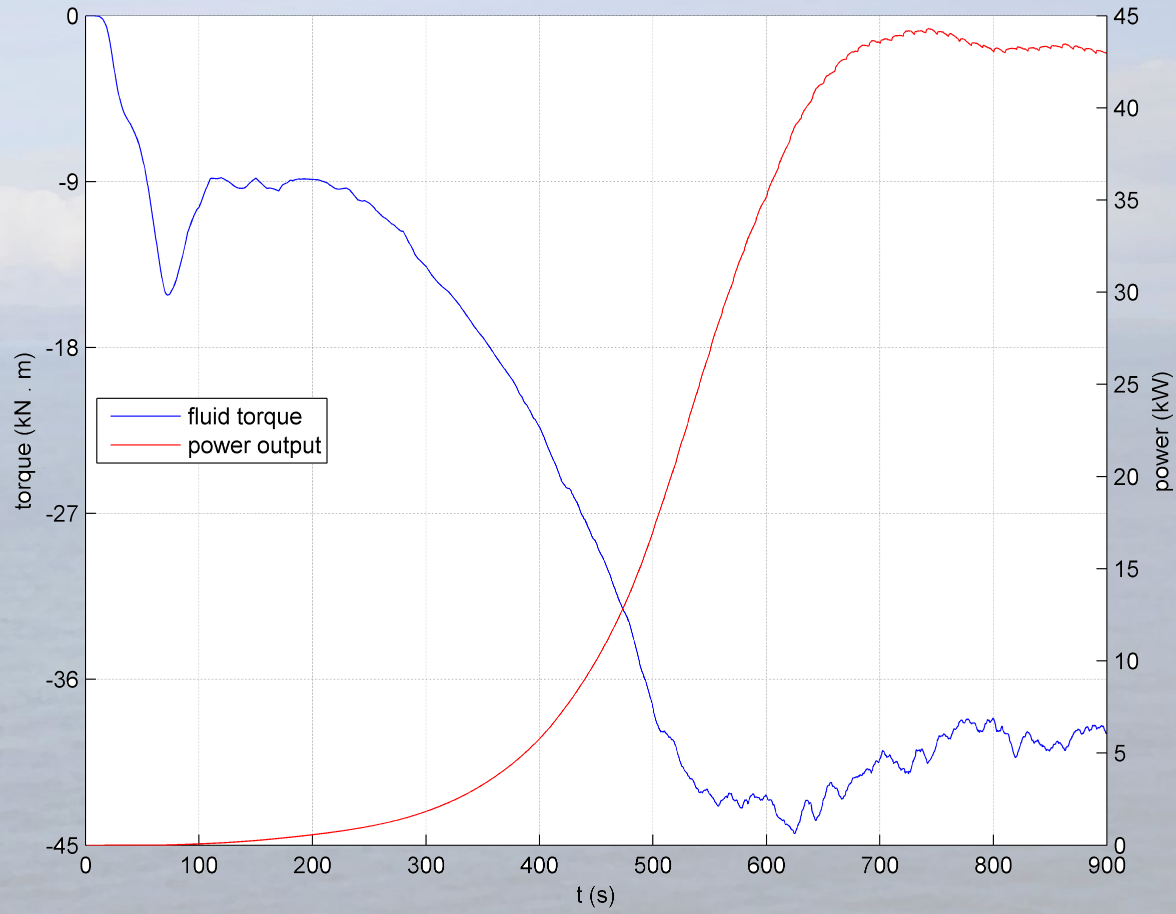
Specification :: turbine parameters

- 950 kW turbine: 54.5m diameter, 50m hub-height
- Lift/drag characteristics taken from NACA data
- Blade geometry (chord length, blade twist) and performance data taken from manufacturer's technical manual

Results :: turbine performance

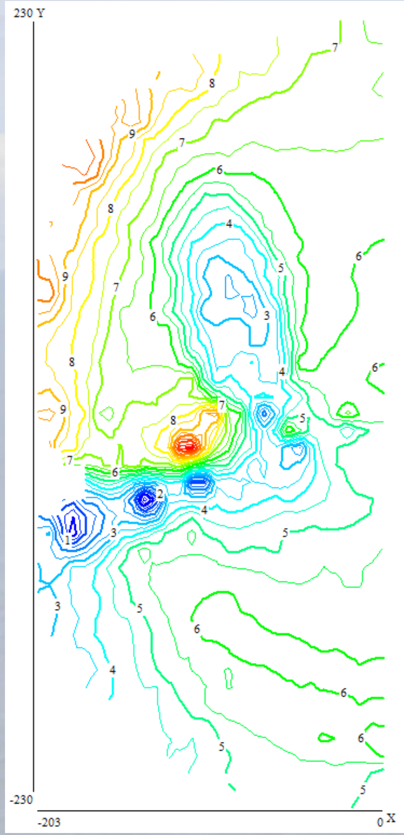


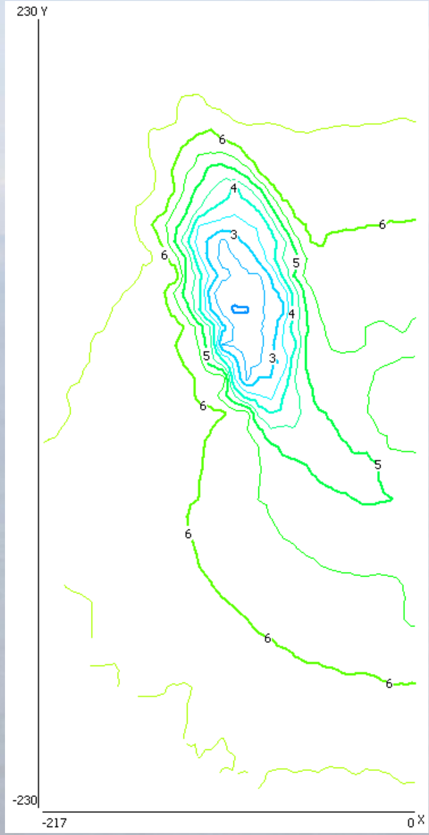


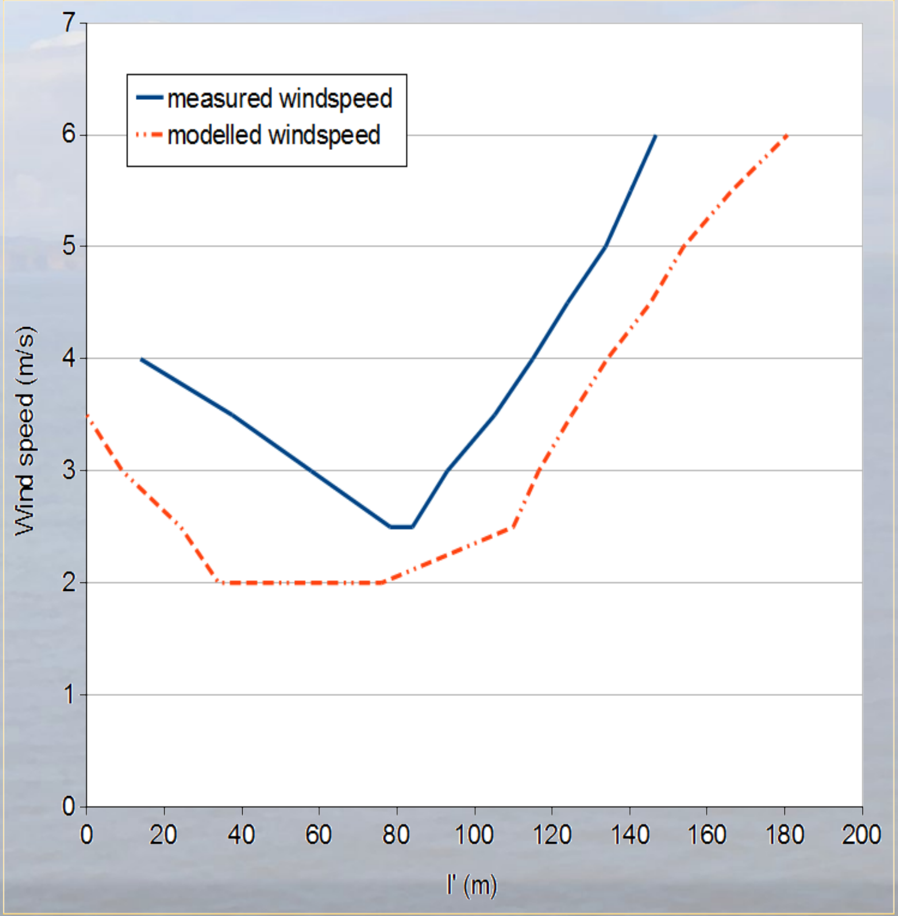


Results :: wake comparison

LIDAR contours Model contours Wake profiles

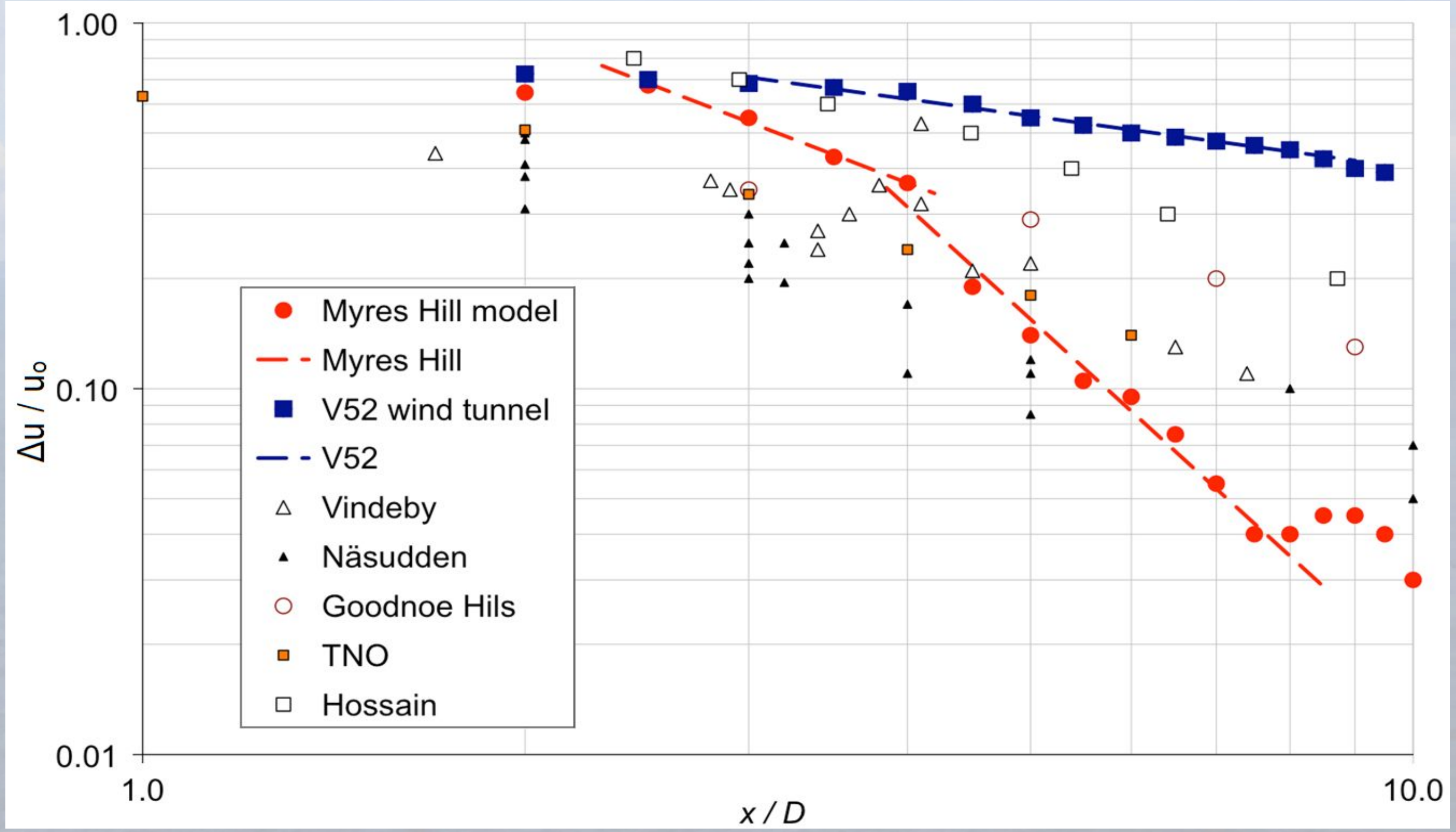




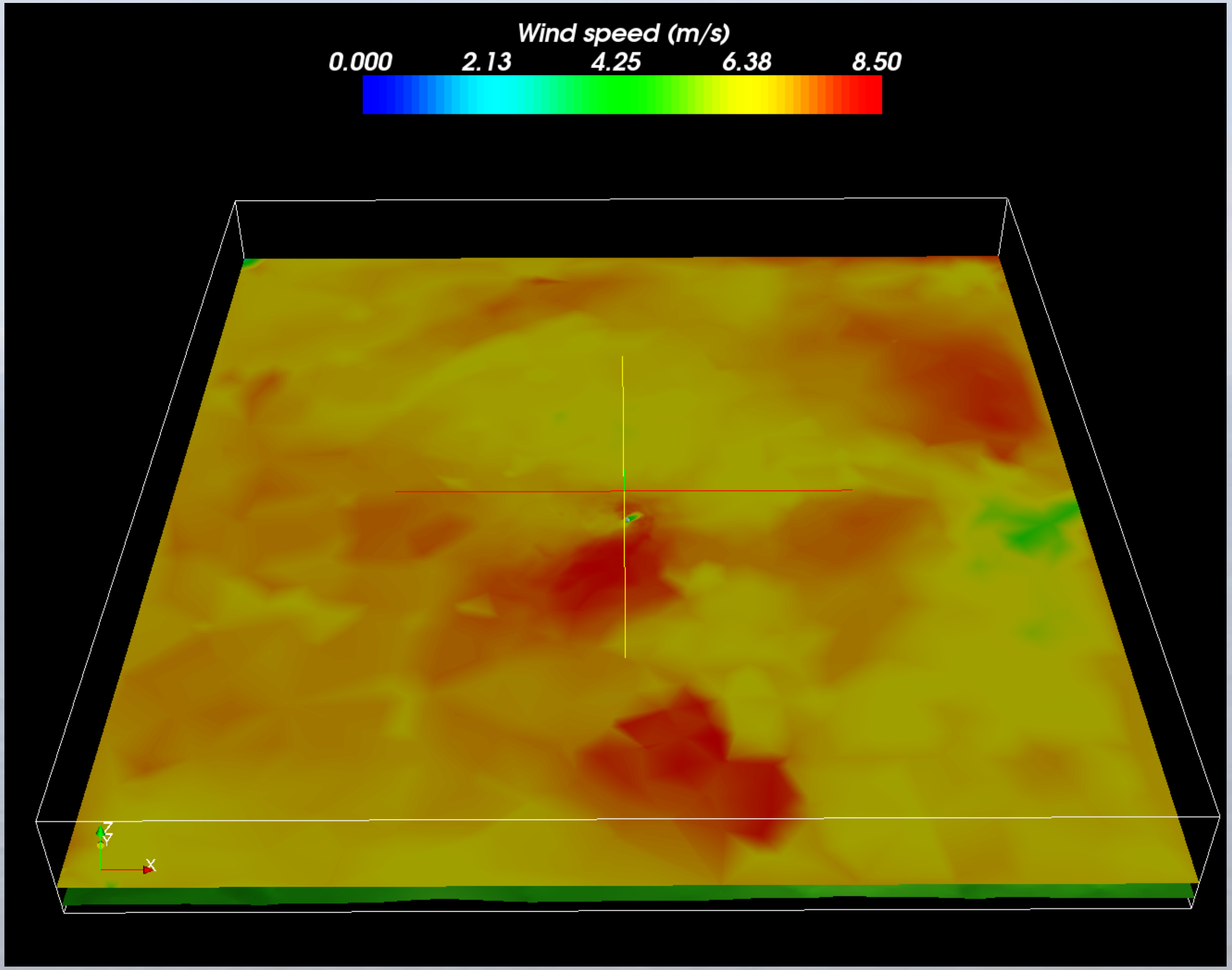


Results :: wake comparison (2)

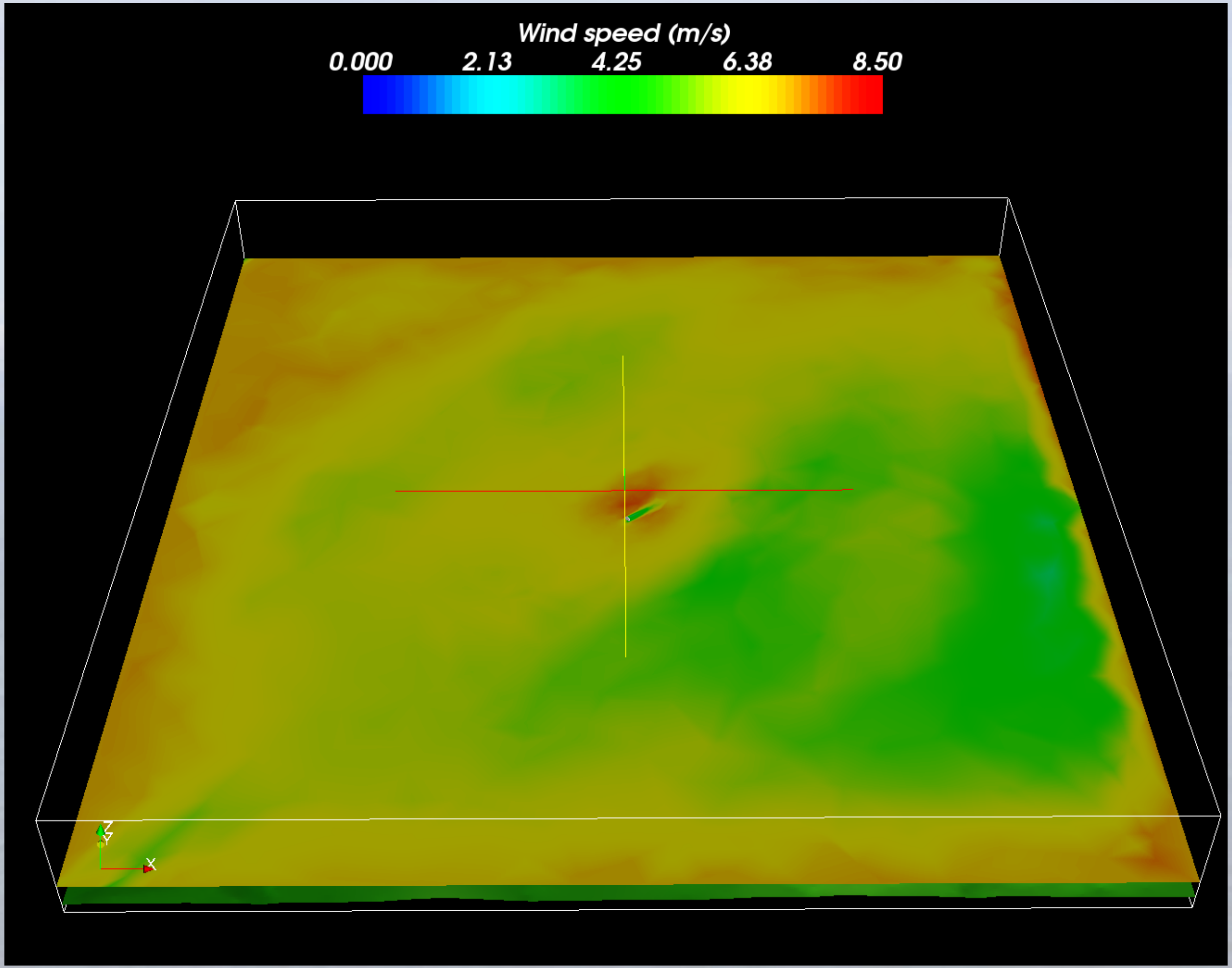
- Wake deficit comparison with other sites (Creech et al, 2010)



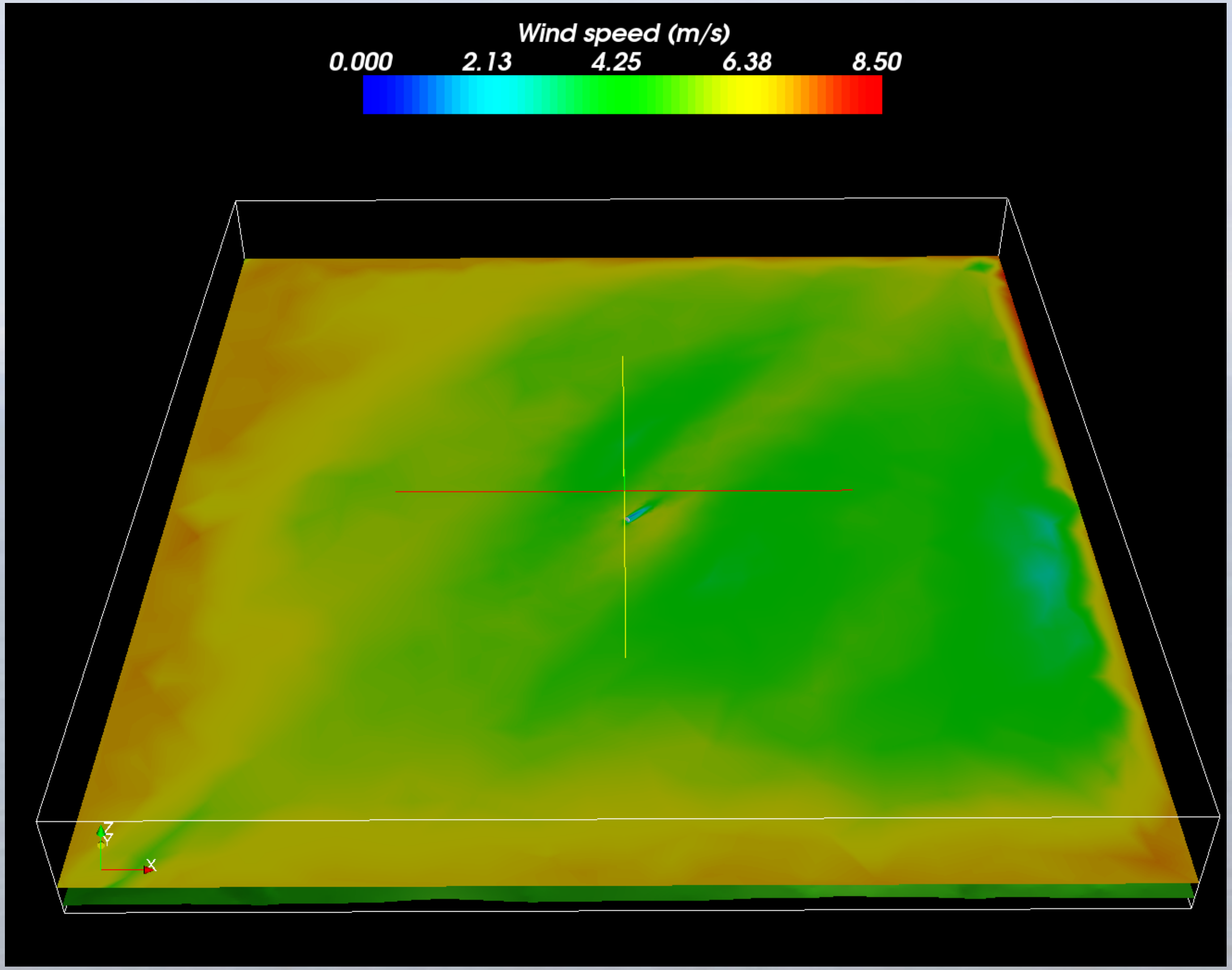
Results :: horizontal slice at t=60s



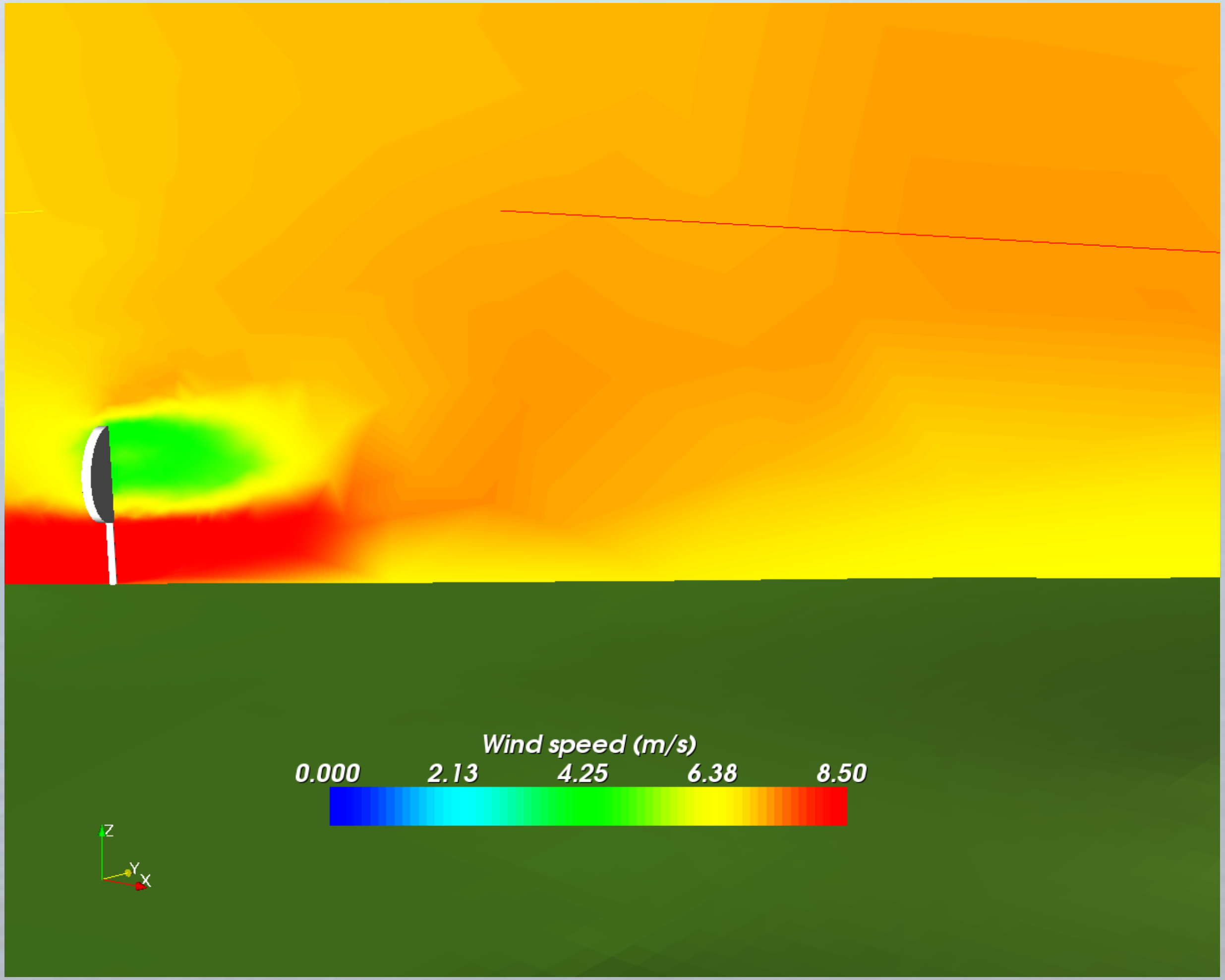
Results :: horizontal slice at t=300s



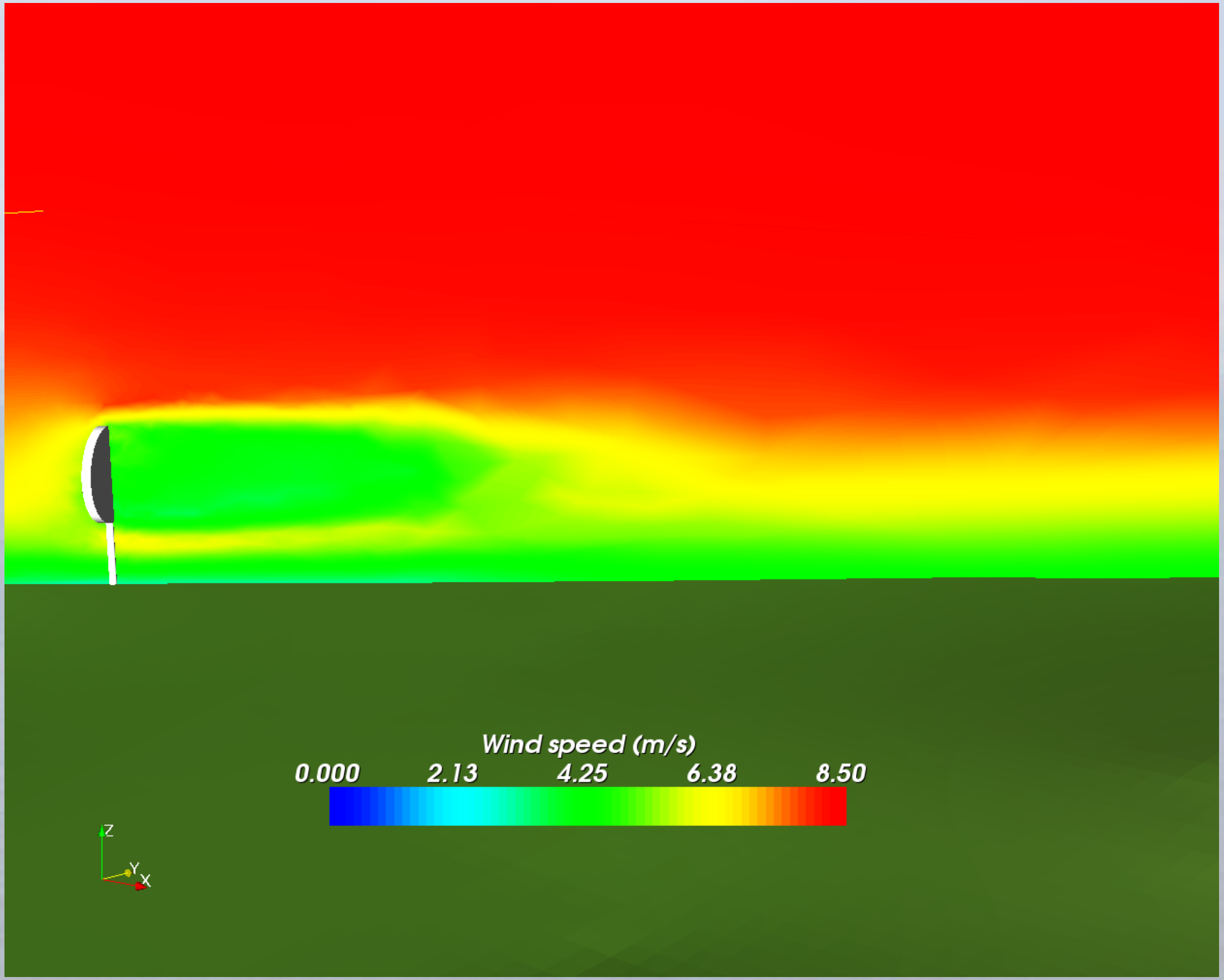
Results :: horizontal slice at t=300s



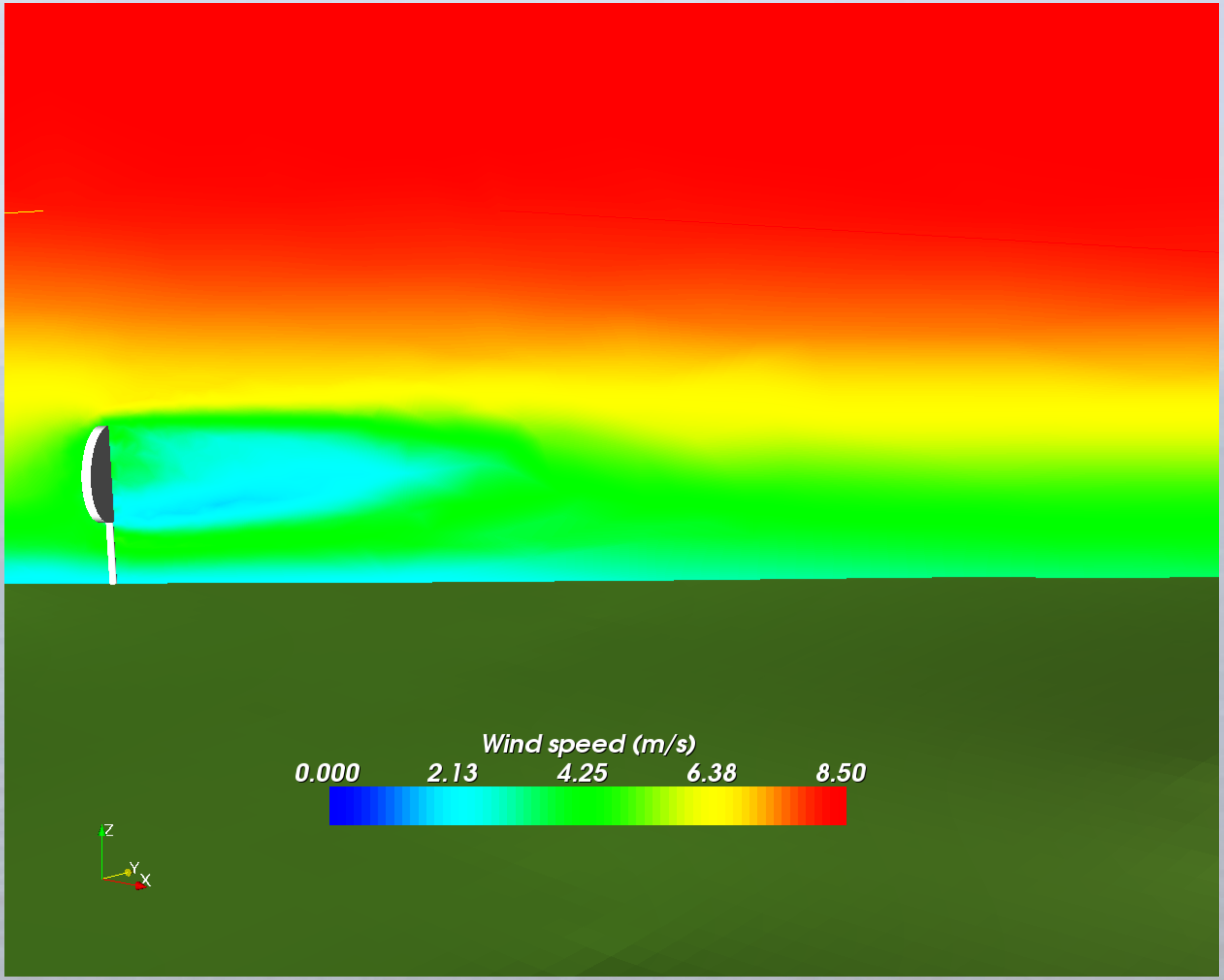
Results :: vertical slice at t=60s



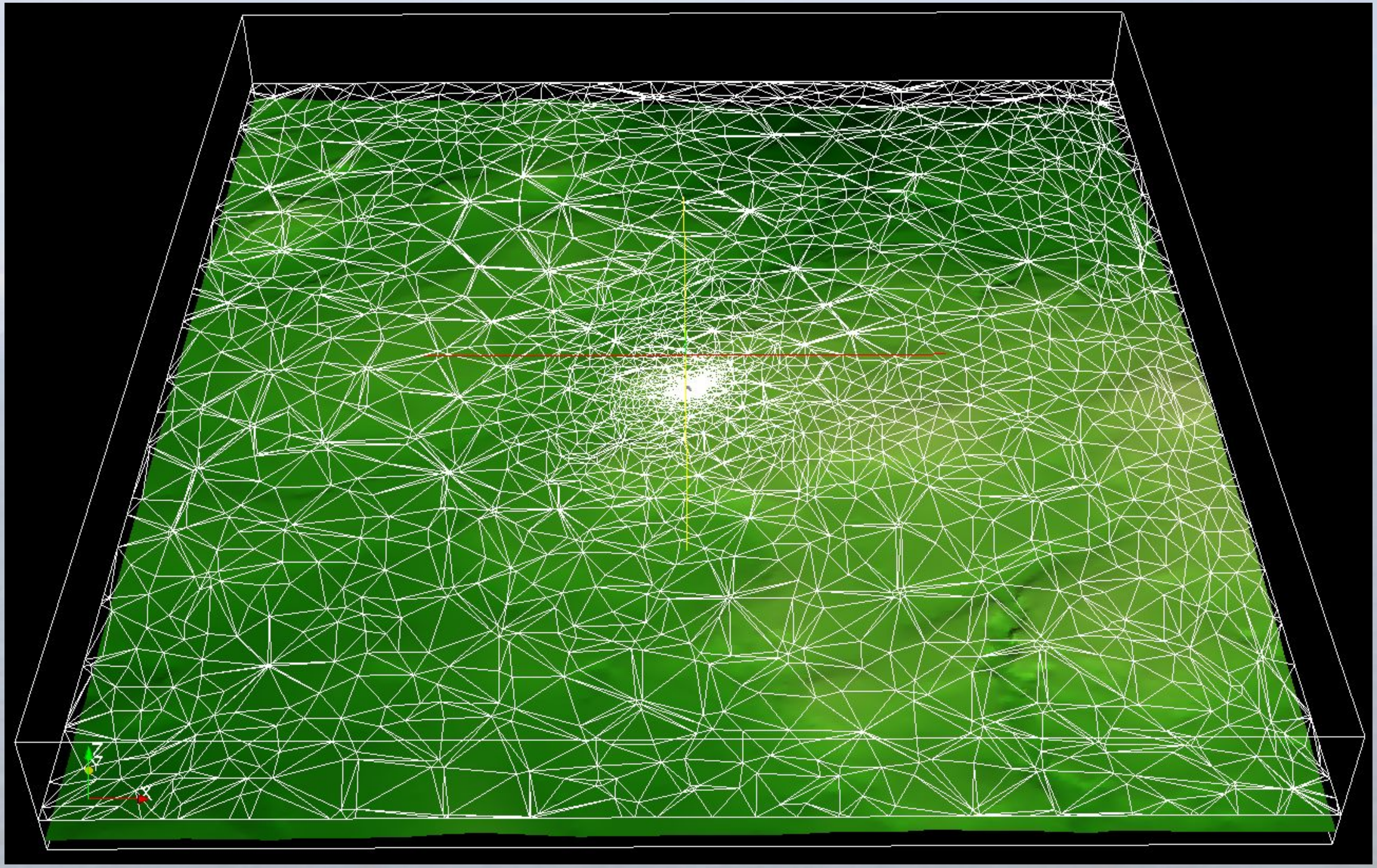
Results :: vertical slice at t=300s



Results :: vertical slice at t=900s



Results :: mesh view at t=300s



Videos

- Vertical slice:
  - whole model, looking NW (click here)
  - zoomed view (click here)
  - contour plot (click here)
- Horizontal slice
  - Zoomed contour plot (click here)

Model summary

Model can simulate:

- Wind or tidal flow over large areas with land relief or seafloor
- Response of multiple turbines to wind or marine currents *and* the up/downstream wake effects
- Transport of 'tracer' properties of fluid

Model provides:

- Per-timestep 3D data set for velocity, pressure, tracer concentrations
- Per-timestep performance data for each turbine
- Time-averaged velocity plots and turbulence plots

Future plans

- Modelling of performance and wakes in small farm configurations
- Validation of marine/wind farm modelling with wake and performance measurments
- Feeding into a virtual grid? Modelling actual electrical supply over typical periods – additional expertise required
- Utilisation as a planning tool: small-scale test cases required

End