Validation of a CFD model with a triple-lidar system upstream of a wind turbine in complex terrain

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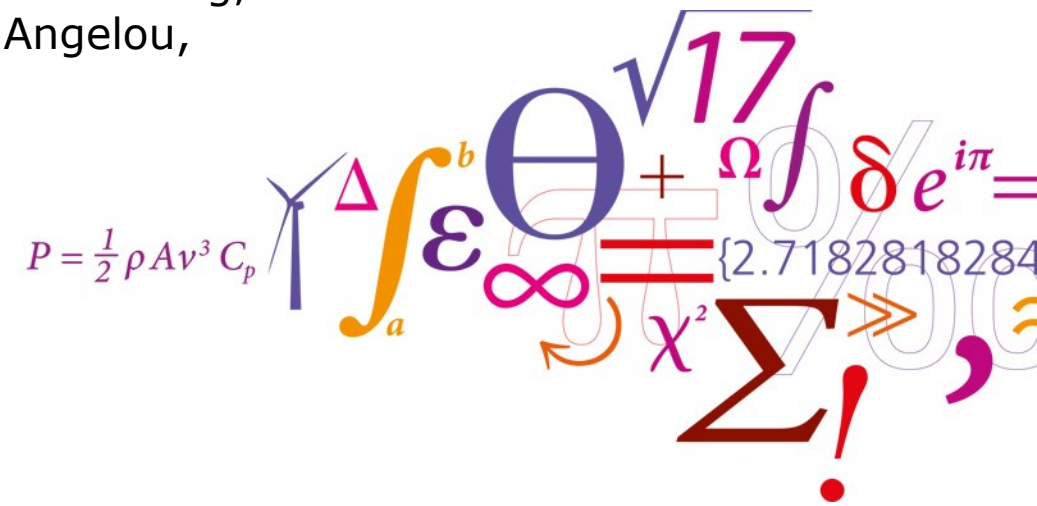
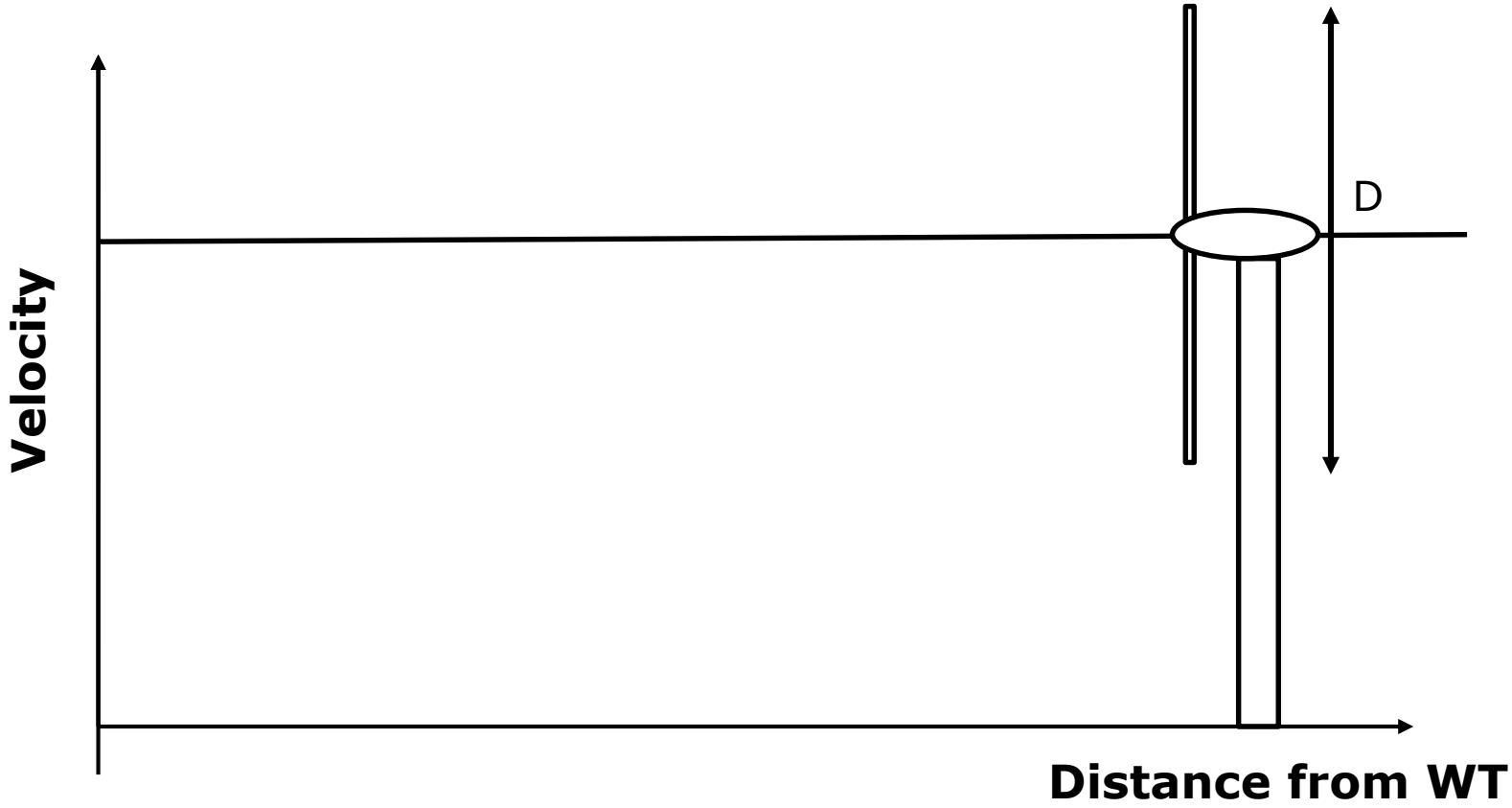


DTU Wind Energy
Department of Wind Energy

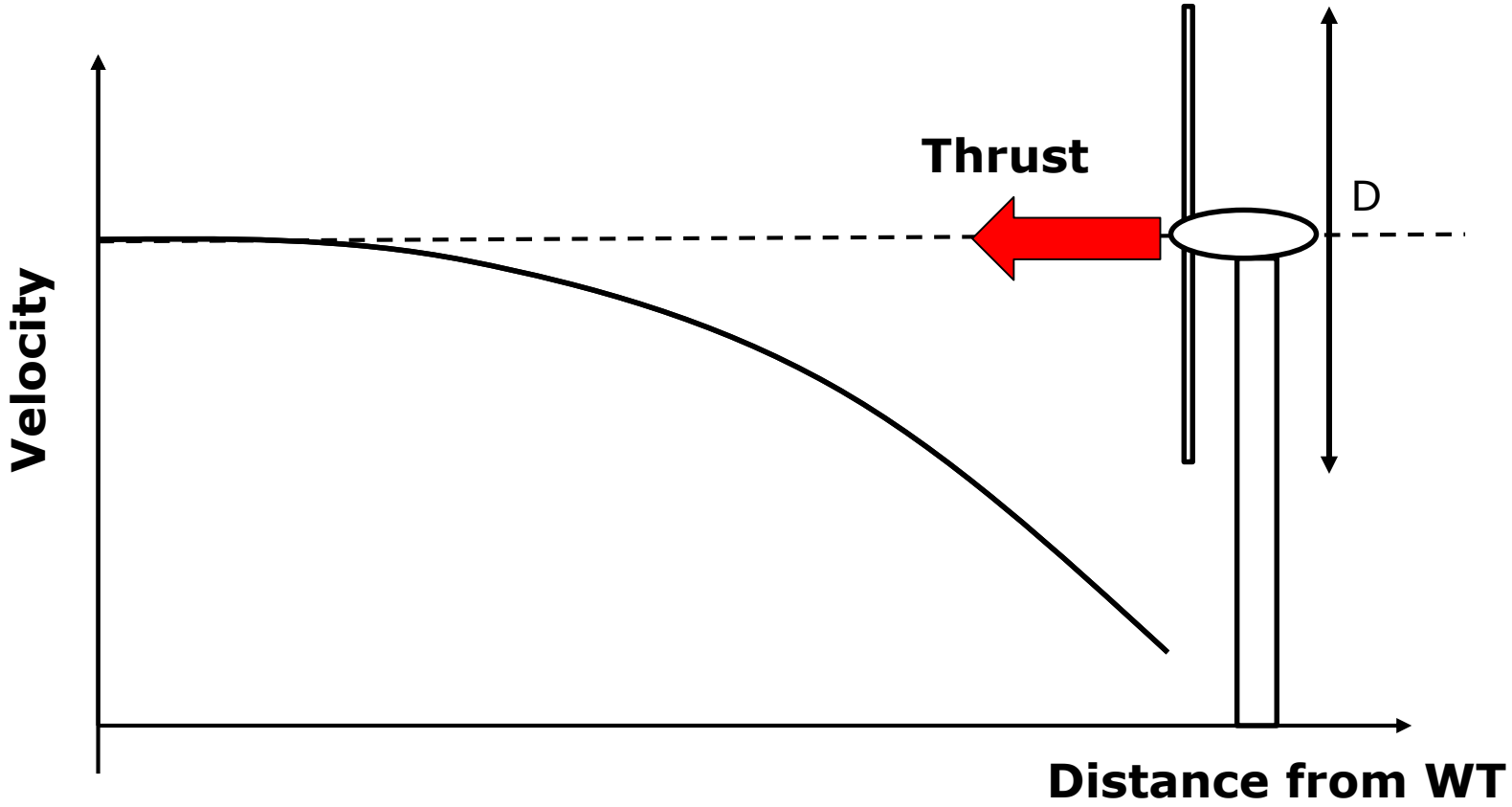
Overview

- The induction zone
- Power curve measurements
- Computational method
- CFD simulations
- Triple-lidar measurements in the induction zone
- CFD – measurement comparison
- Conclusion
- Future work

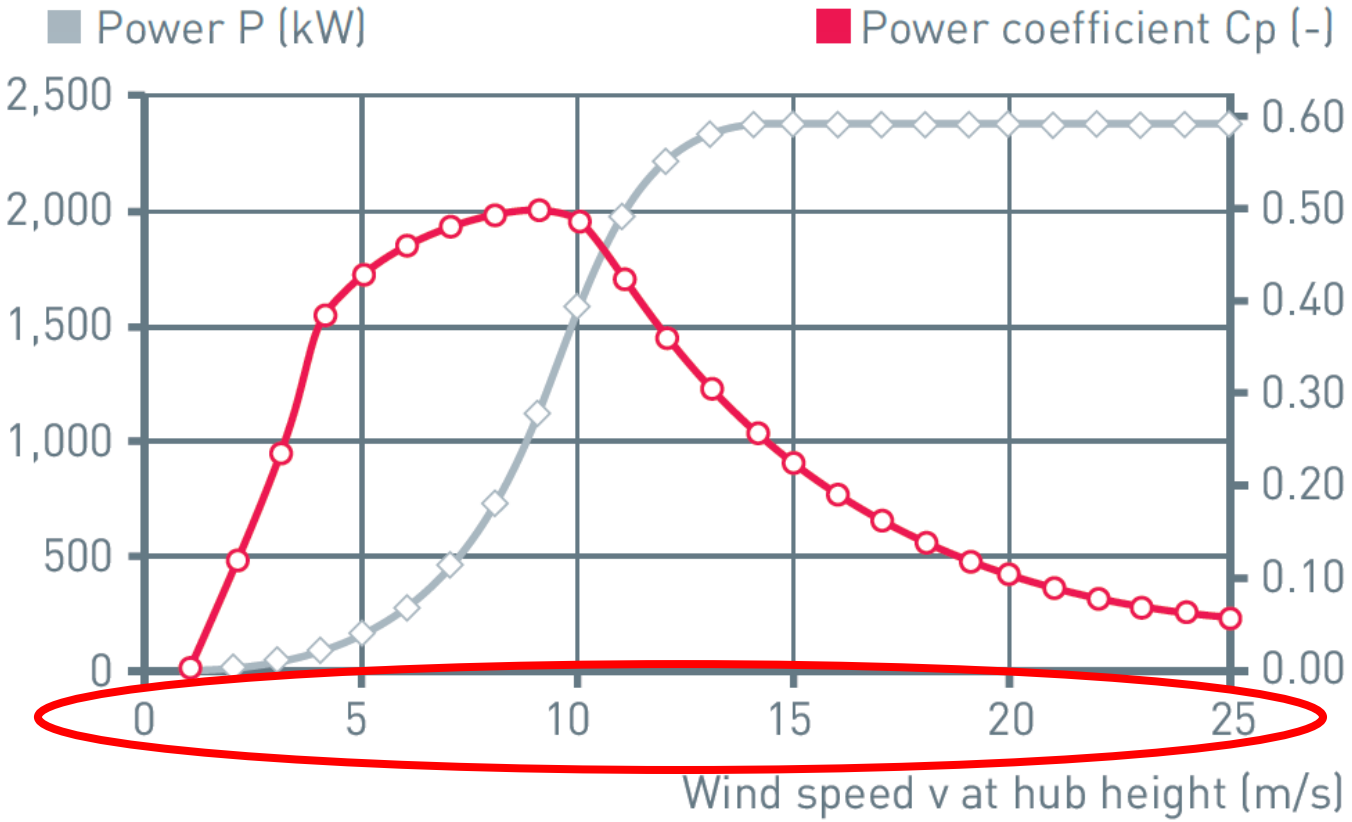
The induction zone



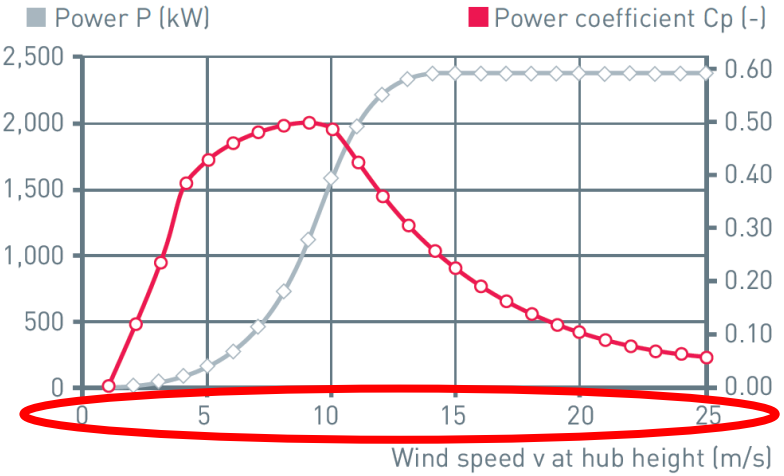
The induction zone

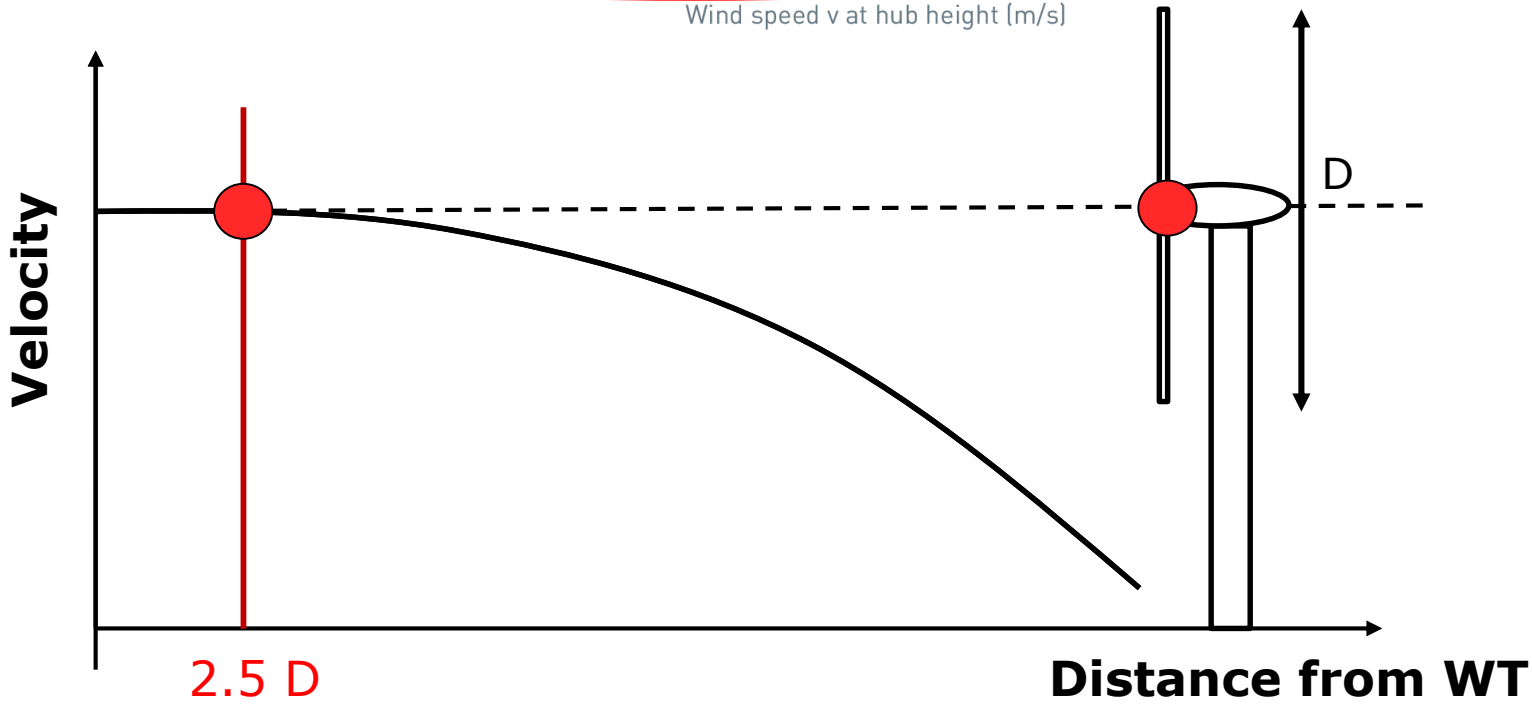


Power curve measurements

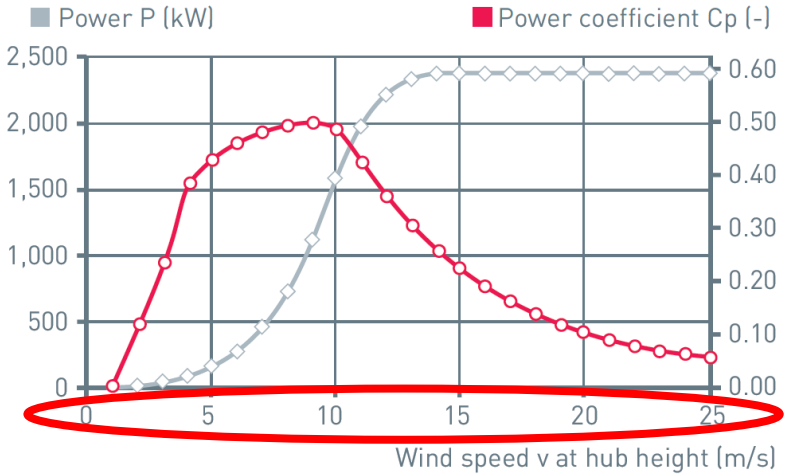


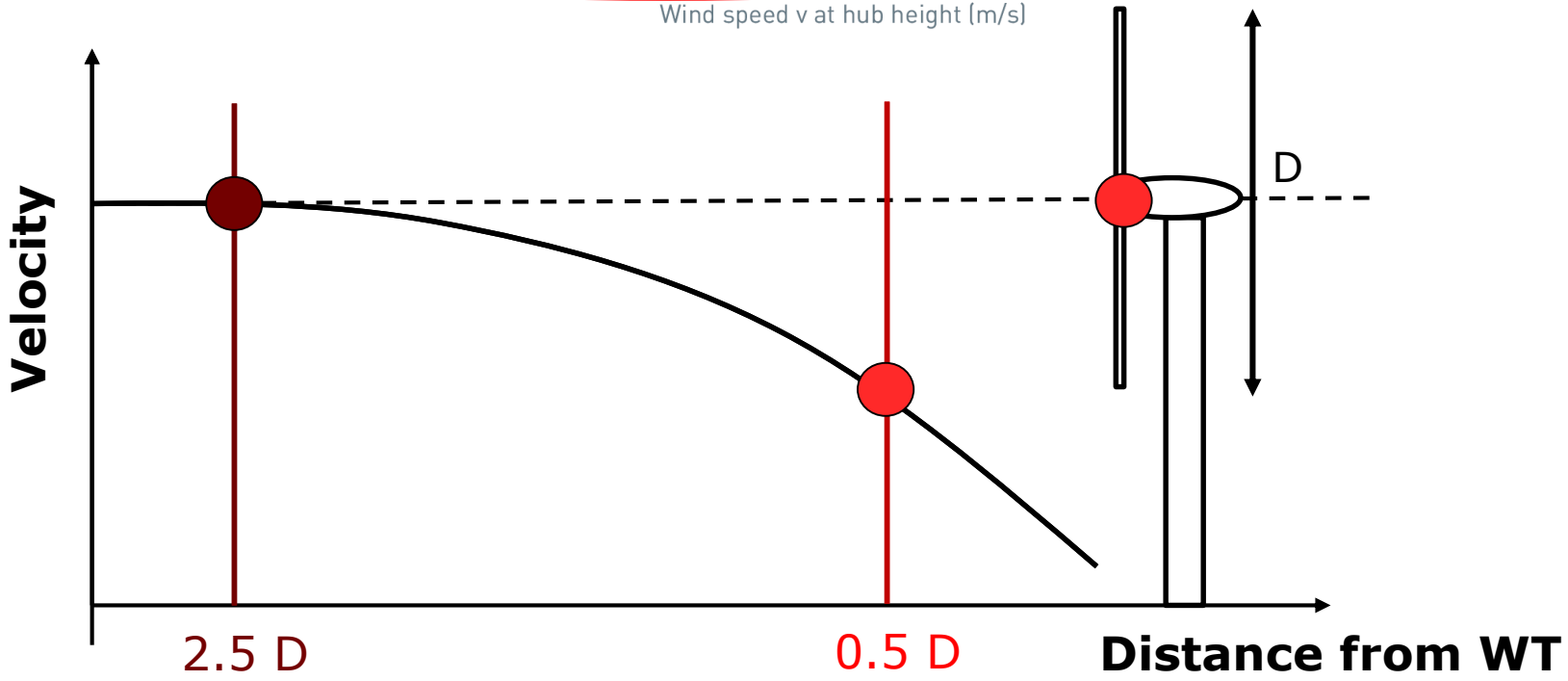
Power curve measurements



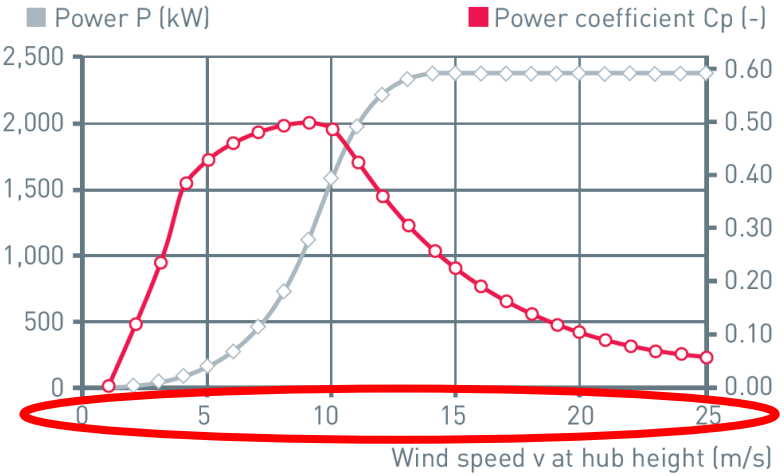


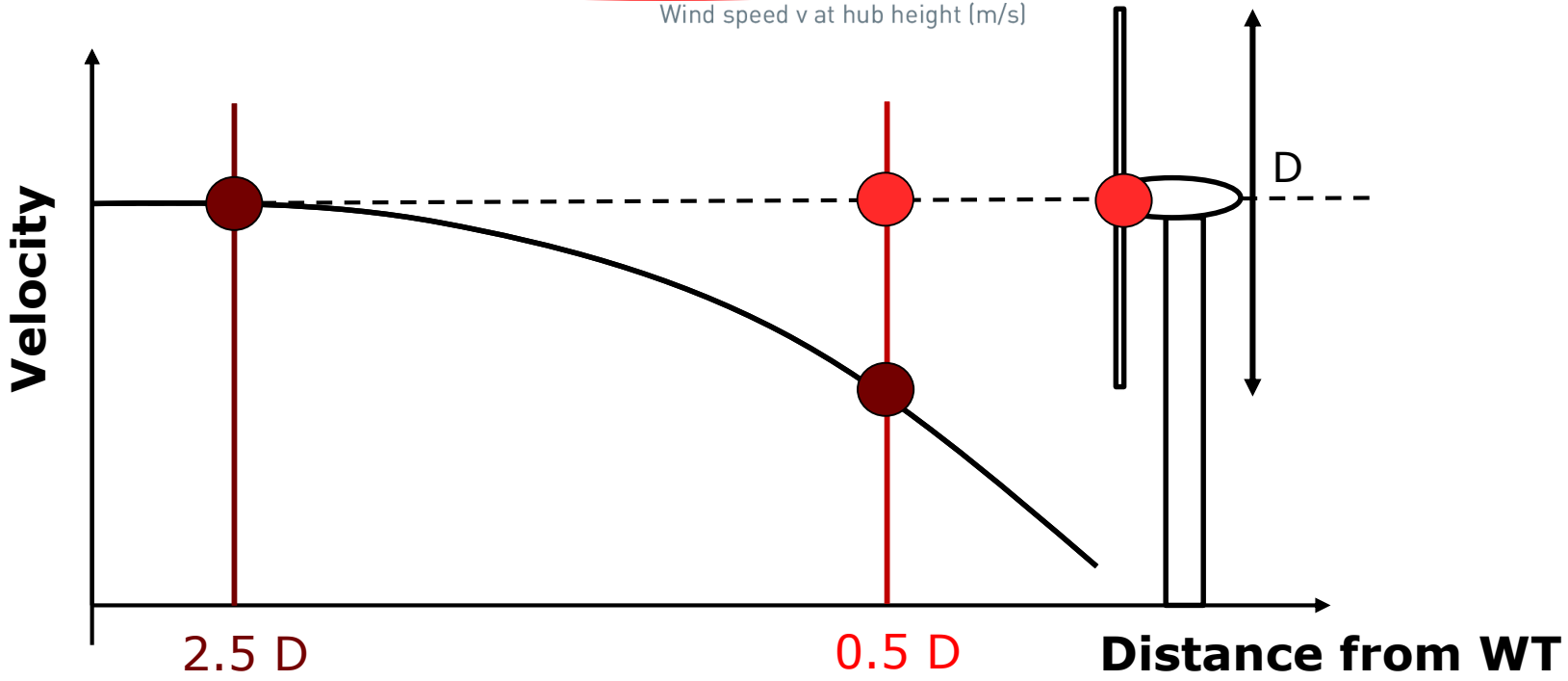
Power curve measurements



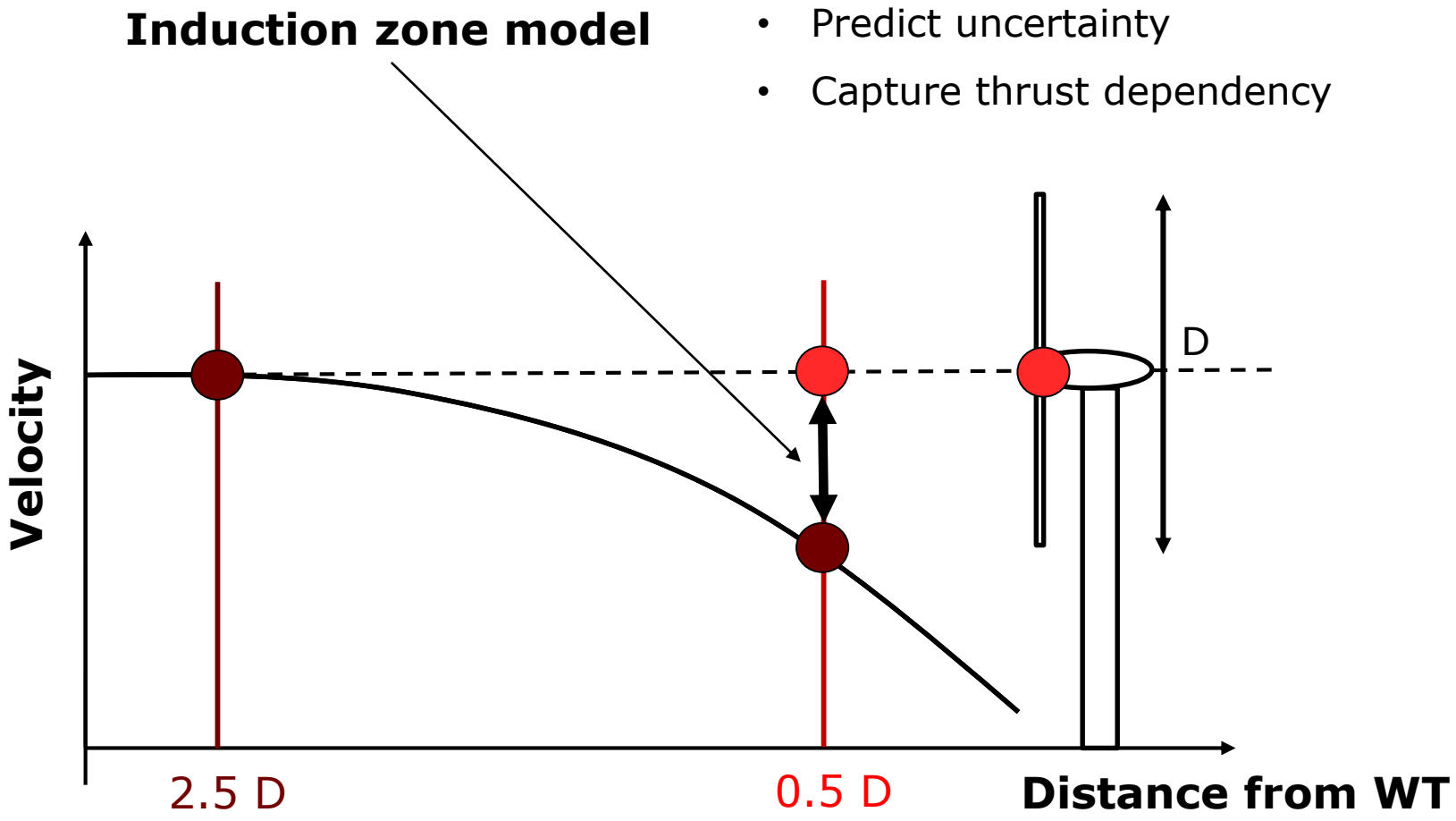


Power curve measurements

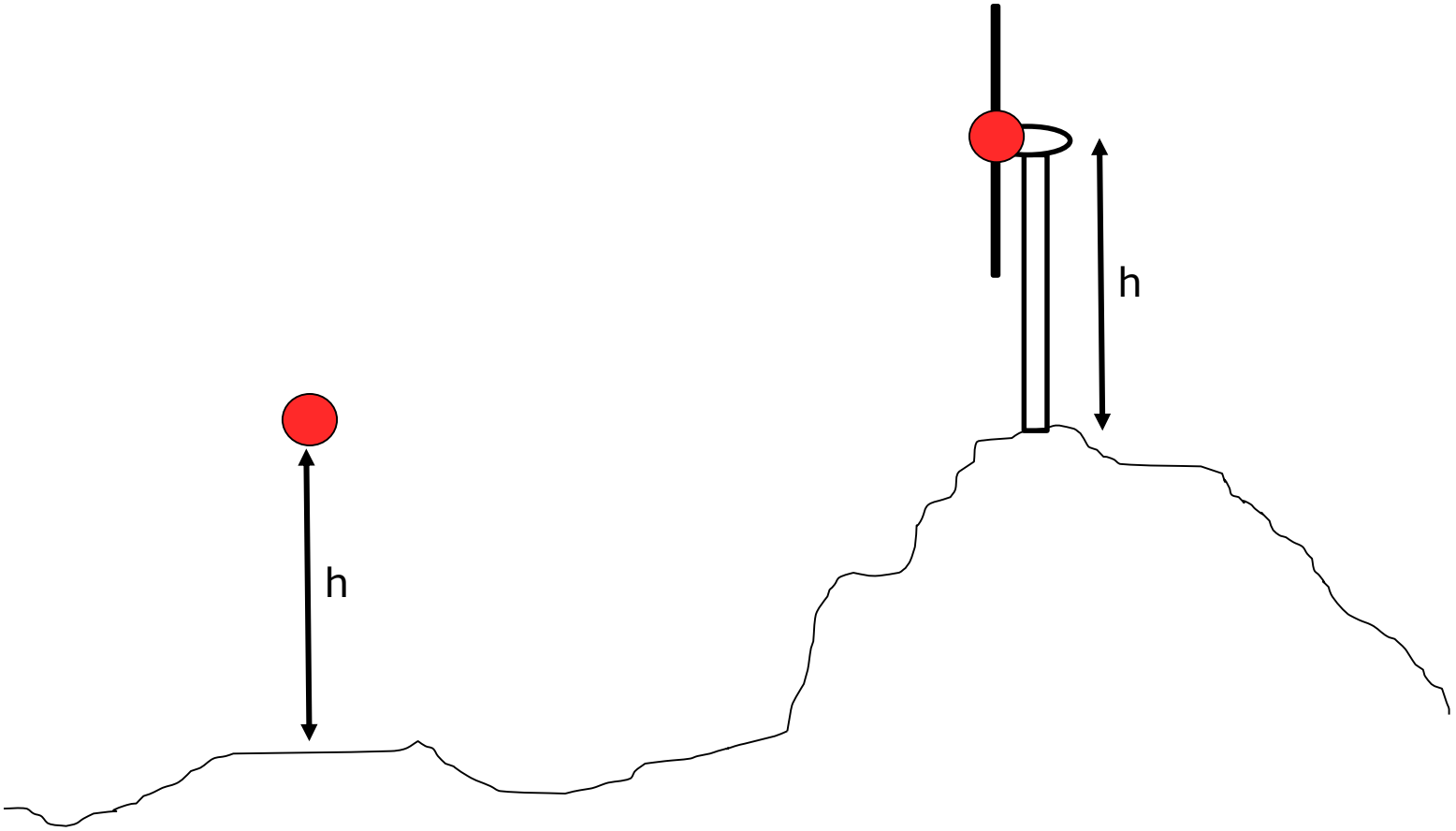




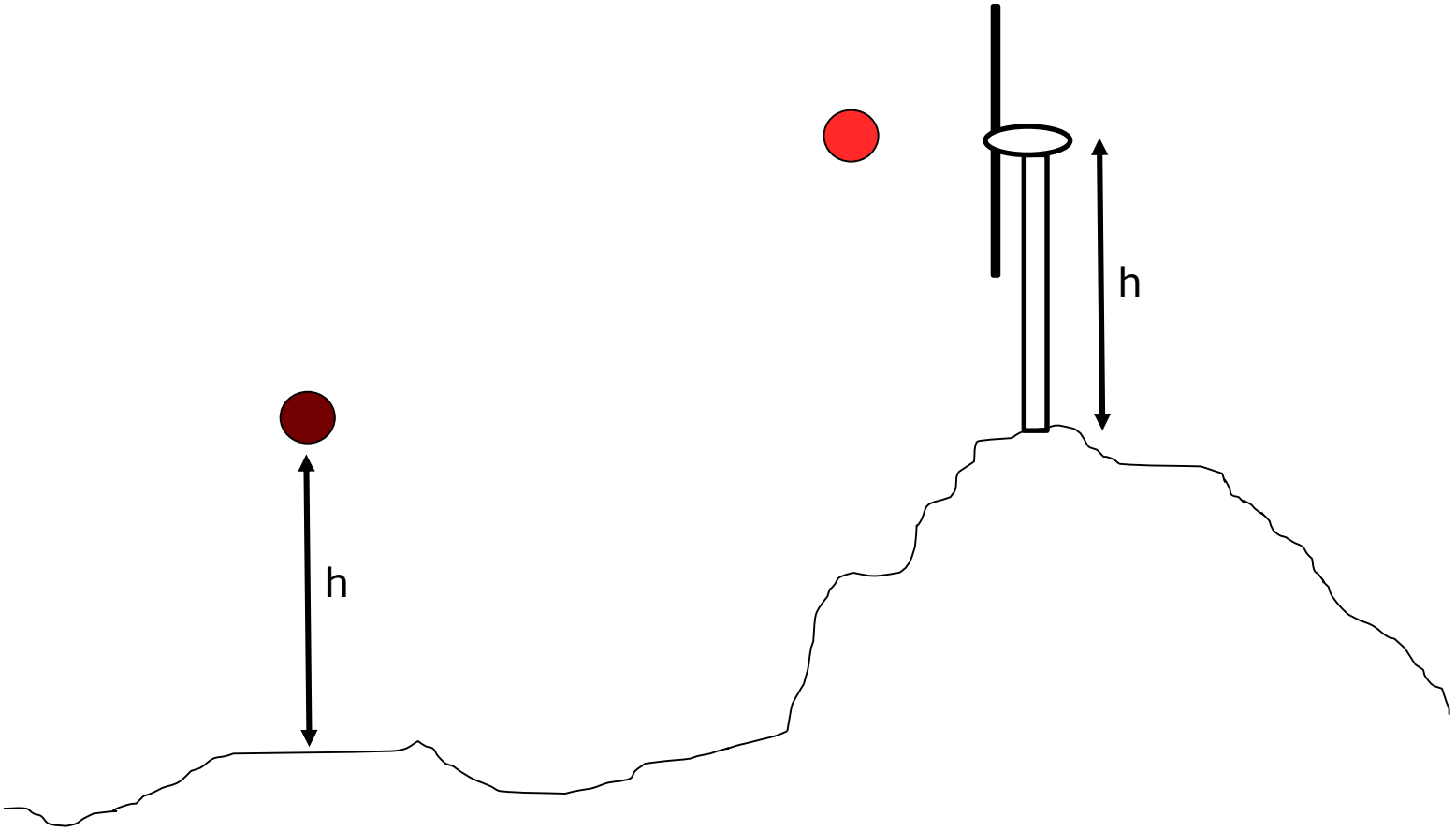
Power curve measurements



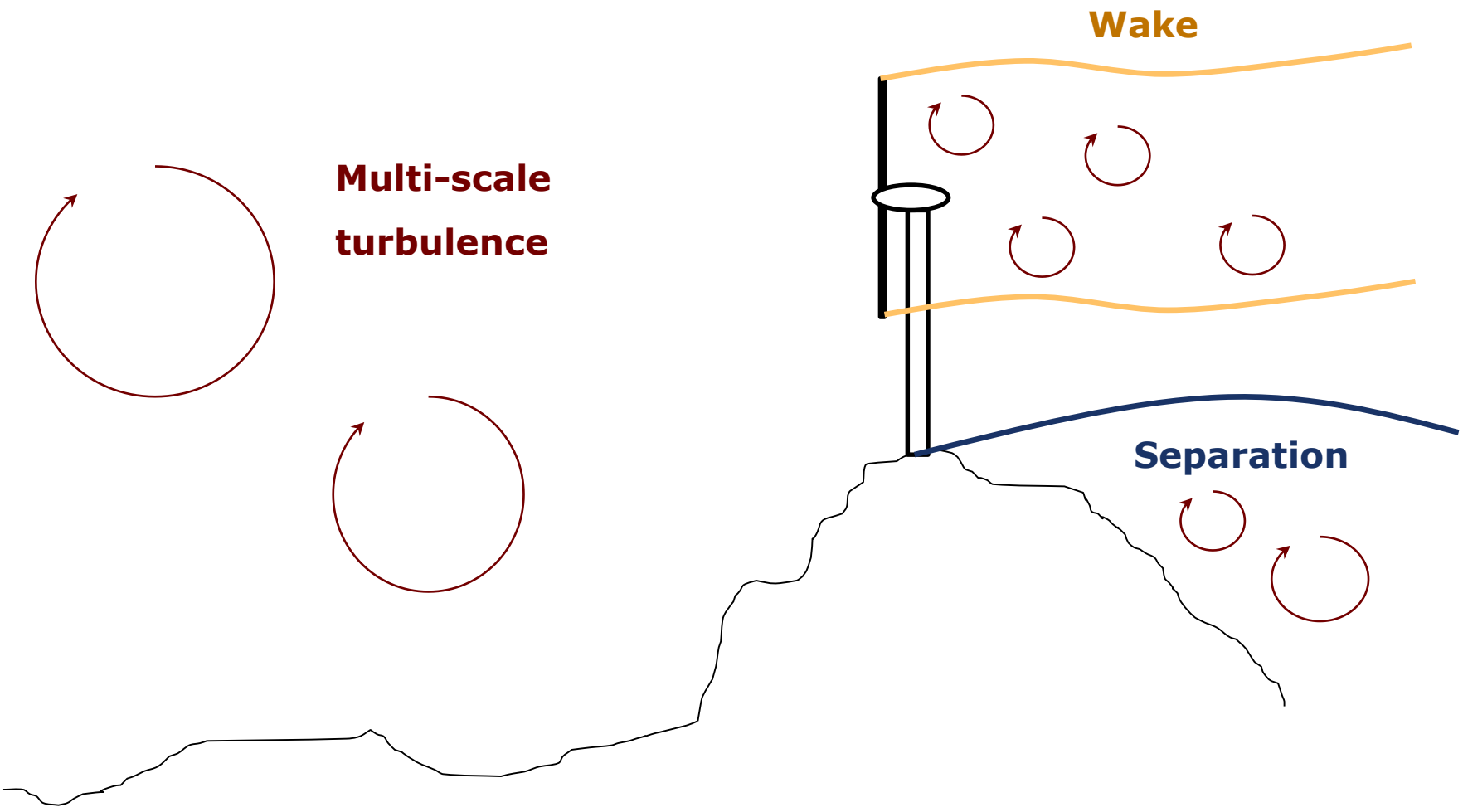
Power curve measurements in complex terrain



Power curve measurements in complex terrain



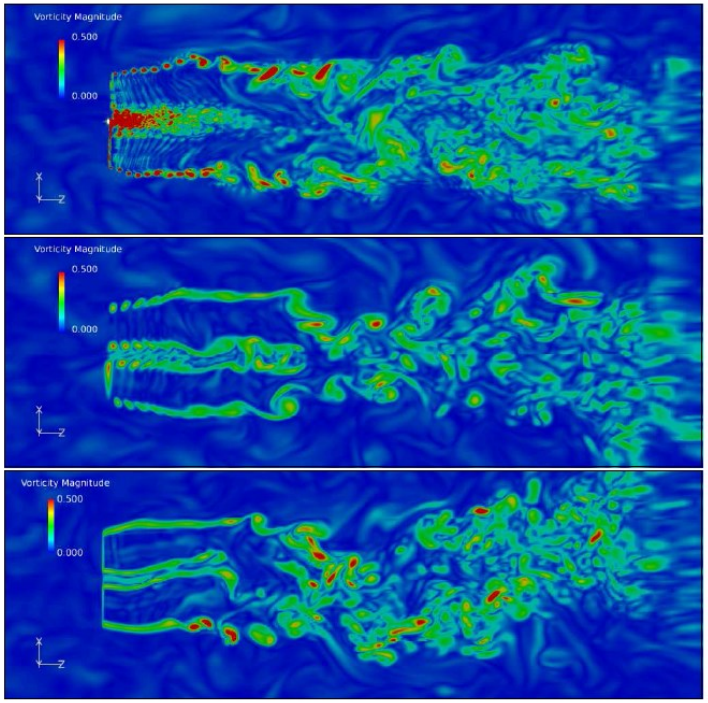
Modeling the induction zone in complex terrain



EllipSys3D

General

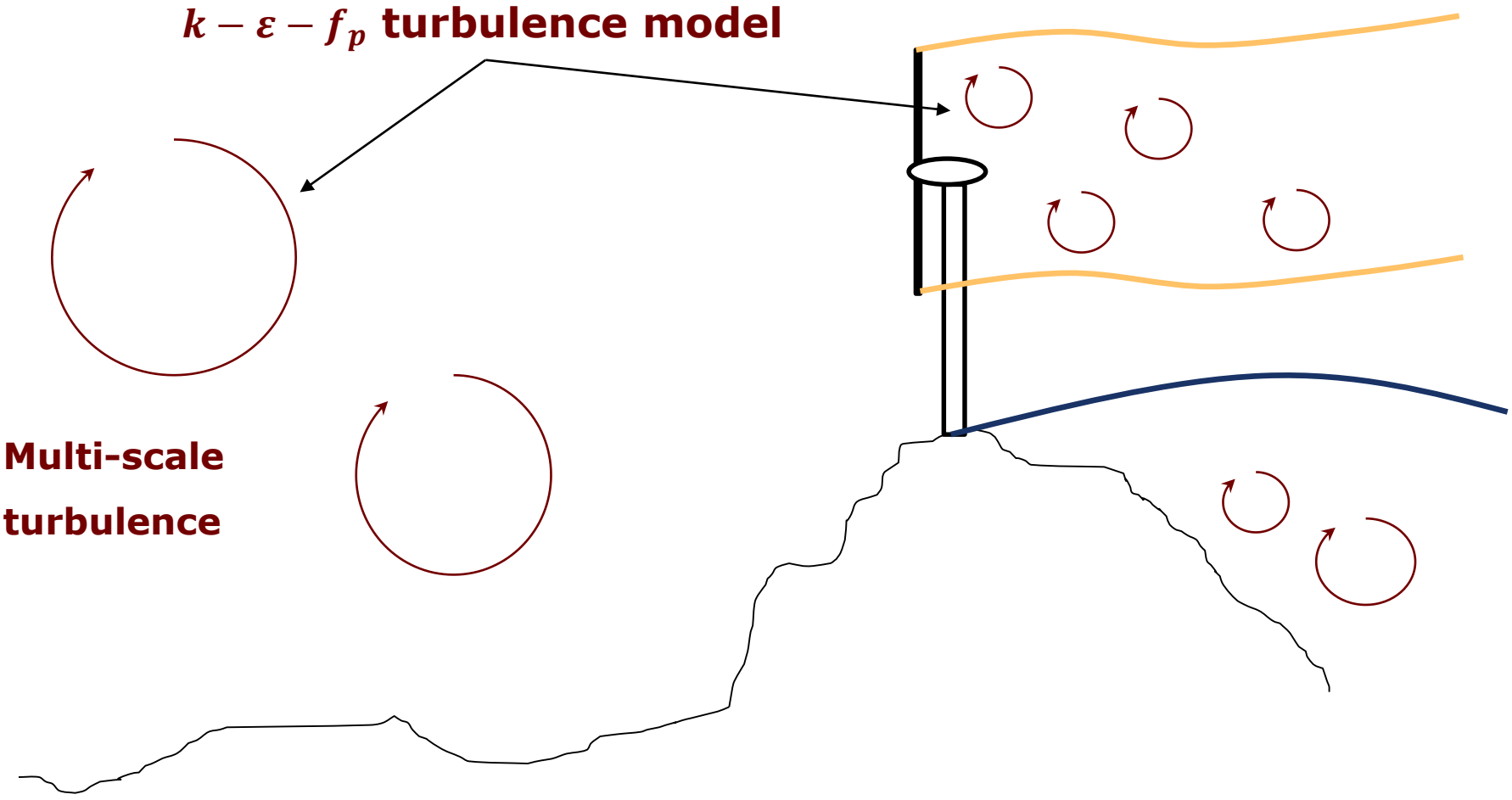
- Multi-purpose finite volume solver
- Block-structured grid with collocated variables
- Highly parallelised
- Body forces are implemented via modified Rhie-Chow algorithm



Complex terrain

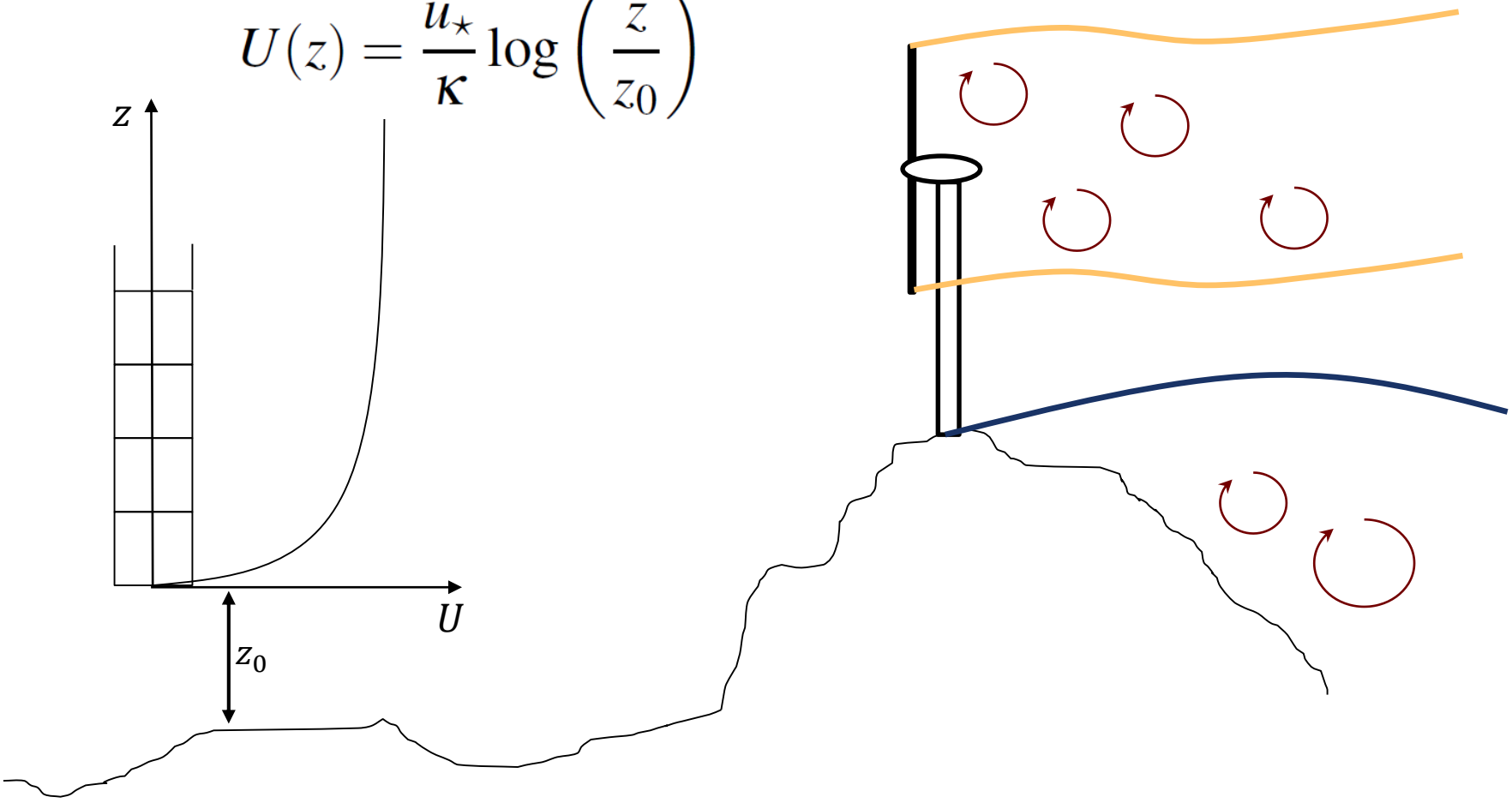
- Steady-state incompressible RANS
- QUICK scheme solved convective terms
- SIMPLE the pressure-linked terms

Modeling the induction zone in complex terrain



Modeling the induction zone in complex terrain

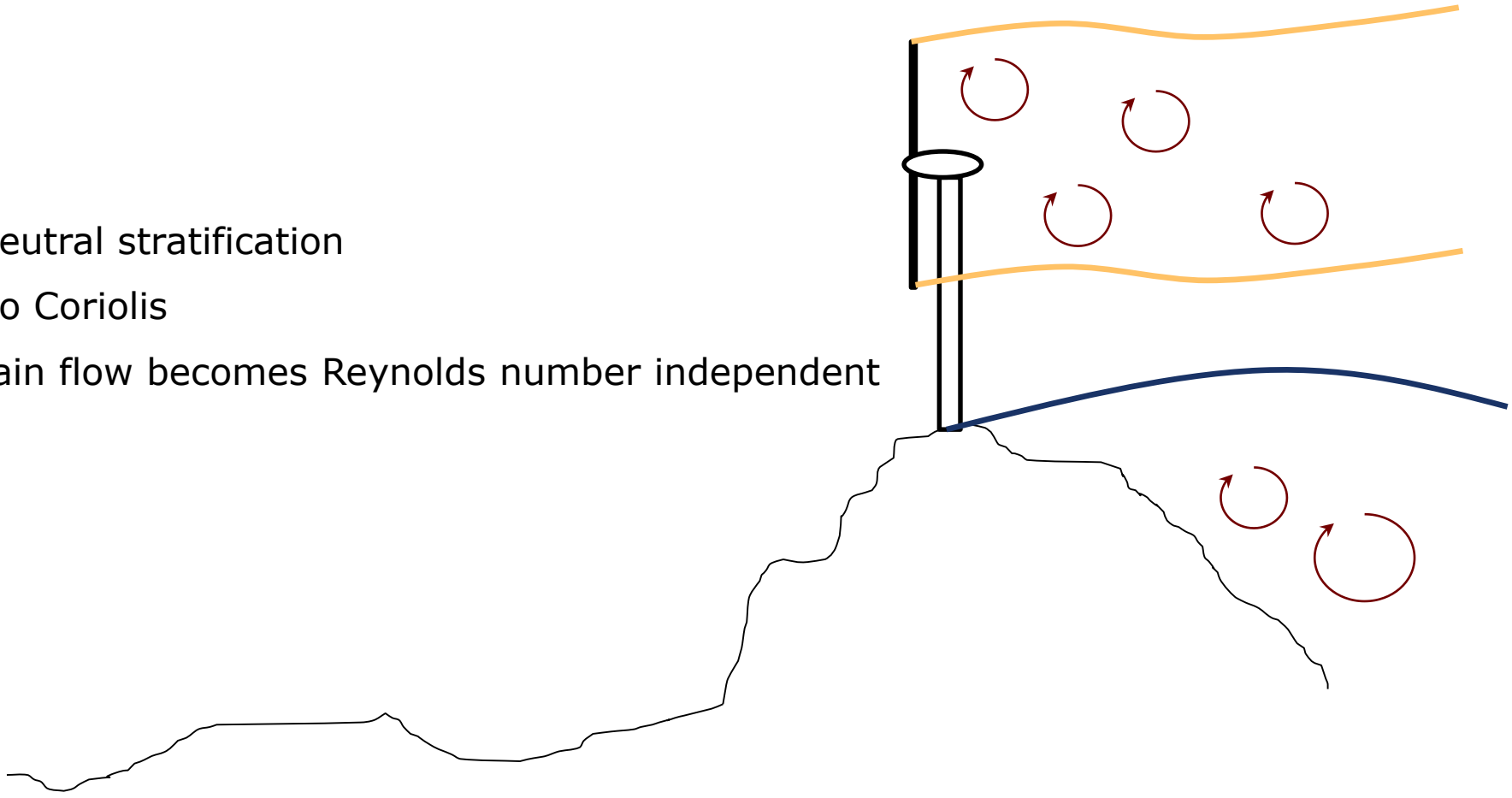
$$U(z) = \frac{u_\star}{\kappa} \log\left(\frac{z}{z_0}\right)$$



Modeling the induction zone in complex terrain

- Neutral stratification
- No Coriolis

Terrain flow becomes Reynolds number independent



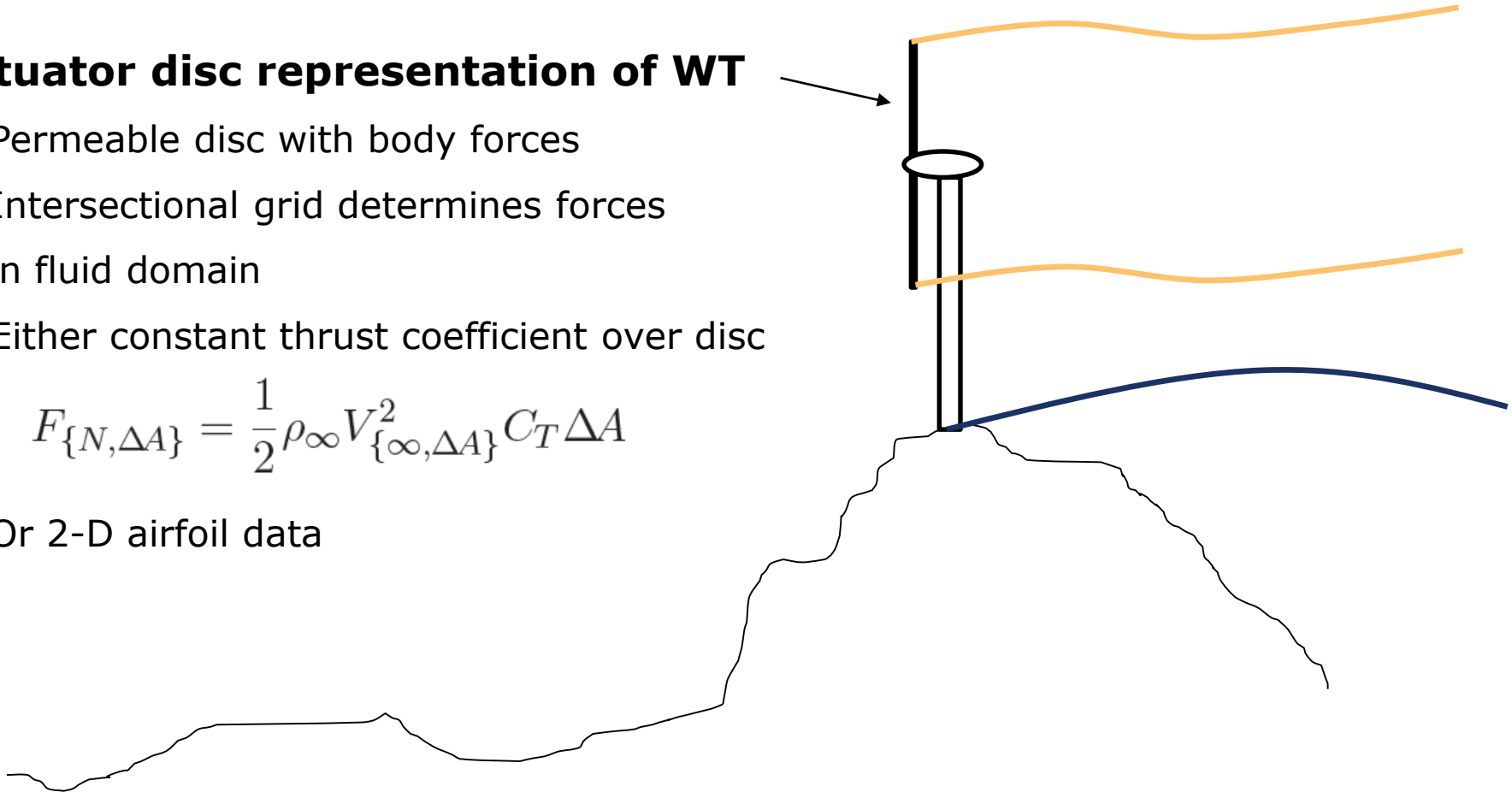
Modeling the induction zone in complex terrain

Actuator disc representation of WT

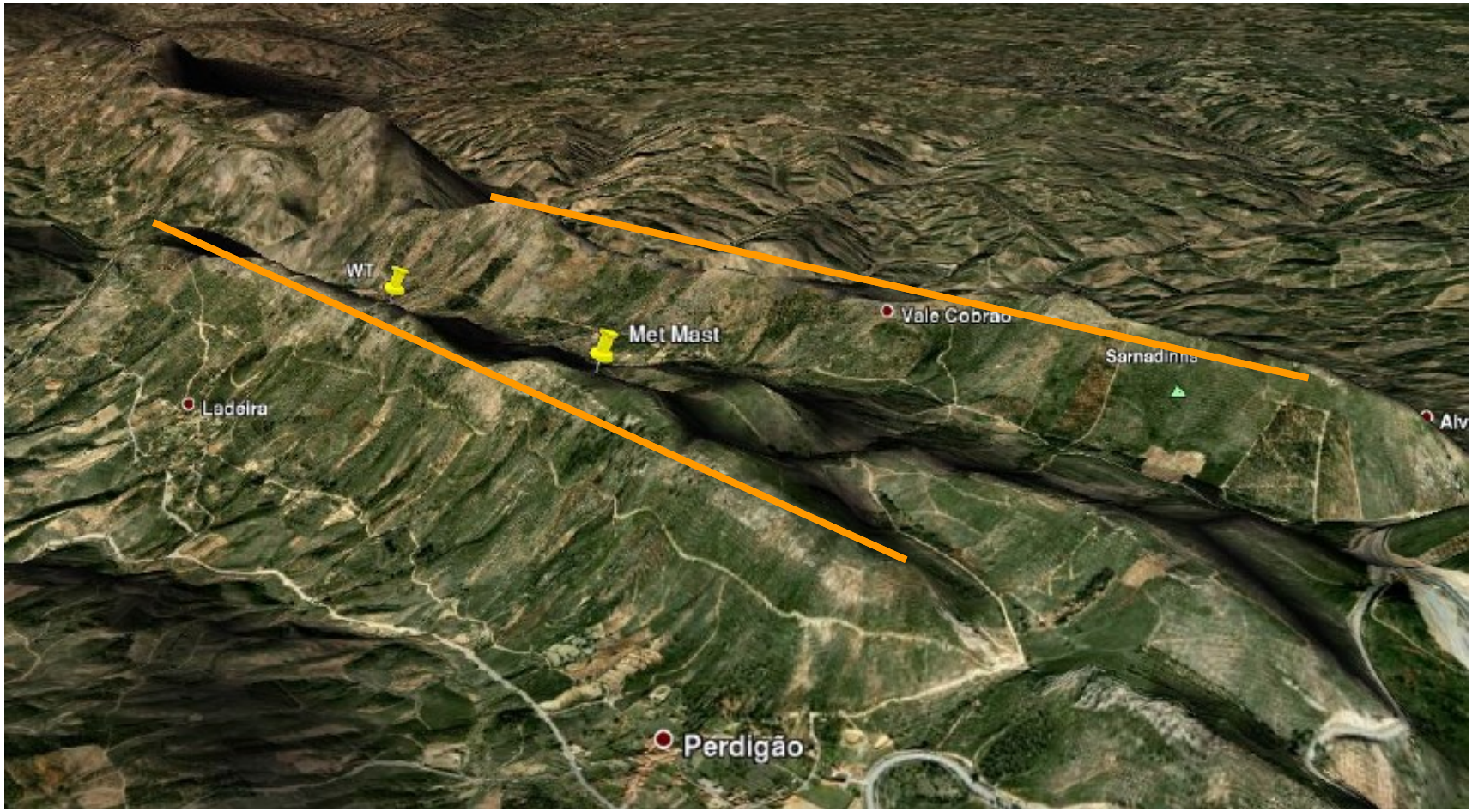
- Permeable disc with body forces
- Intersectional grid determines forces in fluid domain
- Either constant thrust coefficient over disc

$$F_{\{N,\Delta A\}} = \frac{1}{2}\rho_\infty V^2_{\{\infty,\Delta A\}} C_T \Delta A$$

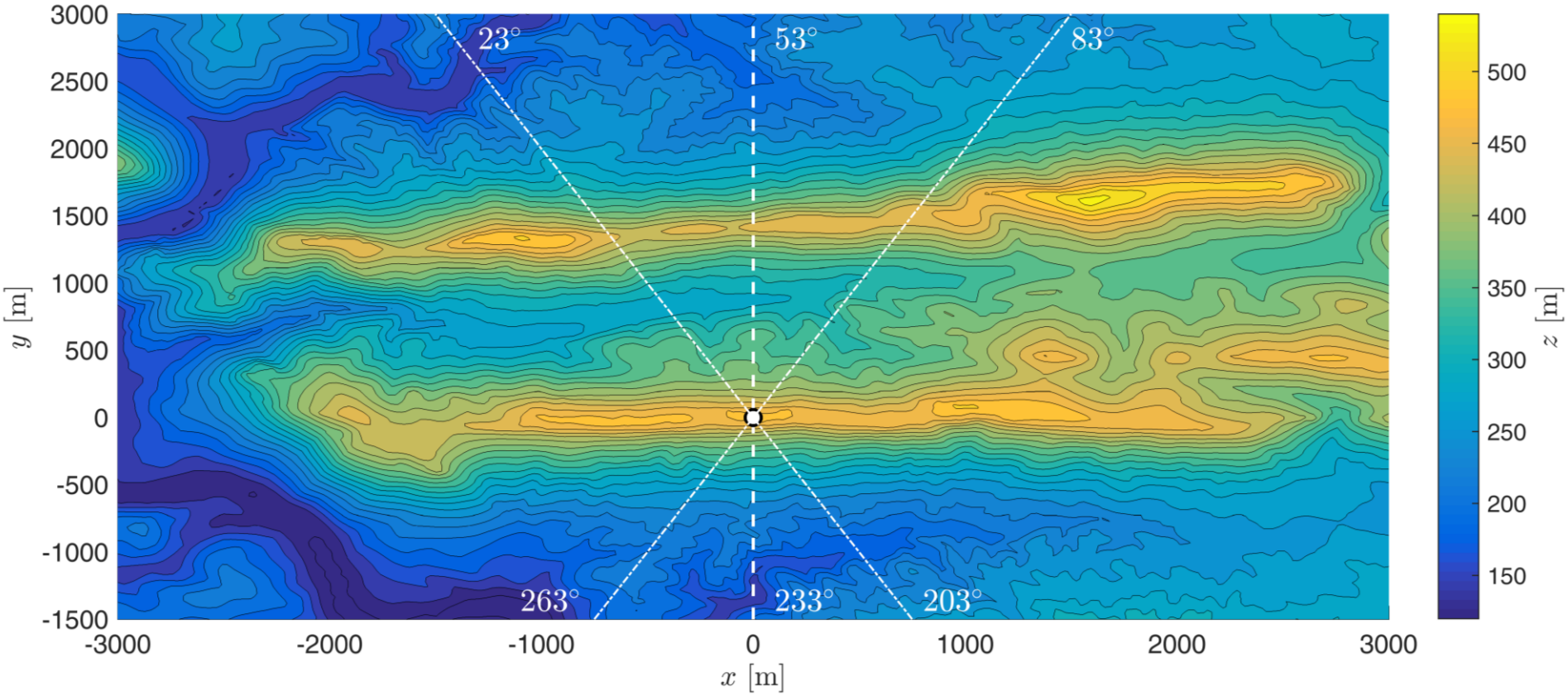
- Or 2-D airfoil data



Complex terrain test case: Perdigão



Complex terrain test case: Perdigão

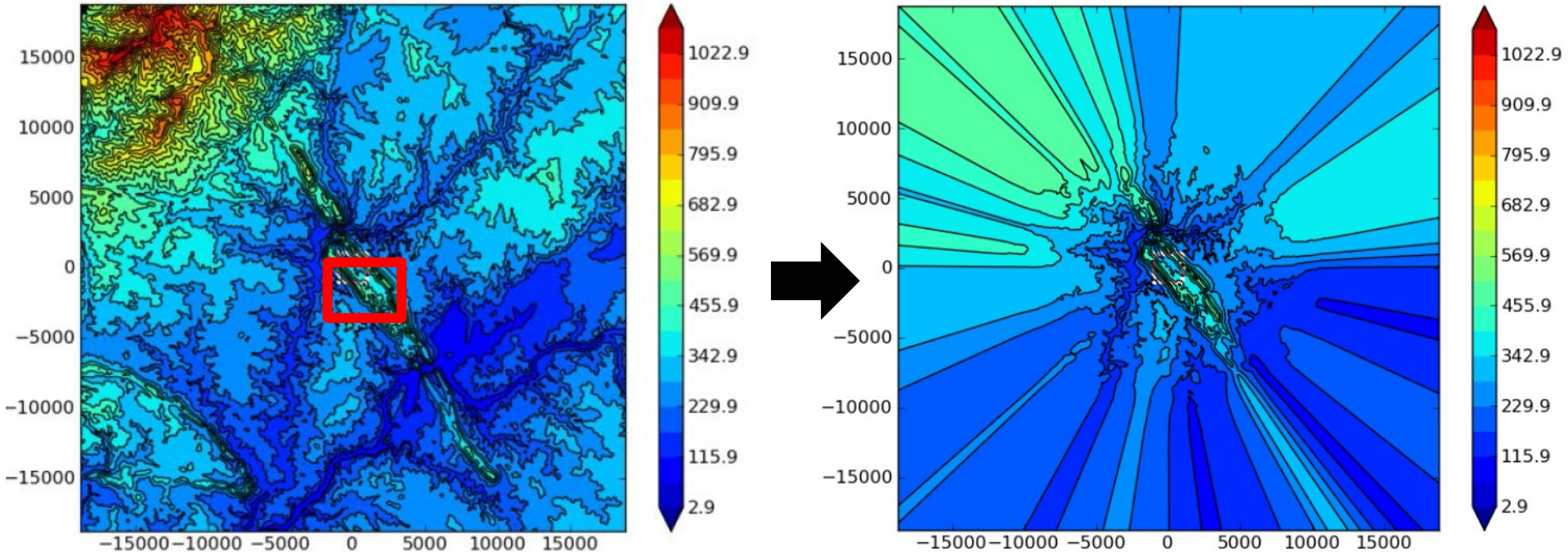


Complex terrain test case: Perdigão

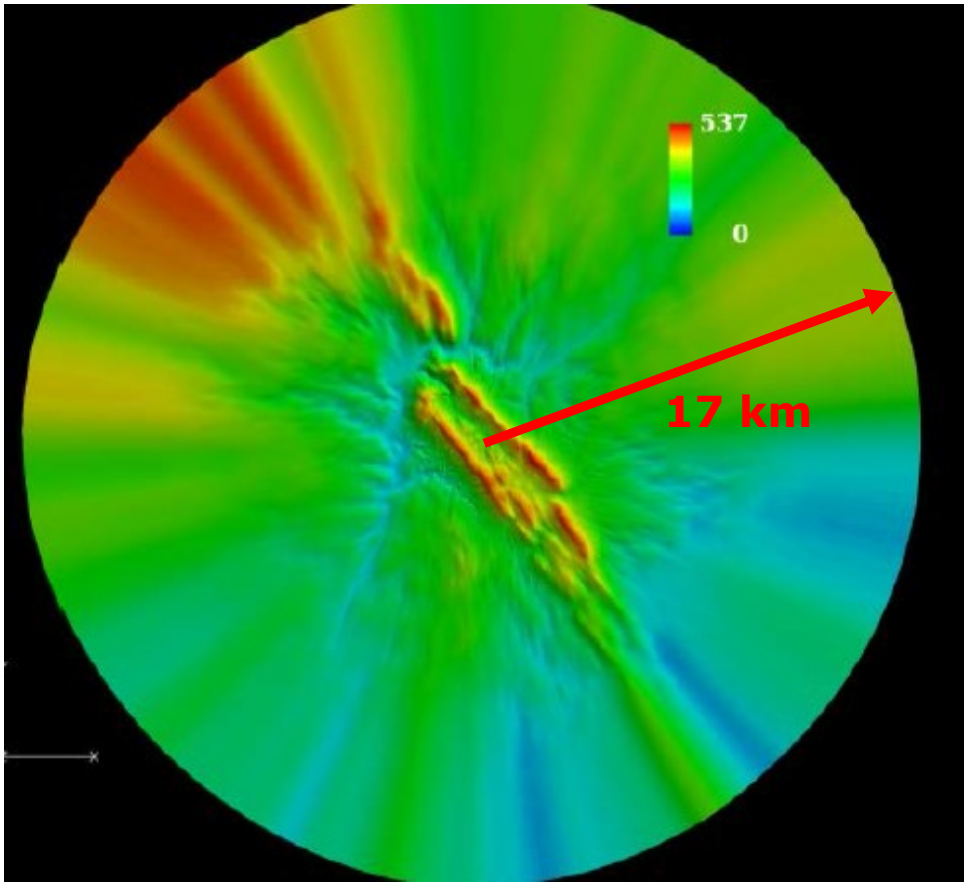
Terrain treatment for mesh generation

Far-field terrain and reference roughness

- Smoothed over grid spacing and towards the edges of the domain



The domain



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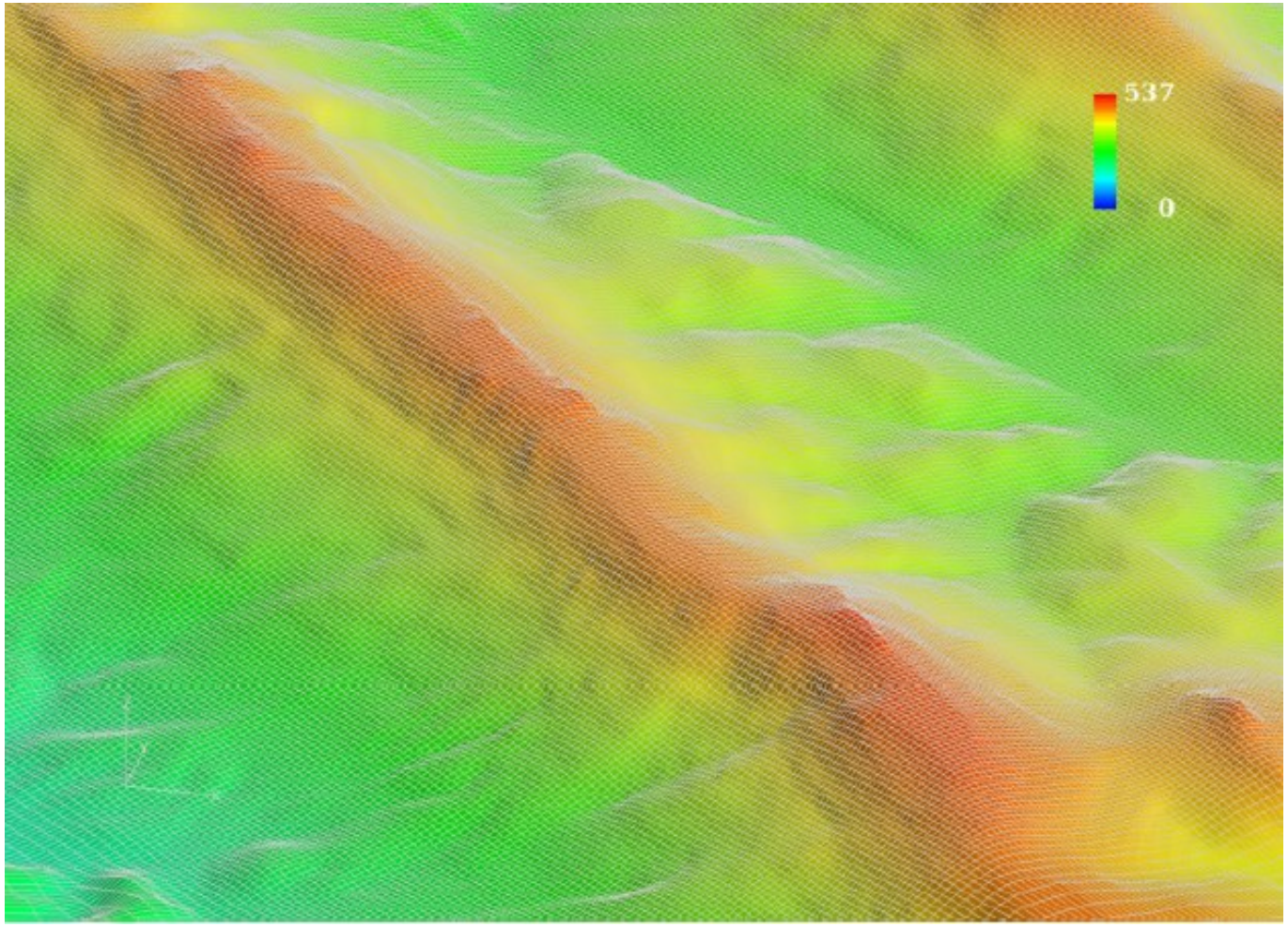
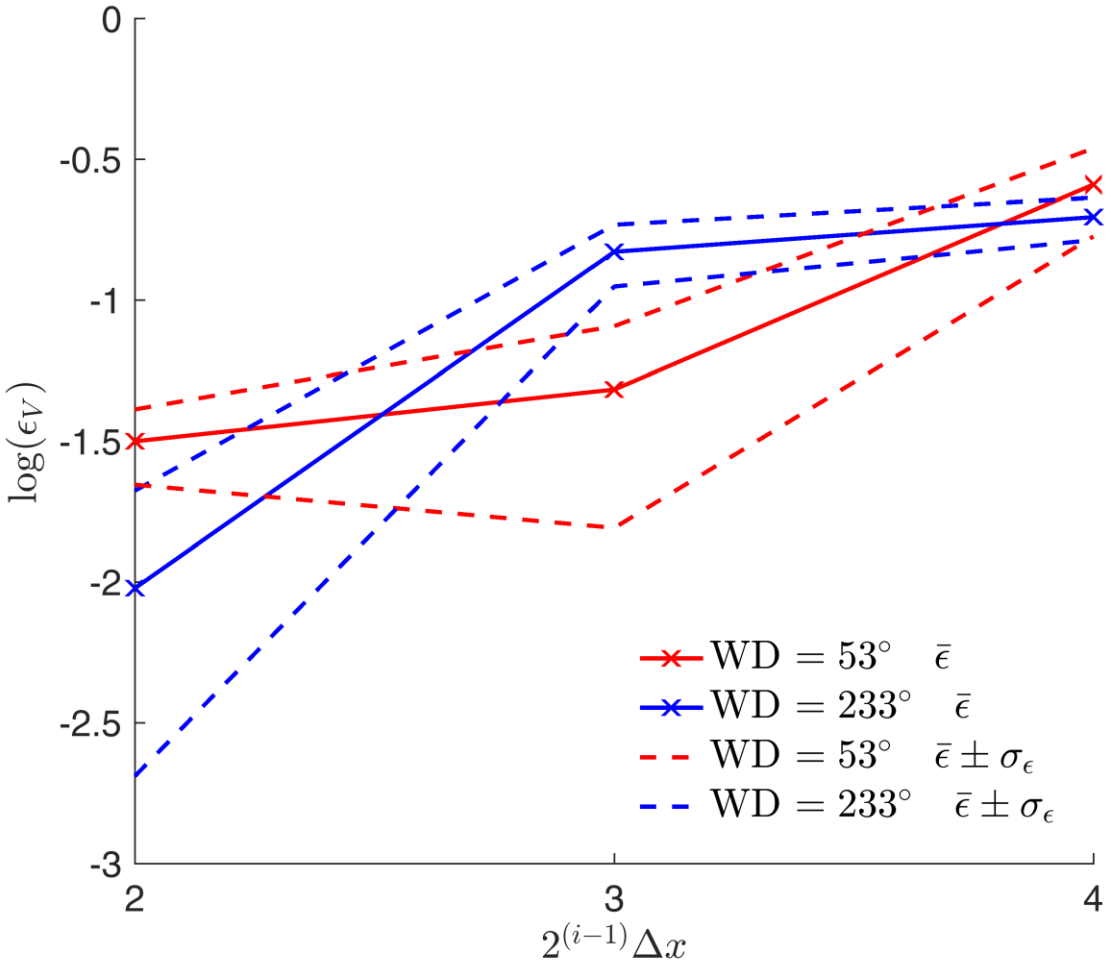


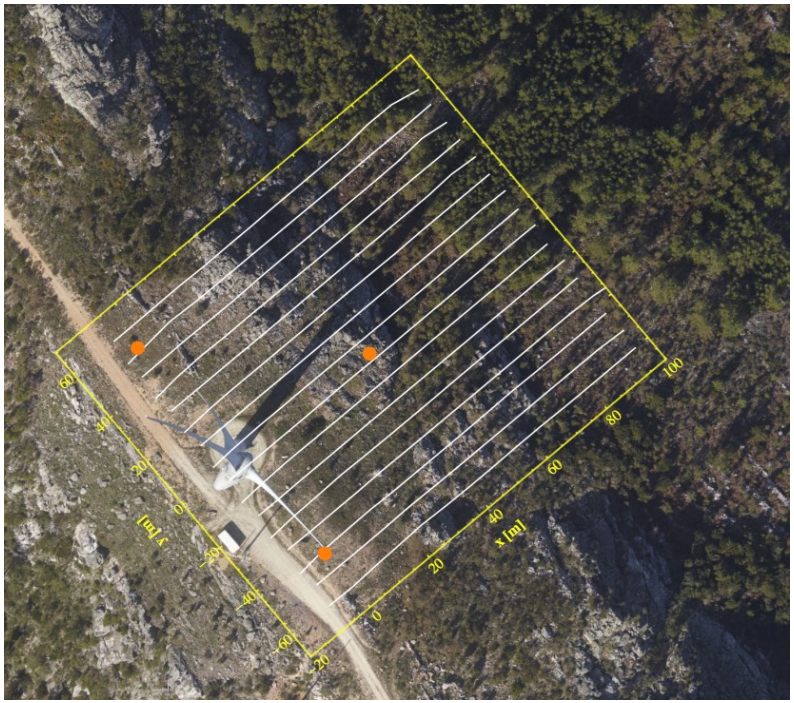
Grid sensitivity

$$\Delta x = \frac{R}{16} = 2.56\,m \longrightarrow 2.13M\ cells$$



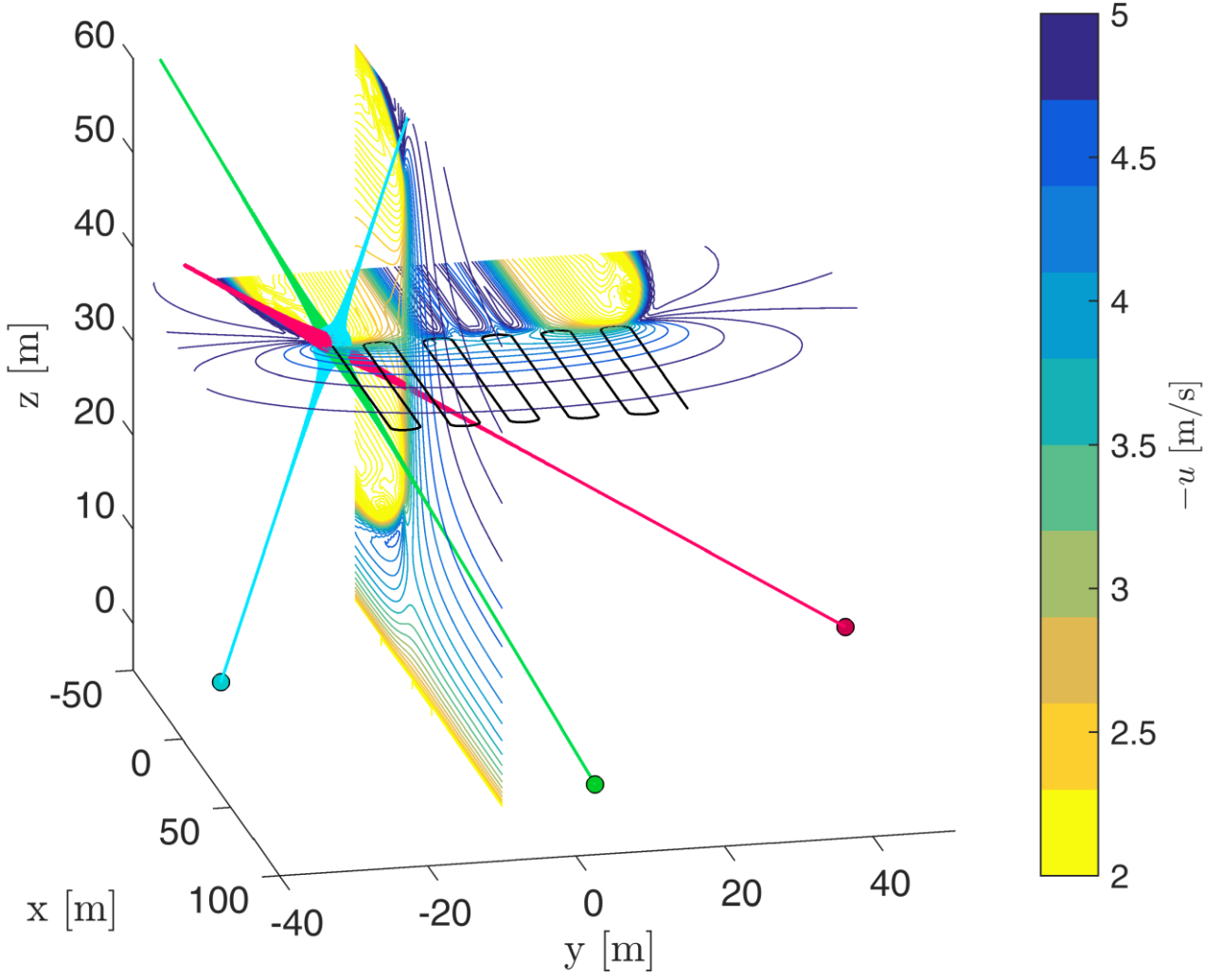
Measurements at Perdigão

- Synchronised lidar measurements around WT and valley



Measurements at Perdigão

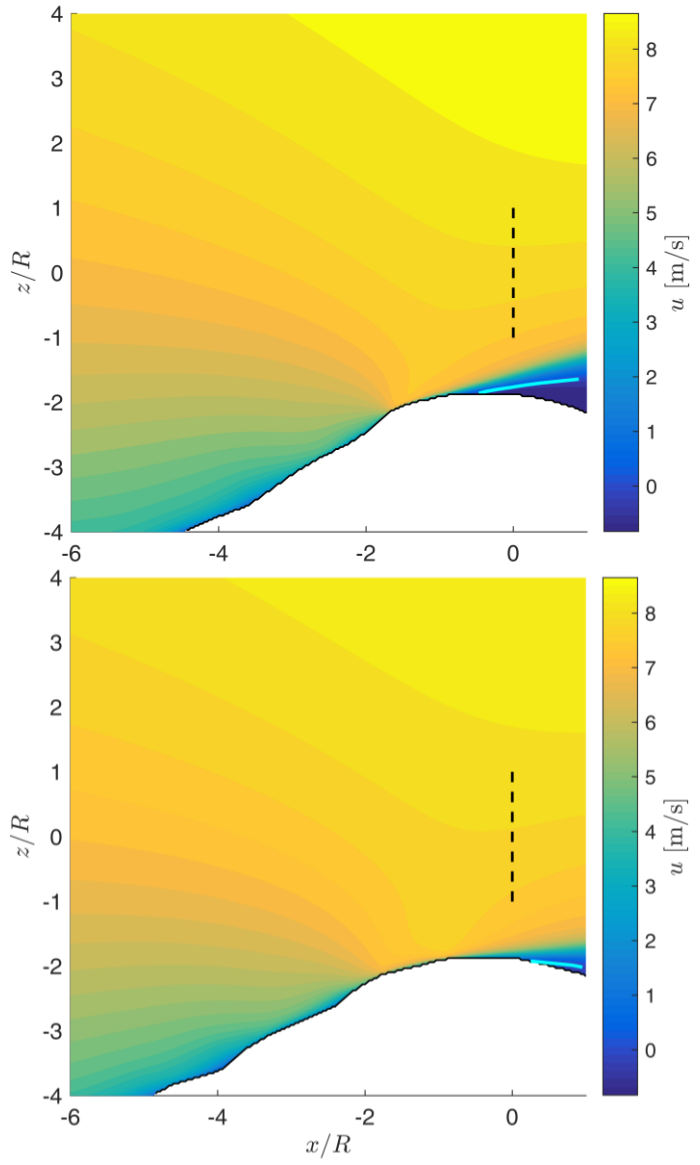
Synchronised triple-lidar

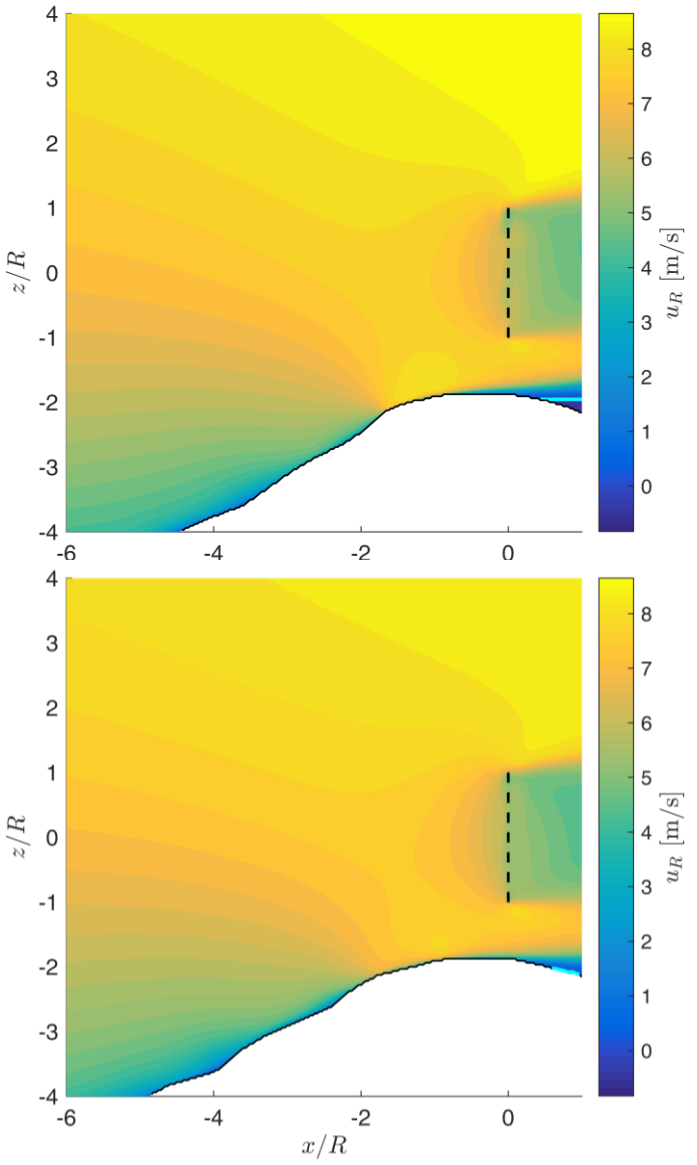


CFD Results

218°

263°



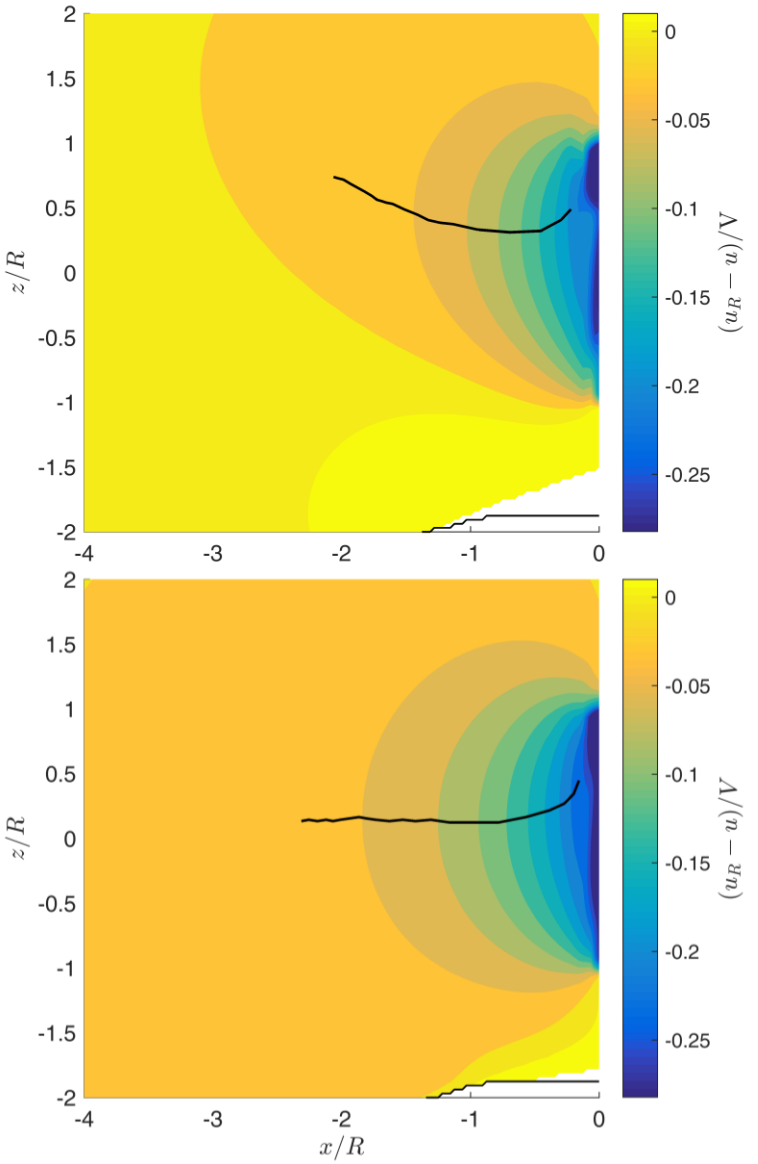


CFD Results

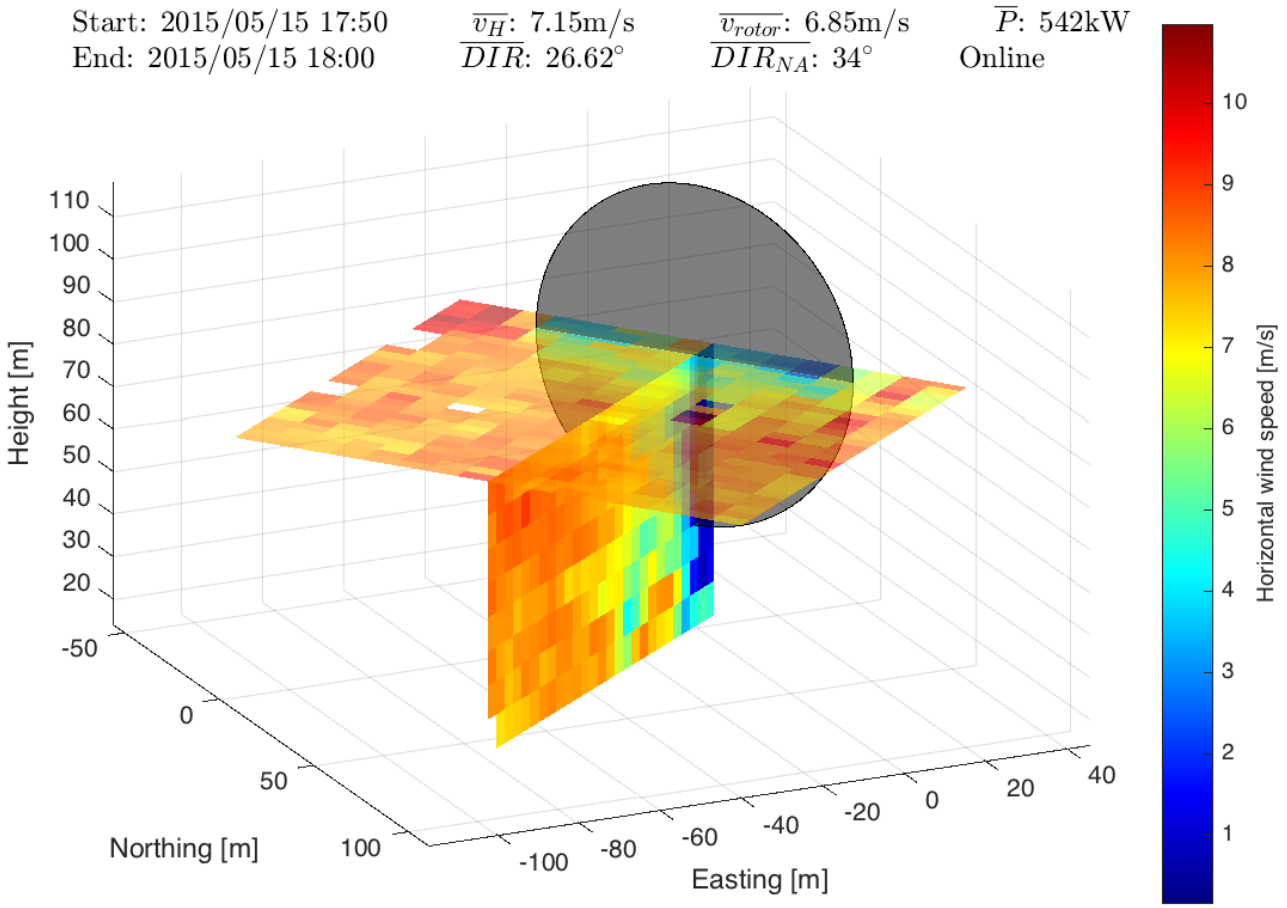
Wind directions

218°

263°

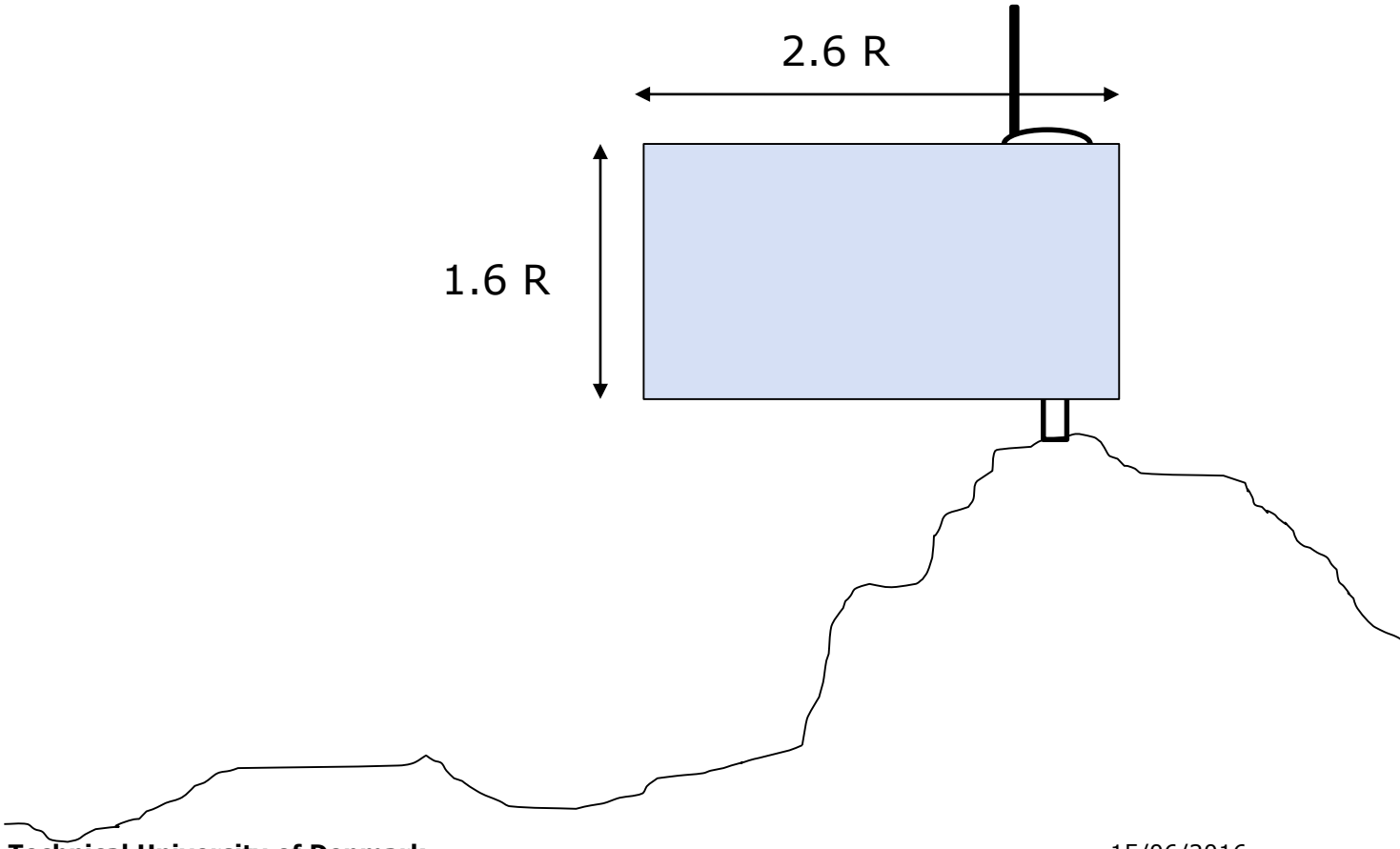


Triple-lidar results

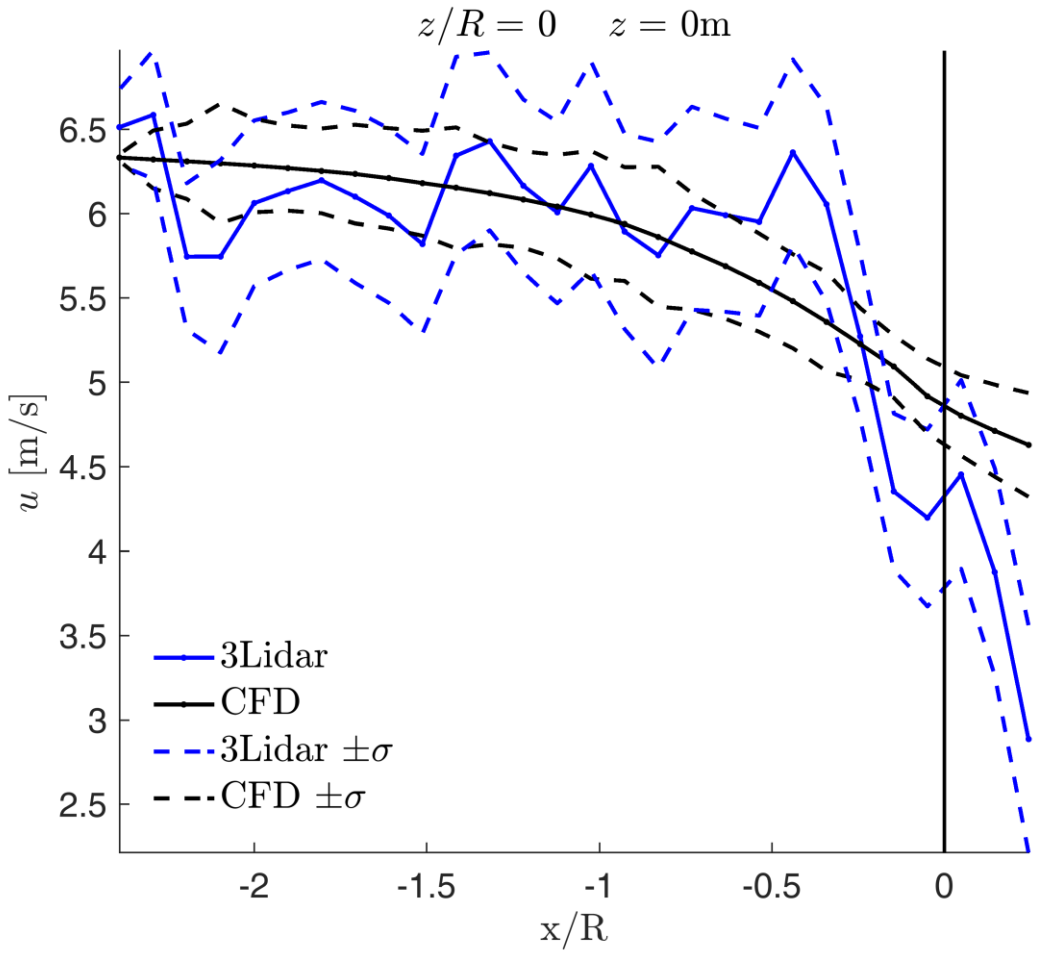


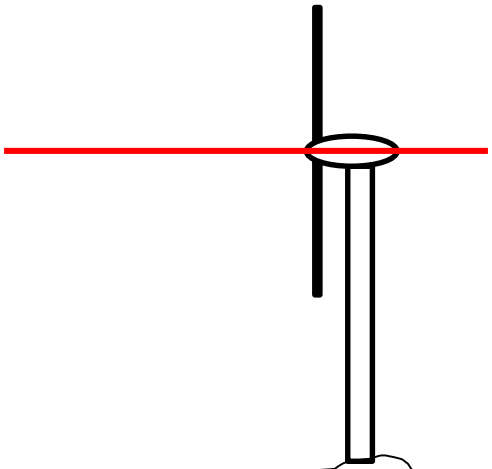
By R. Menke

Comparaison triple-lidar and CFD

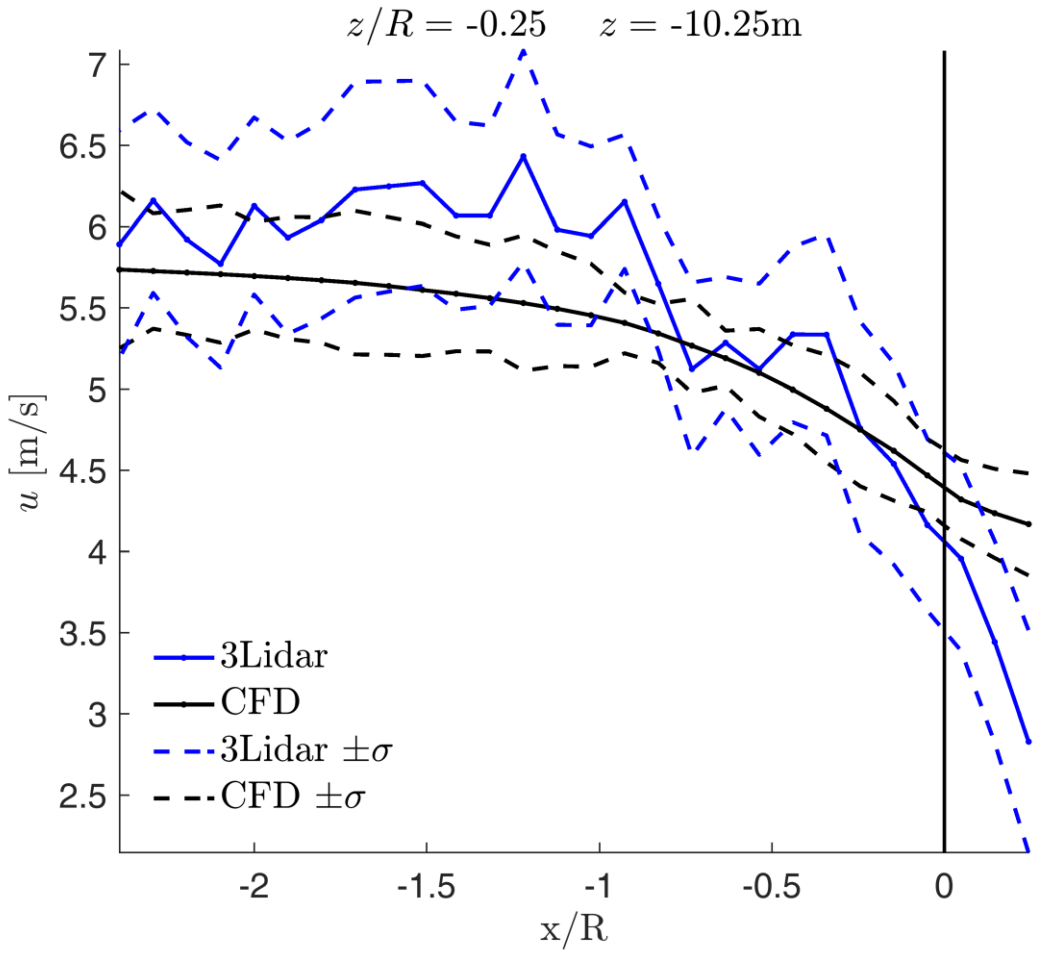


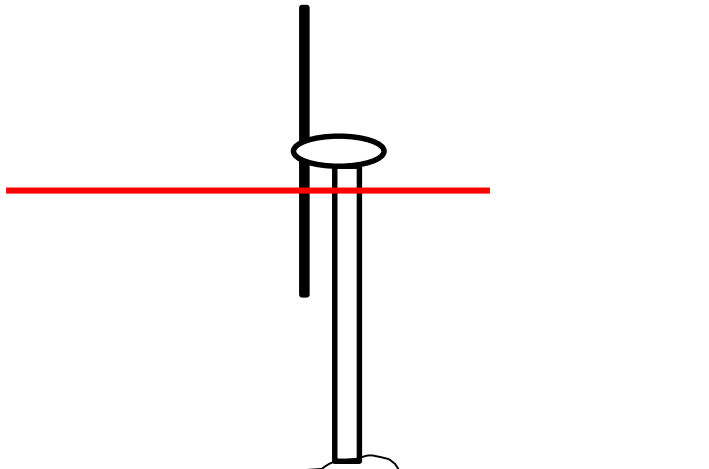
Comparaison triple-lidar and CFD



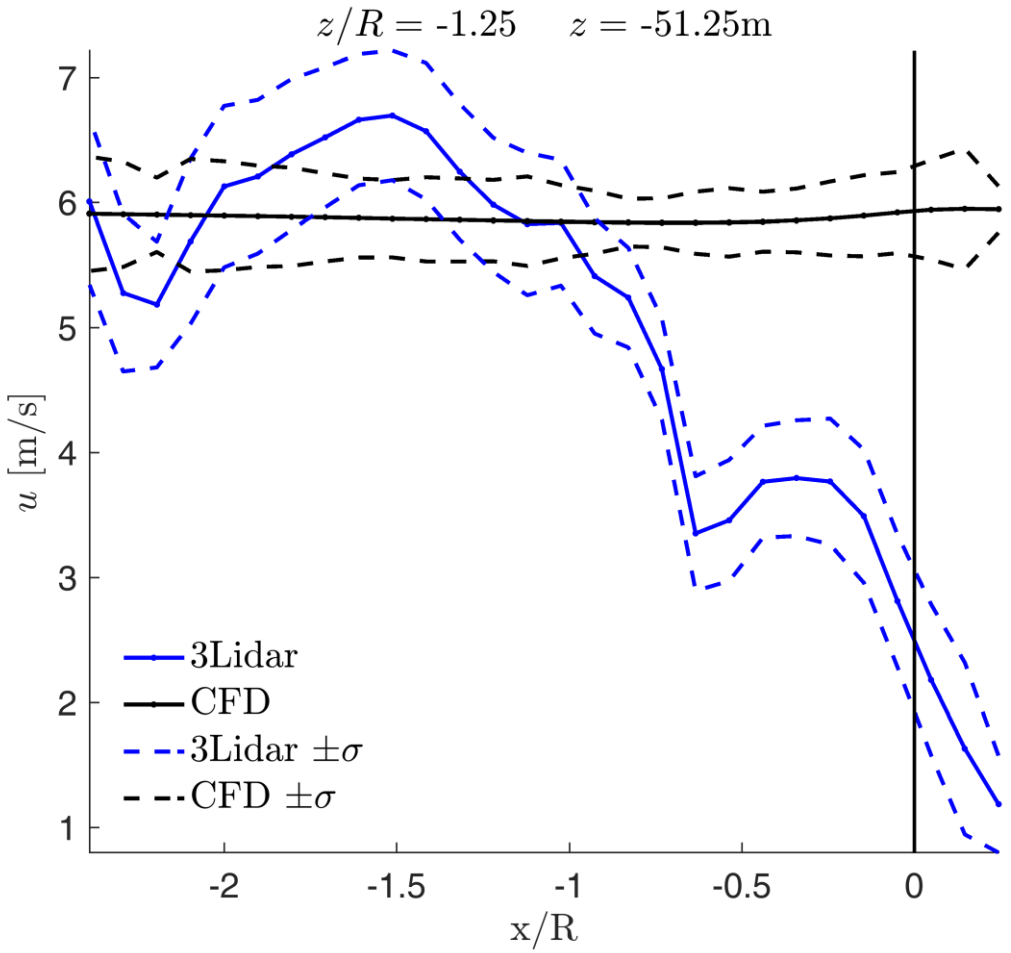


Comparaison triple-lidar and CFD





Comparaison triple-lidar and CFD



Conclusion

- Automated complex terrain simulations incorporating several pre-processing steps
- Triple-lidar shows high potential for complex flow measurements
- Large uncertainty in inflow conditions needs to be accounted for
- Steady-state RANS seems to capture induction zone correctly
- Computational uncertainty from:
  - Stratification
  - Roughness
  - Turbine
  - Terrain

Future work

- Investigate more measurement periods
- Include variability of wind direction into validation methodology
- Include stratification

Thanks for your attention!

Questions?