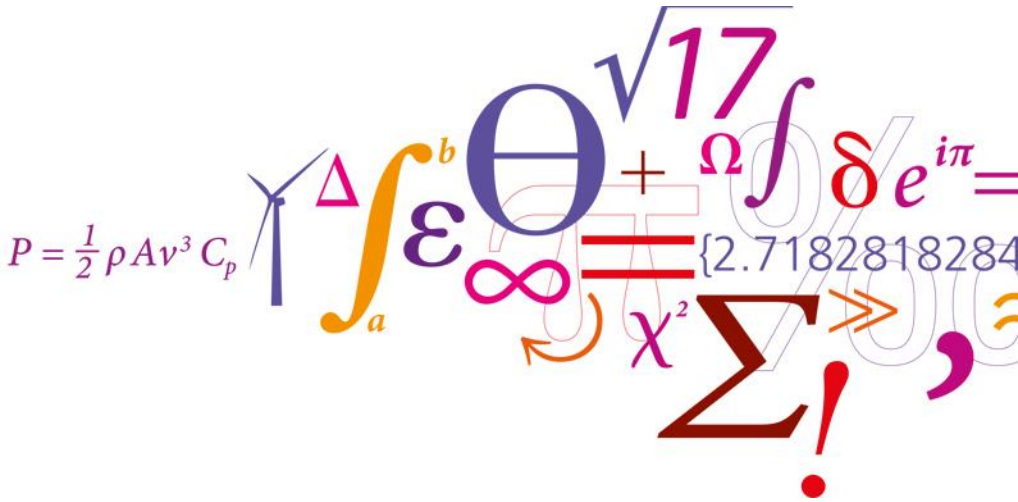
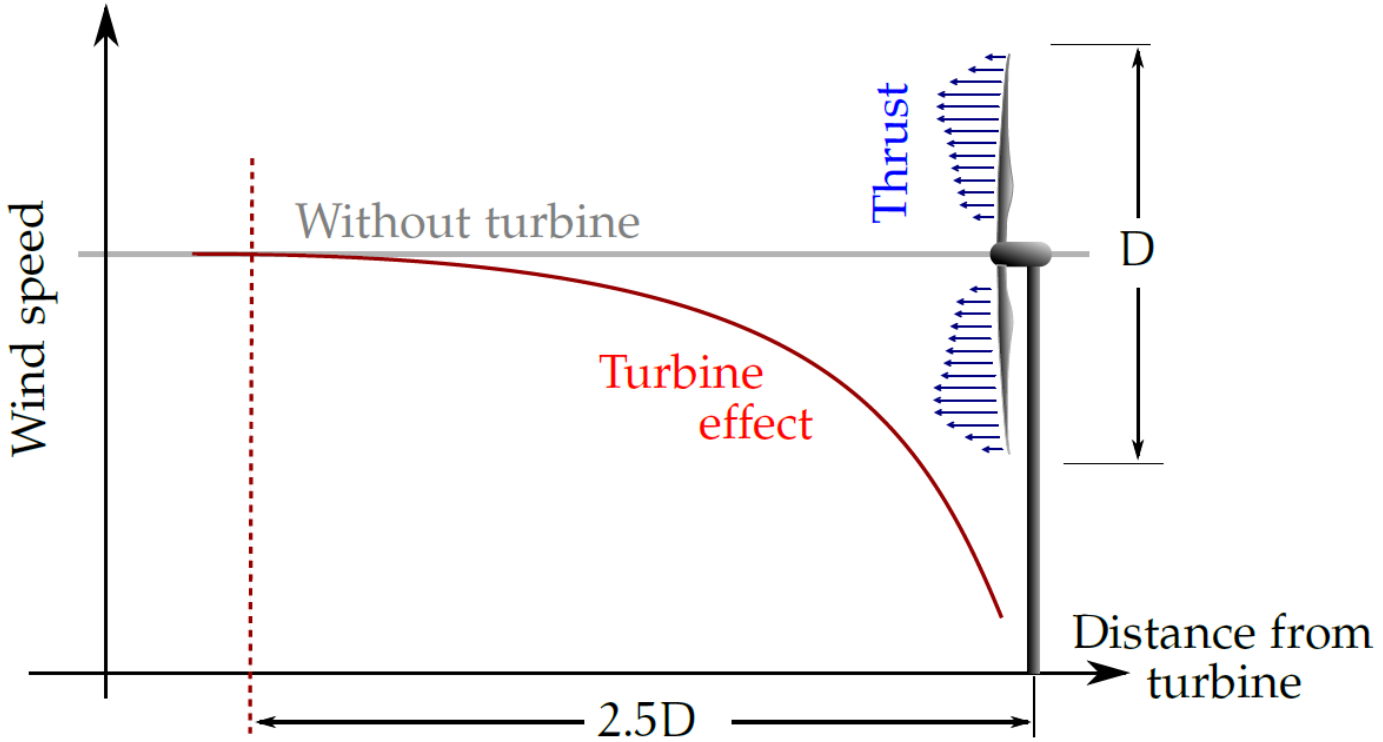
Predicting free-stream wind speed in complex terrain with lidar measurements

Alexander Meyer Forsting, Niels Troldborg,
Andreas Bechmann

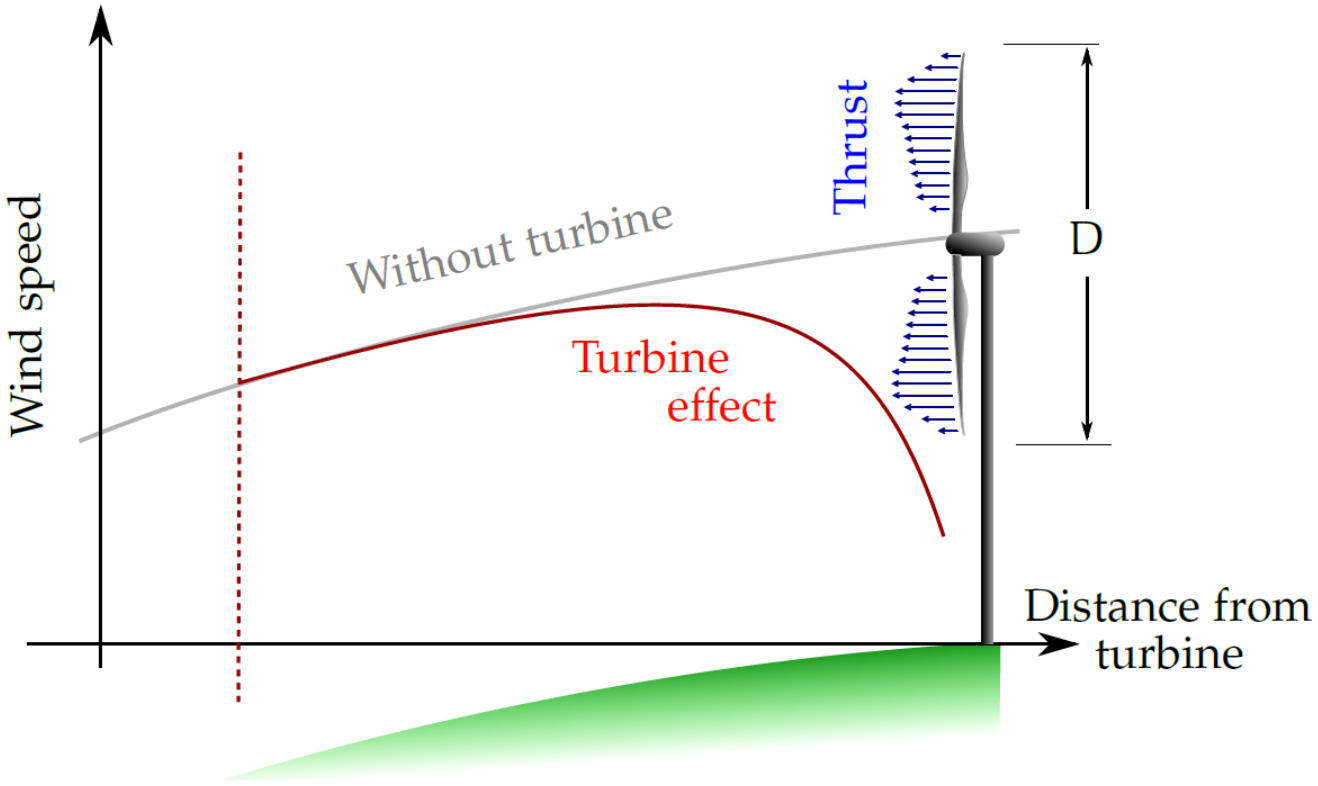


DTU Wind Energy
Department of Wind Energy

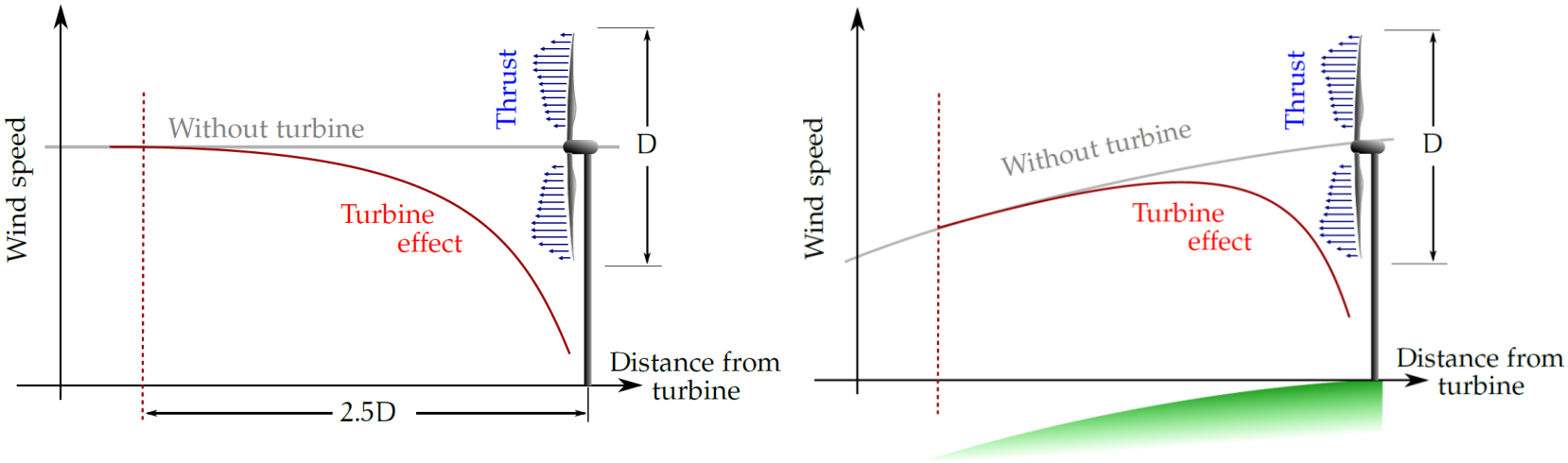
The induction zone



The induction zone in complex terrain



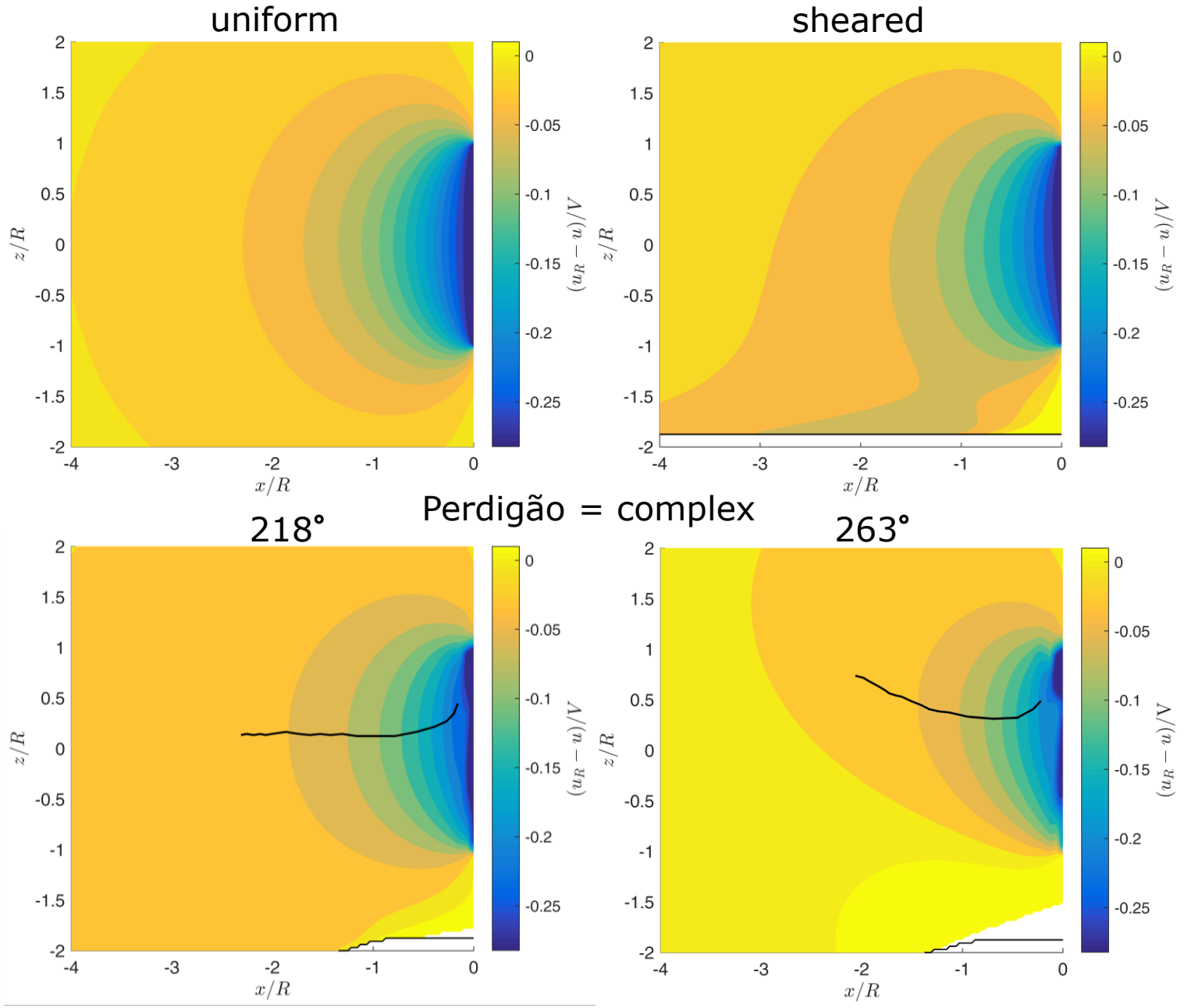
Predict free-stream?



Universal induction zone

Same method to retrieve V_∞

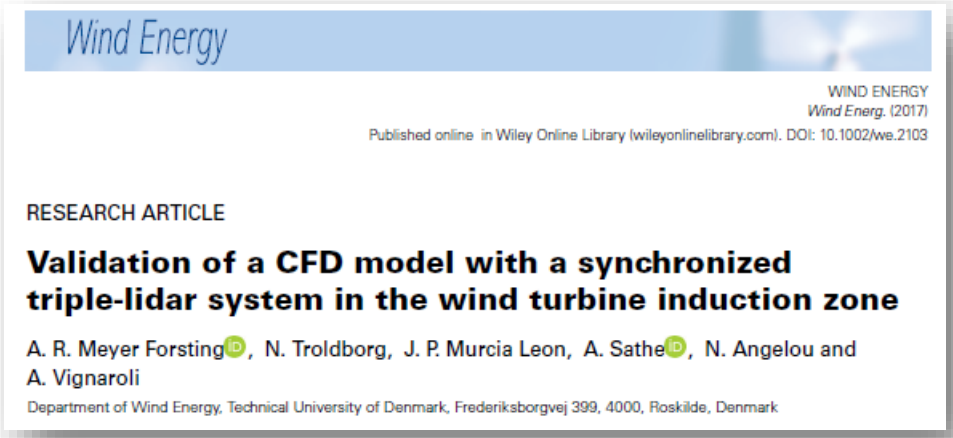
Universal ?



Test universality

Parametric study with EllipSys3D

Use simple vortex model to predict induction zone



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RESEARCH ARTICLE

Validation of a CFD model with a synchronized triple-lidar system in the wind turbine induction zone

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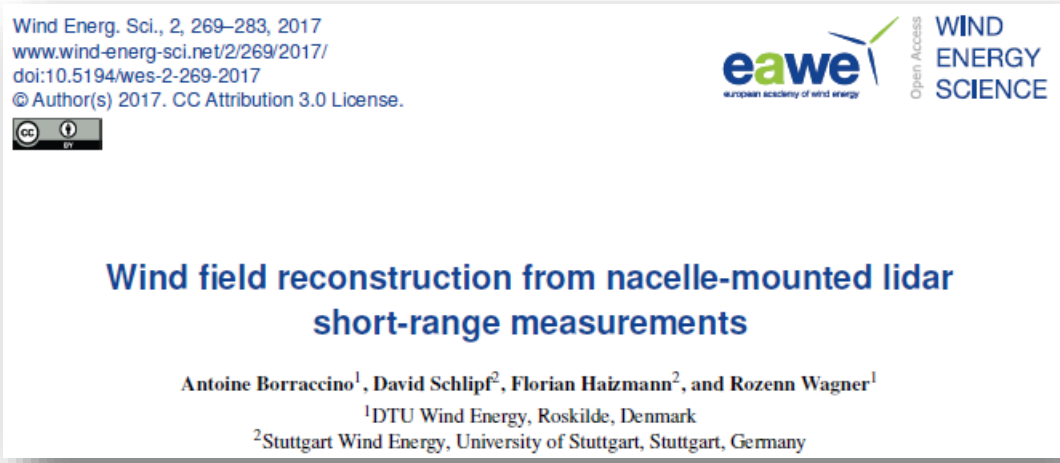

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Wind field reconstruction from nacelle-mounted lidar short-range measurements

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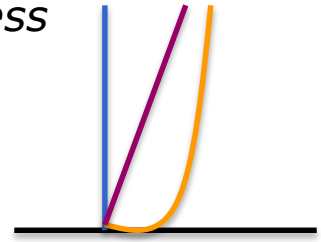
Identify parameters influencing induction zone

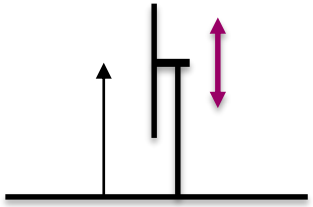
Roughness



⇒ Log-law with **3** different z_0

0, 0.05m and 0.5m

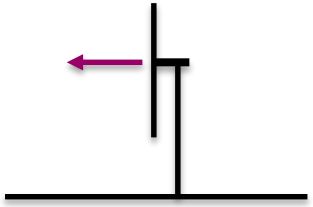
Hub Height



⇒ **3** different h

0.7D, 1D, 1.5D

Thrust coefficient

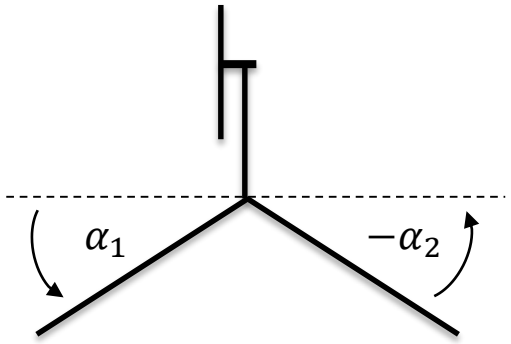


⇒ **3** different C_T

0, 0.36, 0.89

Identify parameters influencing induction zone

Terrain



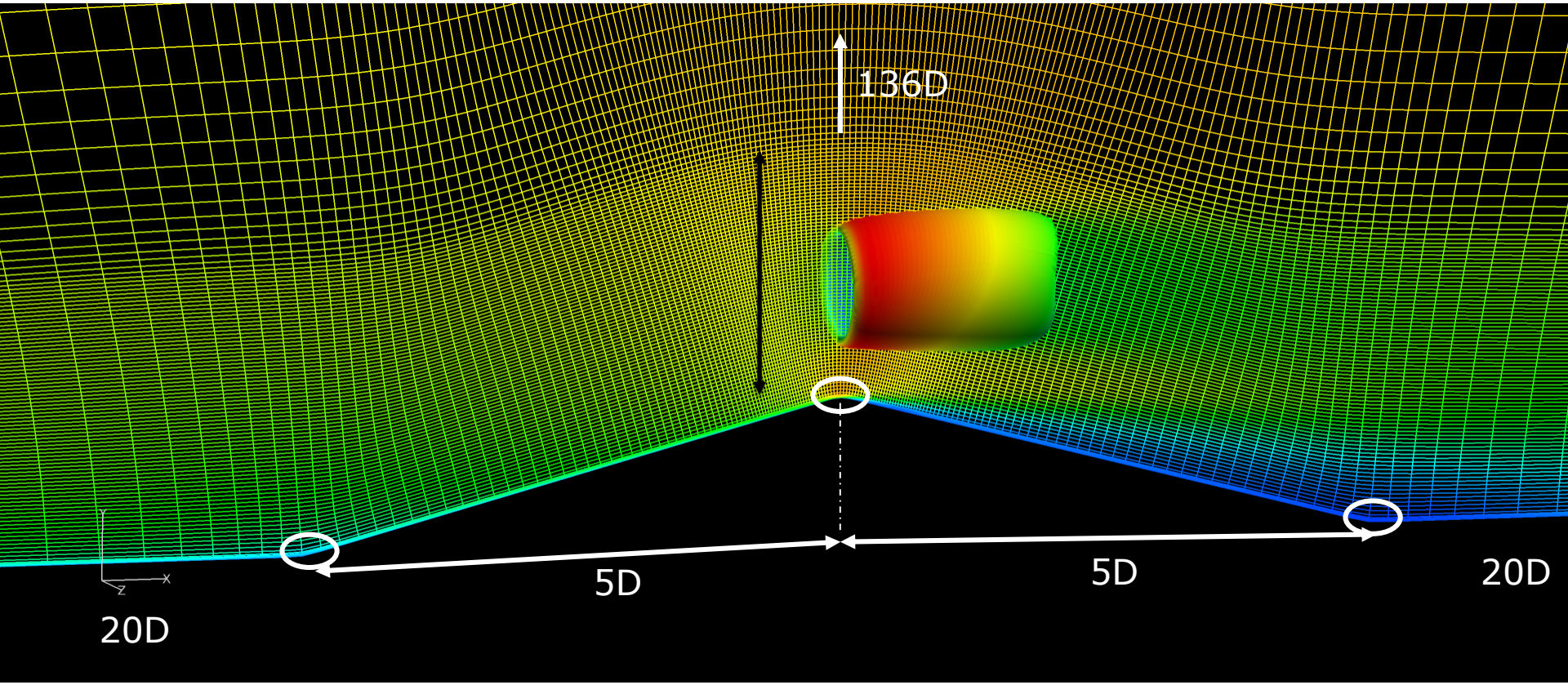
⇒

7 different α, **49** terrains

-15:5:15 degrees

1323 CFD simulations

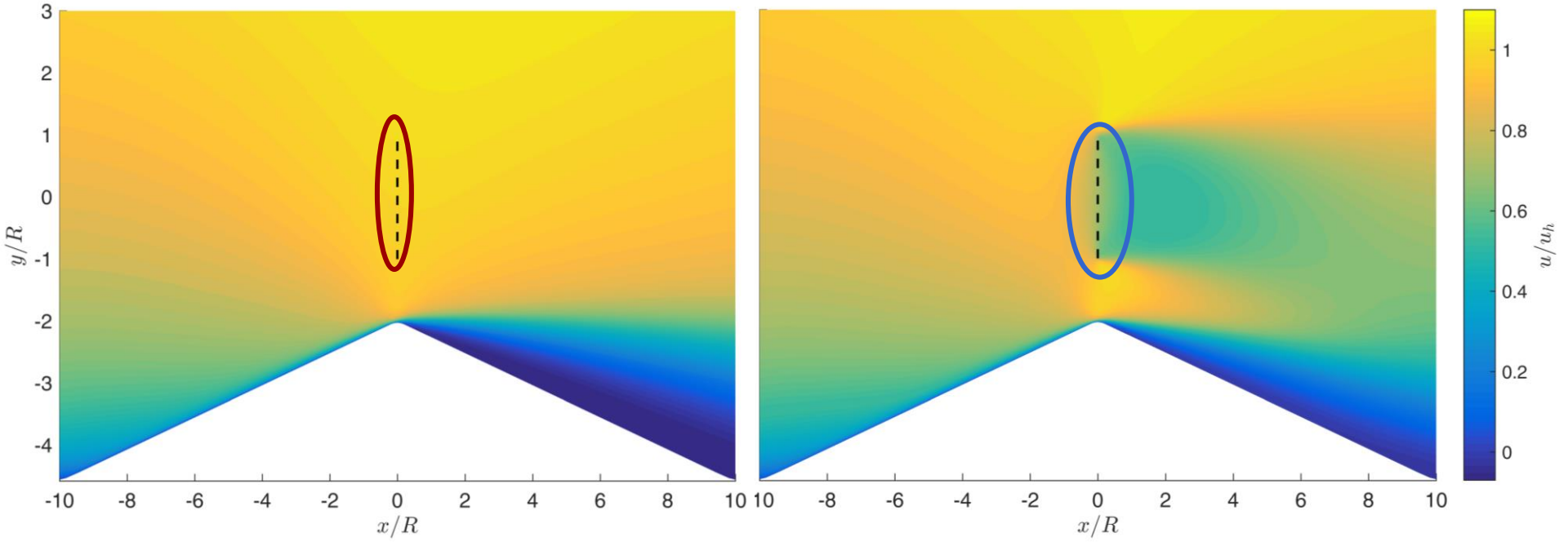
Numerical approach



Flow over hill

Free-stream reference

Turbine flow



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

Test simple model

Use simple induction zone model

$$\tilde{U}(\tilde{r},\tilde{x}) = 1 - a(0,\tilde{x})f(\epsilon)$$

Longitudinal = vortex sheet

$$a(0,\tilde{x}) = a_0(1 + \frac{\tilde{x}}{\sqrt{1+\tilde{x}^2}})$$

$$a_0 = \frac{1}{2}(1 - \sqrt{1-\gamma C_T})$$

Radial variation

$$f(\epsilon) = sech^{\alpha}(\beta\epsilon)$$

$$\tilde{U}(r,x) = \frac{U(r,x)}{U_\infty}, \qquad \epsilon = \frac{r}{r_{1/2}(x)}, \qquad \tilde{r}_{1/2}(x) = \frac{r_{1/2}(x)}{R}, \qquad \tilde{r} = \frac{r}{R}, \qquad \tilde{x} = \frac{x}{R}$$

Model prediction error

Reference: hub height velocity

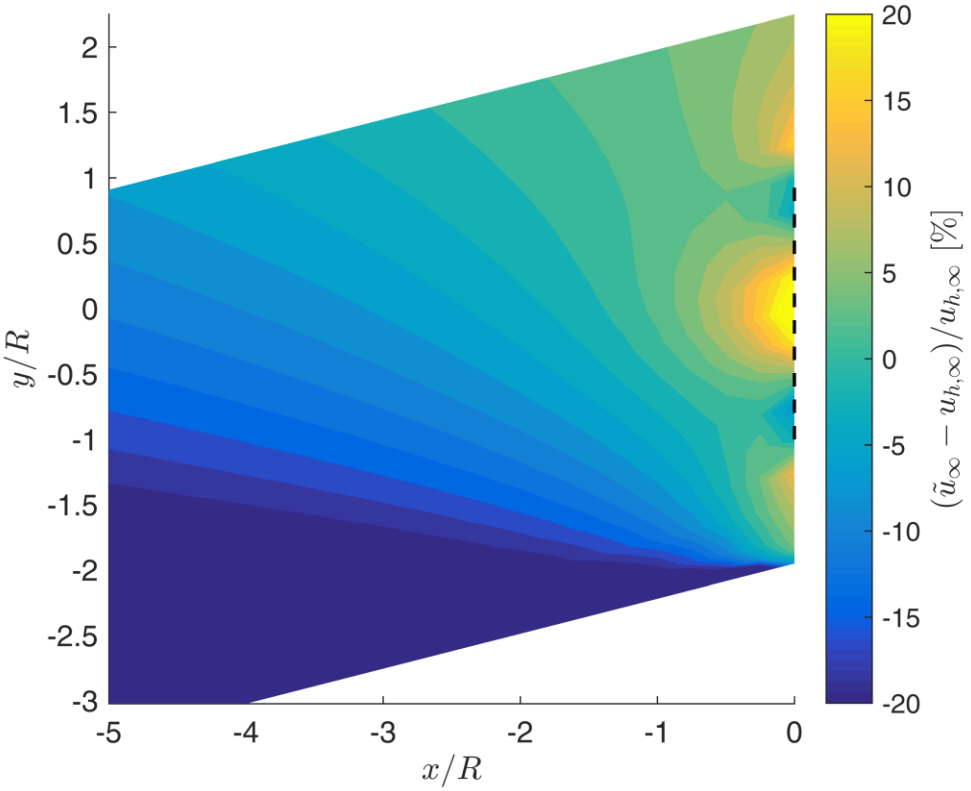
α_1 = 15 deg

α_2 = -15 deg

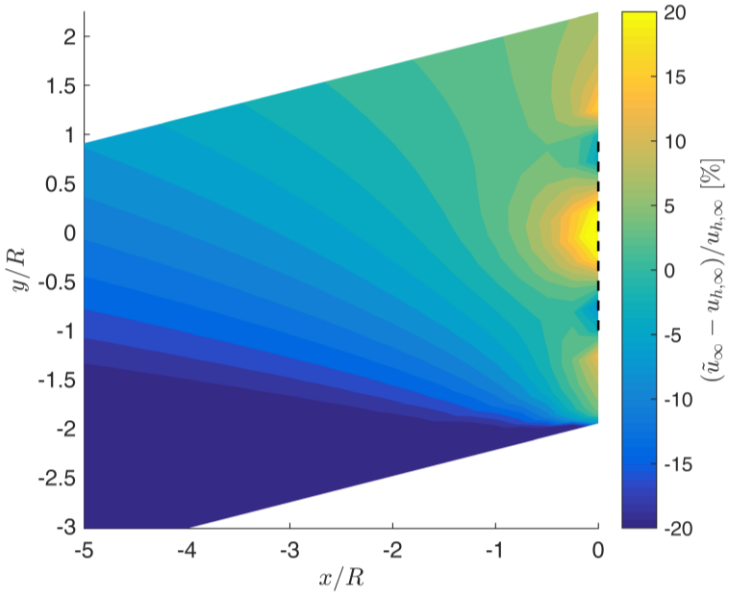
z_0 = 0.5 m

h = 1D

C_T = 0.89



Split error



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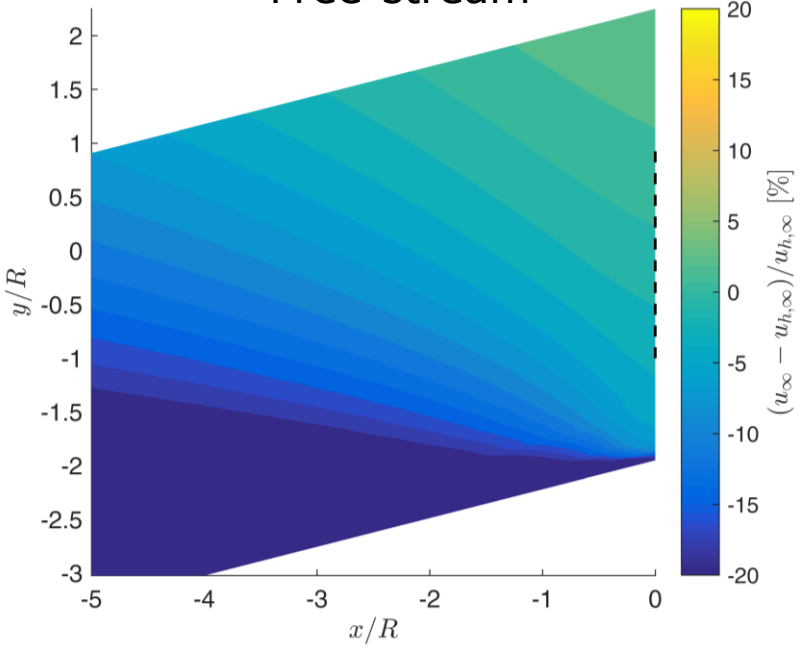
Free-stream



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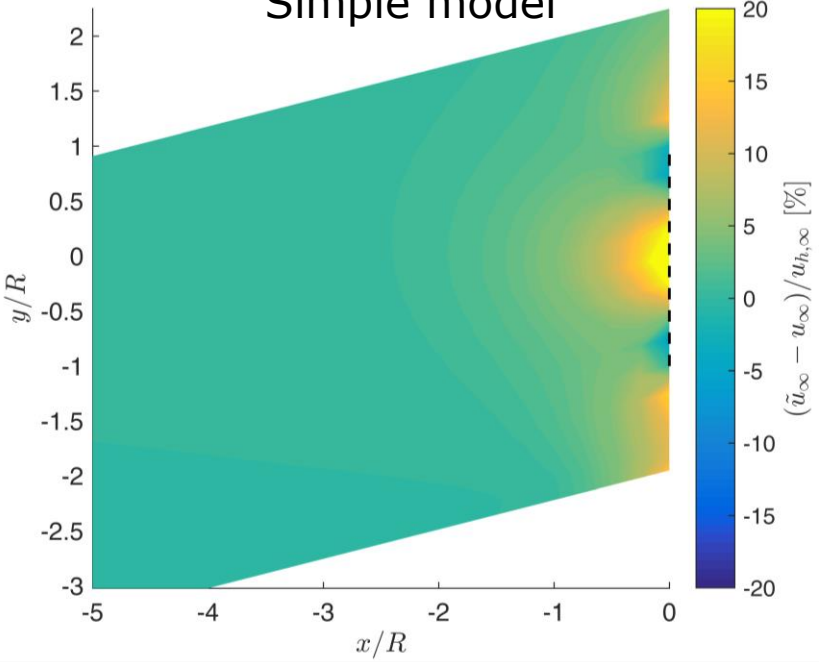
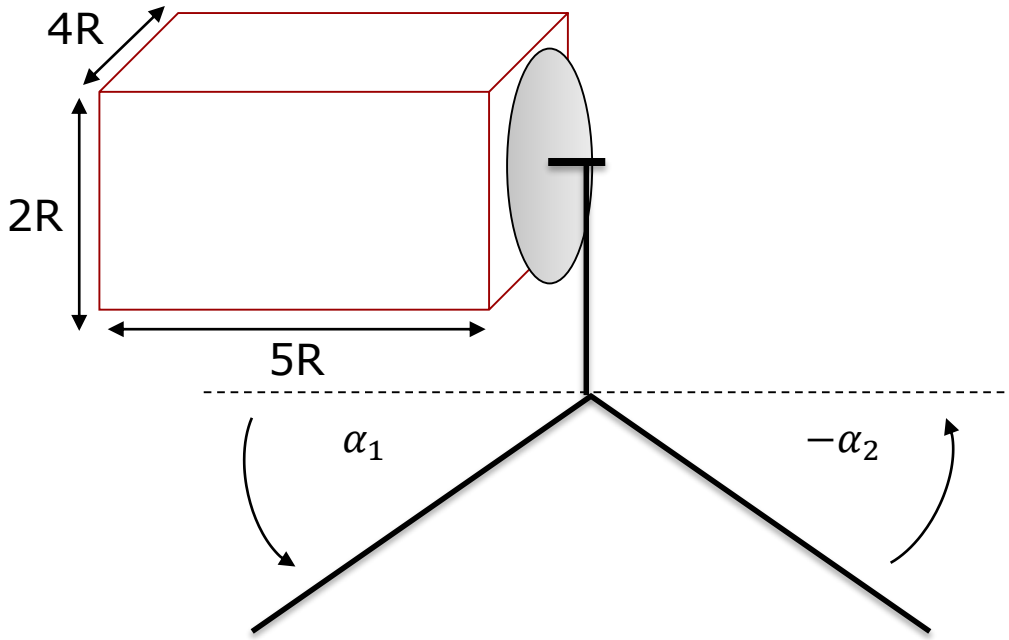
Simple model



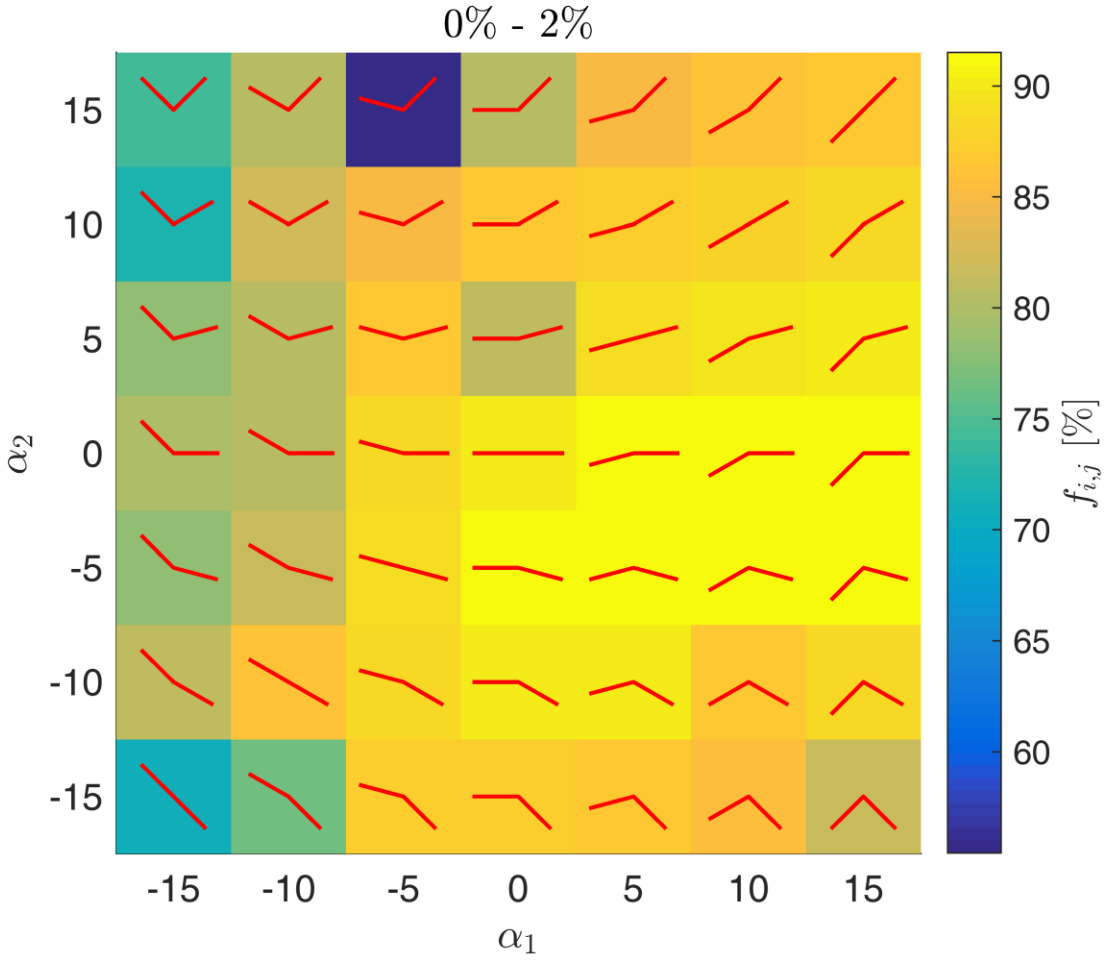
Test simple model

- Isolate simple model error
- Test in an volume upstream

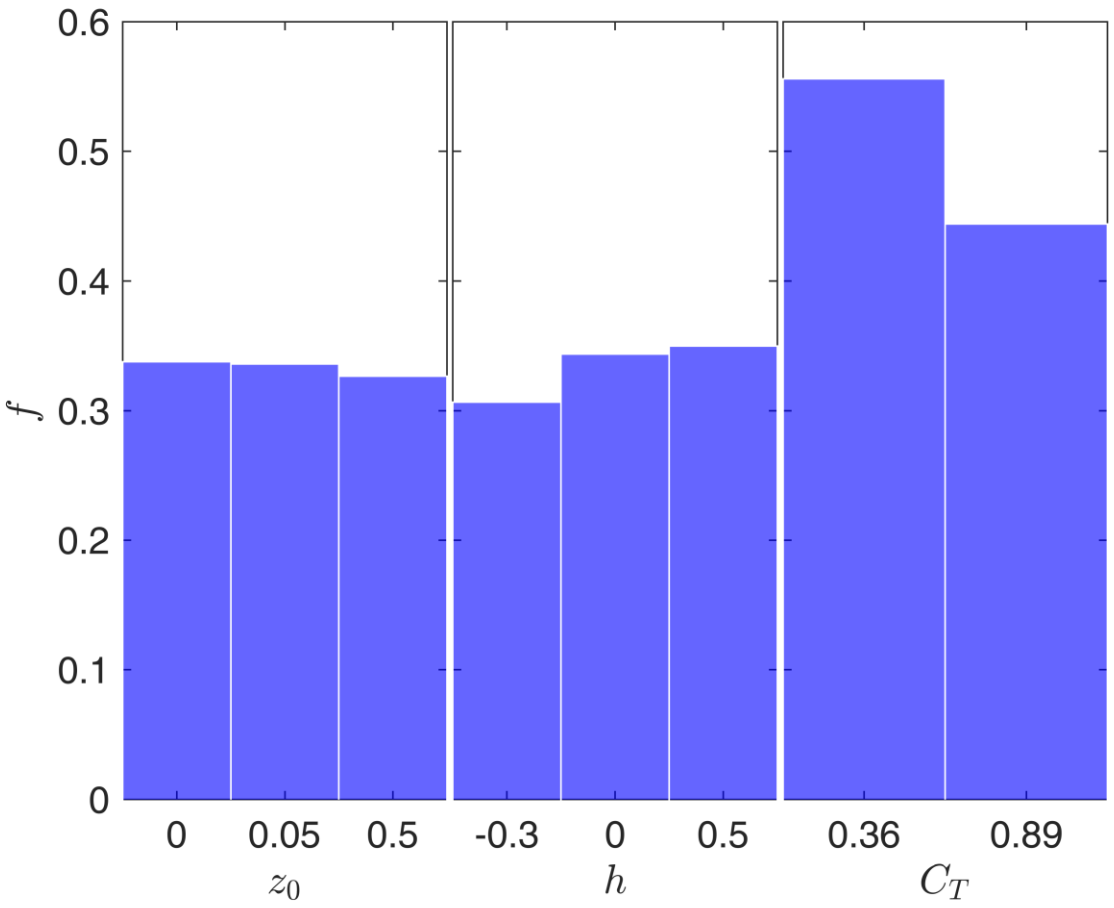


Test simple model

- Only keep points that are below 2% error
- Group data over each hill shape

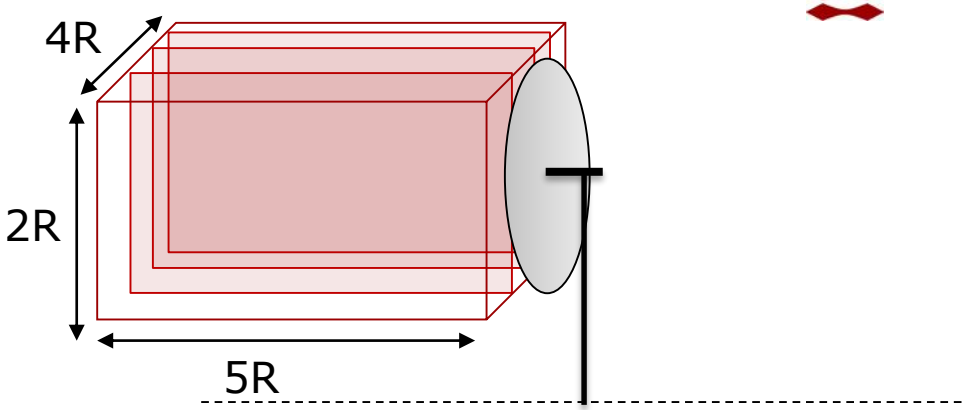


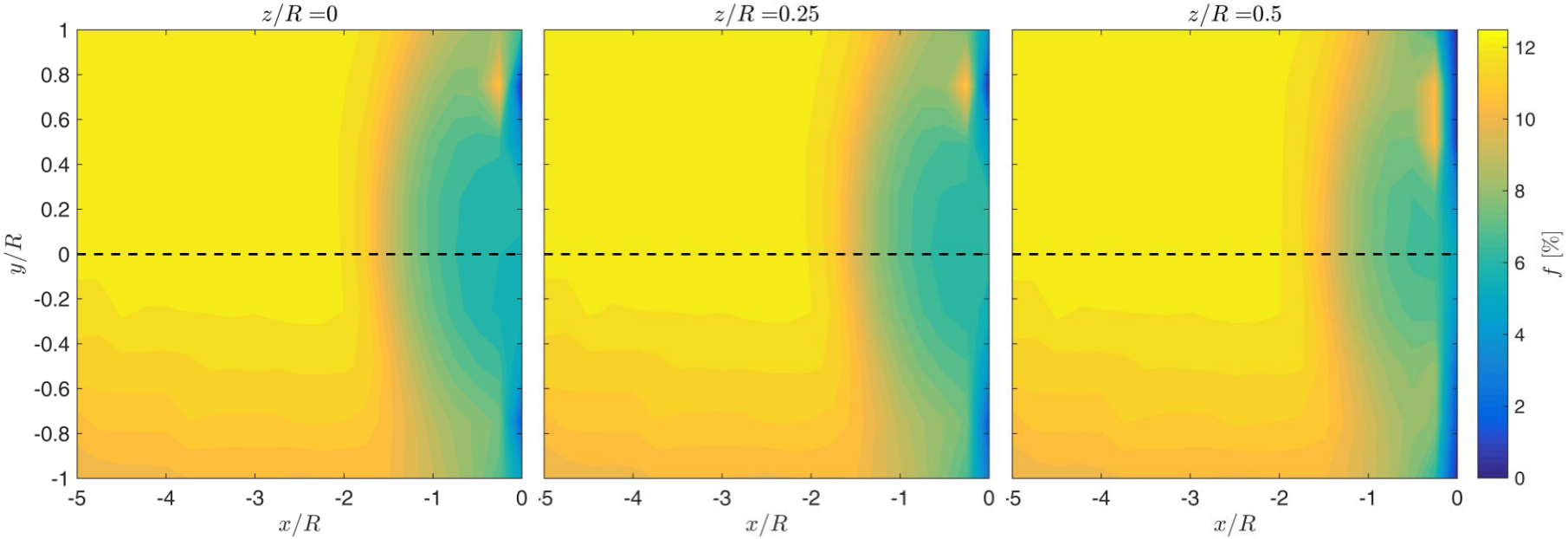
Test simple model



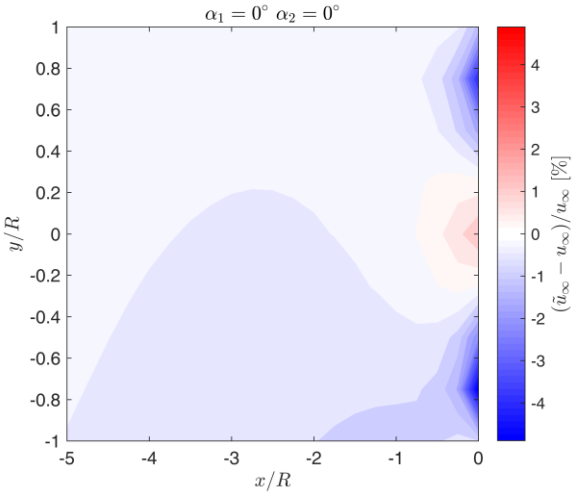
Test simple model

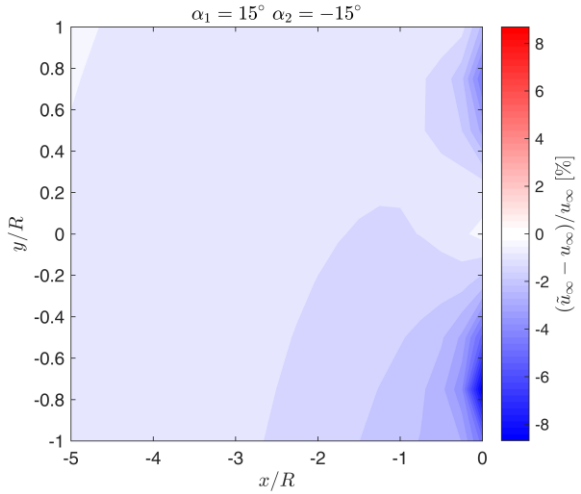
- Point density in x-y planes along constant depth

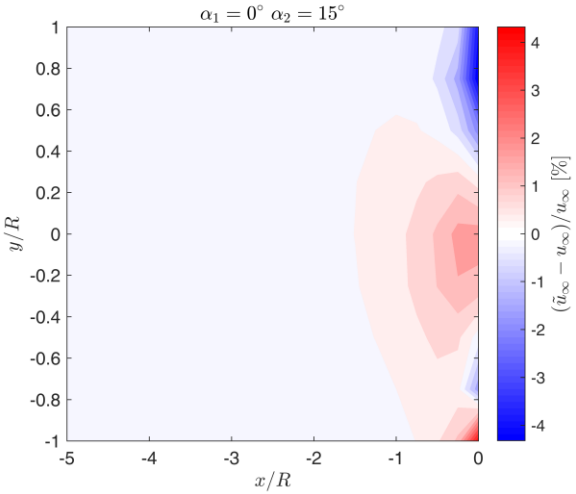


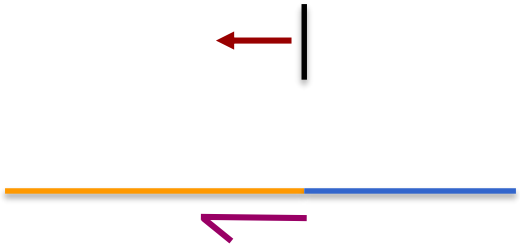


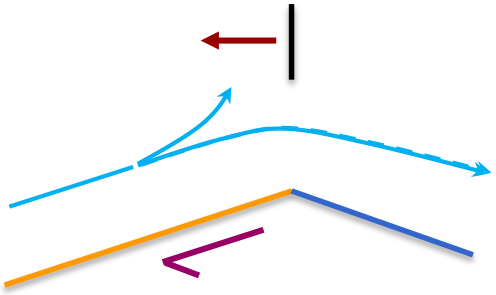
Error source

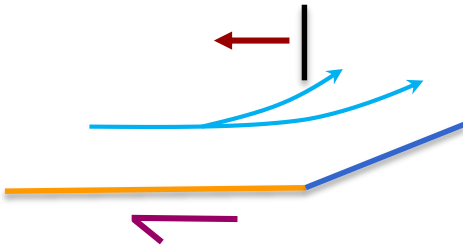




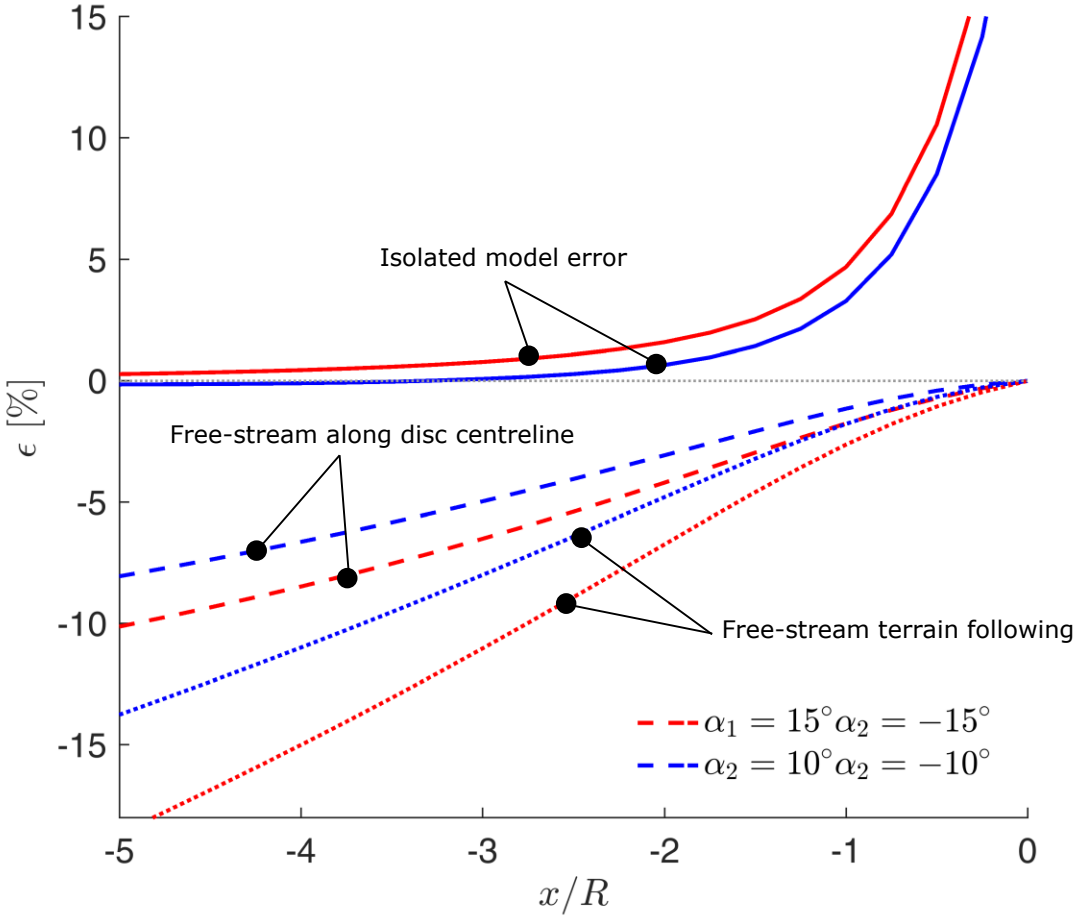


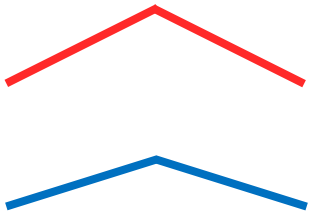




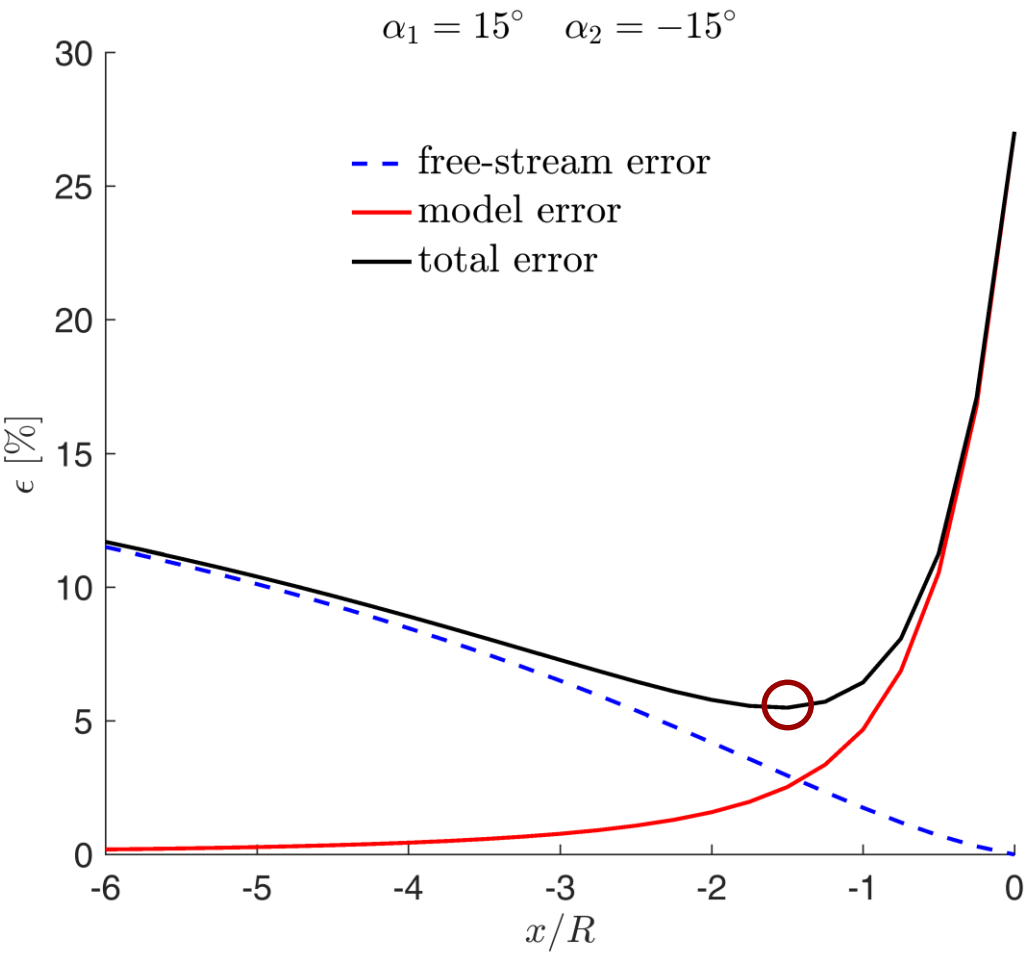


Error evolution along centreline



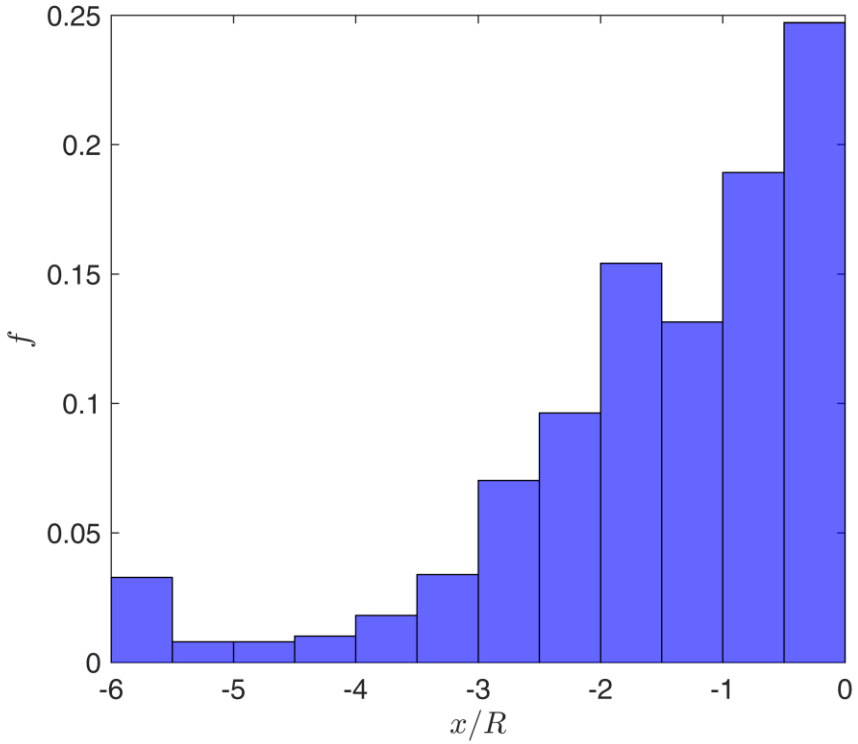


Minimise error



Minimum error location

- Minimum along centreline



Conclusions

- Simple induction model works fine in moderate terrain
- Largest error from free-speed evolution
- Optimal measurement location lies close to rotor $x < 3R$

Outlook

Measuring the free-stream

1. Measure relative close to turbine and use generic thrust curve
2. Use simple terrain model to predict $V_\infty(x)$
3. Fit induction model + $V_\infty(x)$

Acknowledgements

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Thanks for your attention!