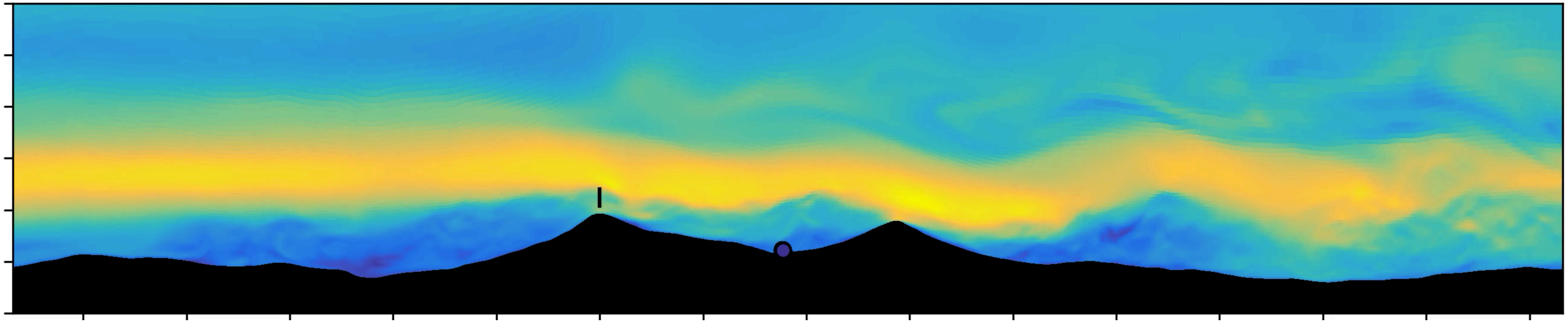
Multi-scale modeling of a wind turbine wake over complex terrain in different atmospheric stability regimes



Adam S. Wise[1], James M.T. Neher[1], Robert S. Arthur[2], Jeffrey D. Mirocha[2], Fotini K. Chow[1], Julie K. Lundquist[3,4]

[1]University of California, Berkeley

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19th Conference on Mountain Meteorology Virtual Meeting

15 July 2020

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Wind farms are commonly sited in complex terrain where terrain-induced flow features are present

- Acceleration over ridgelines

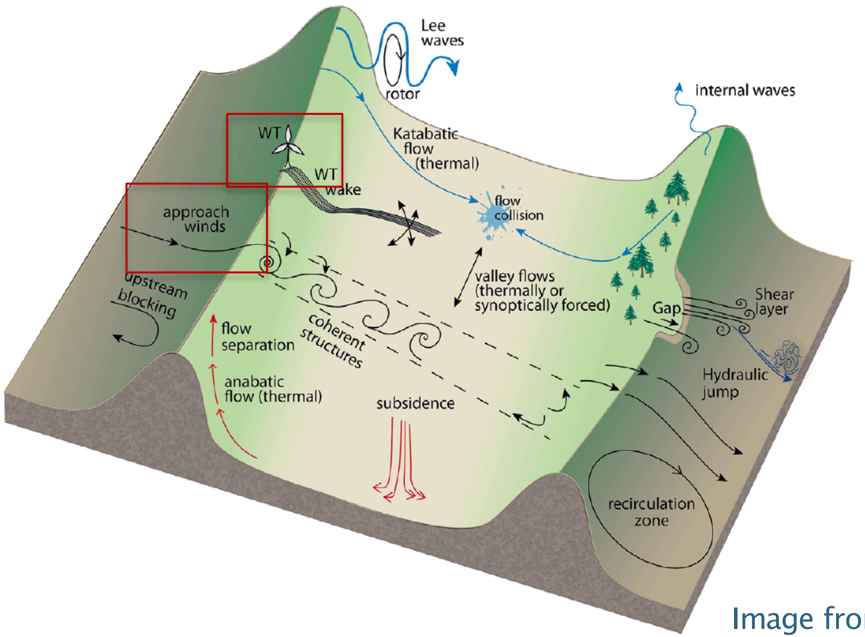

Image from Fernando et al. BAMS 2018

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Wind farms are commonly sited in complex terrain where terrain-induced flow features are present

- Acceleration over ridgelines
- Recirculation zones

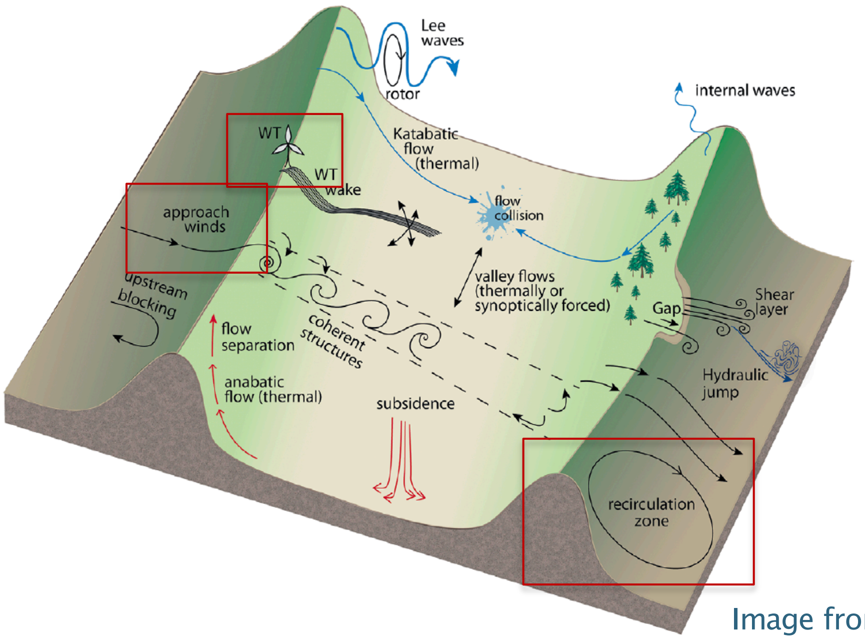

Image from Fernando et al. BAMS 2018

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Wind farms are commonly sited in complex terrain where terrain-induced flow features are present

- Acceleration over ridgelines
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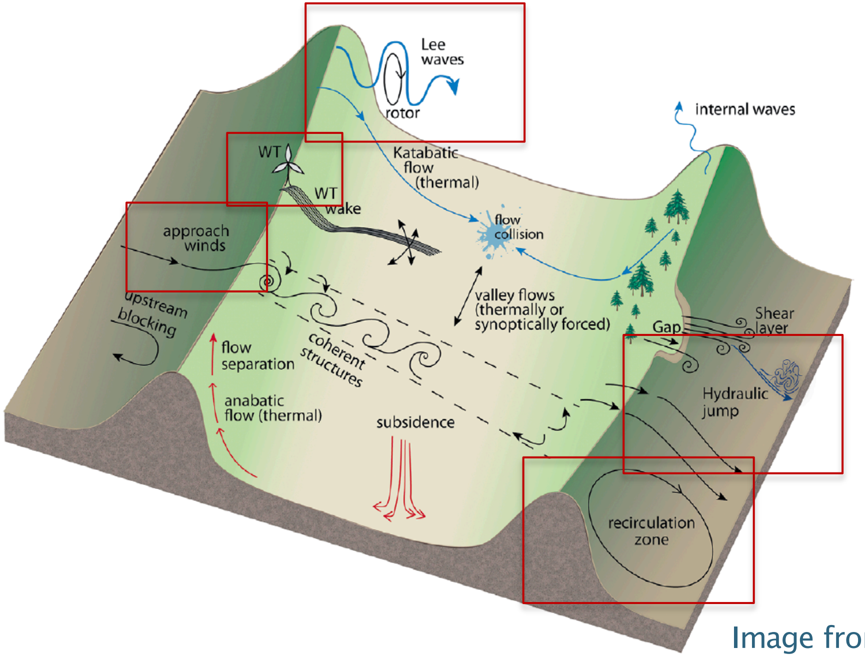

Image from Fernando et al. BAMS 2018

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Wind farms are commonly sited in complex terrain where terrain-induced flow features are present

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Research Question:
How do wakes behave in complex terrain?

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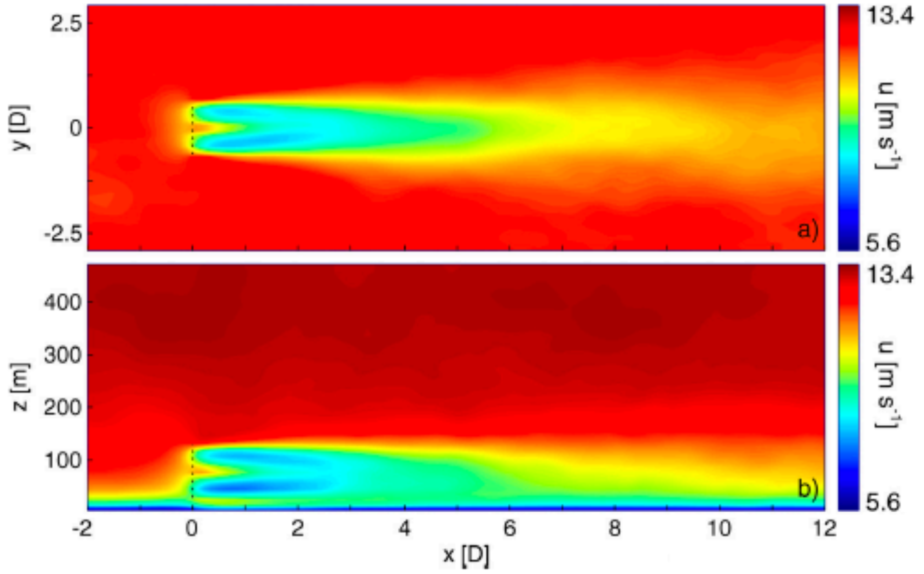

Image modified from Mirocha et al. 2015

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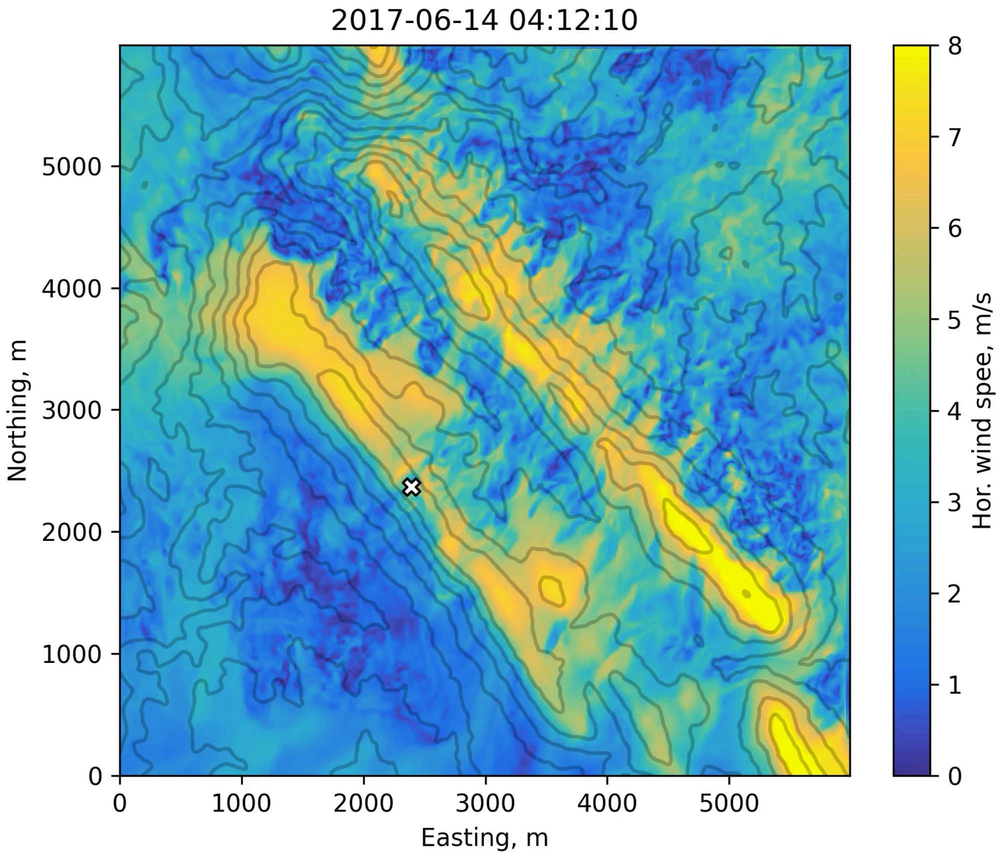
Goal: Use WRF-LES-GAD in complex terrain to confirm importance of stability on wake propagation

- Wind inflow in different atmospheric stability regimes

- Interaction of wake and microscale features



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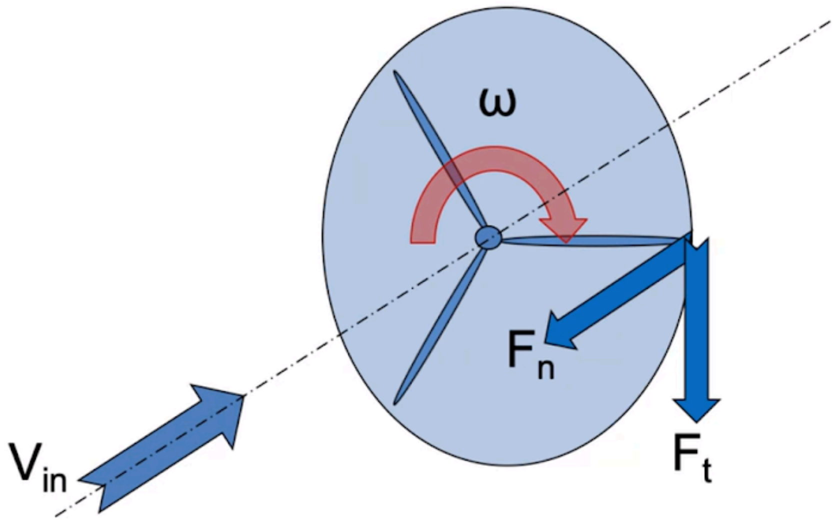
Goal: Use WRF-LES-GAD in complex terrain to confirm importance of stability on wake propagation

- WRF: Weather Research and Forecasting model
- LES: Large-eddy simulation
- GAD: Generalized actuator disk



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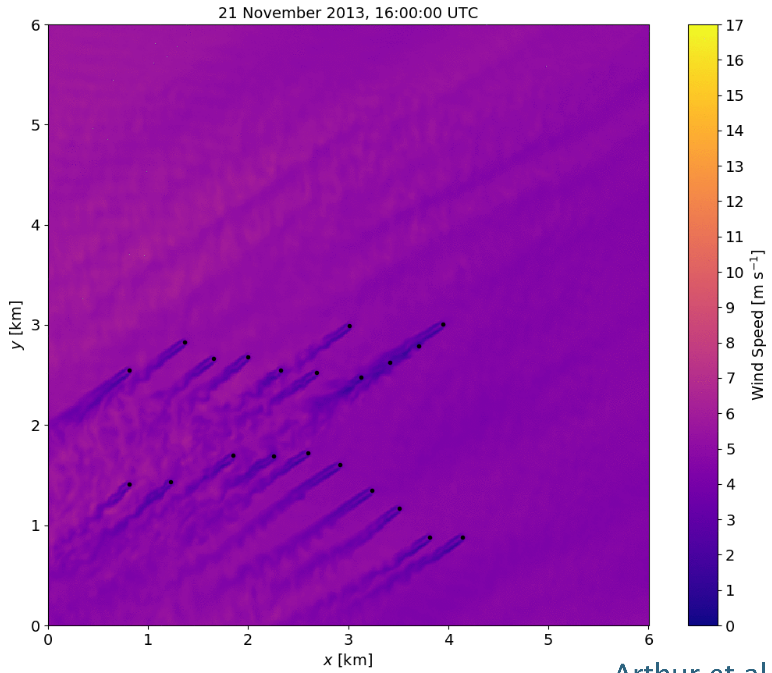
Goal: Use WRF-LES-GAD in complex terrain to confirm importance of stability on wake propagation

- Previously validated in different stability conditions for flat terrain
  - Mirocha et al. 2014
  - Mirocha et al. 2015

- Modifications to GAD parameterization to handle inflow in complex terrain



Arthur et al. *Atmosphere* 2020

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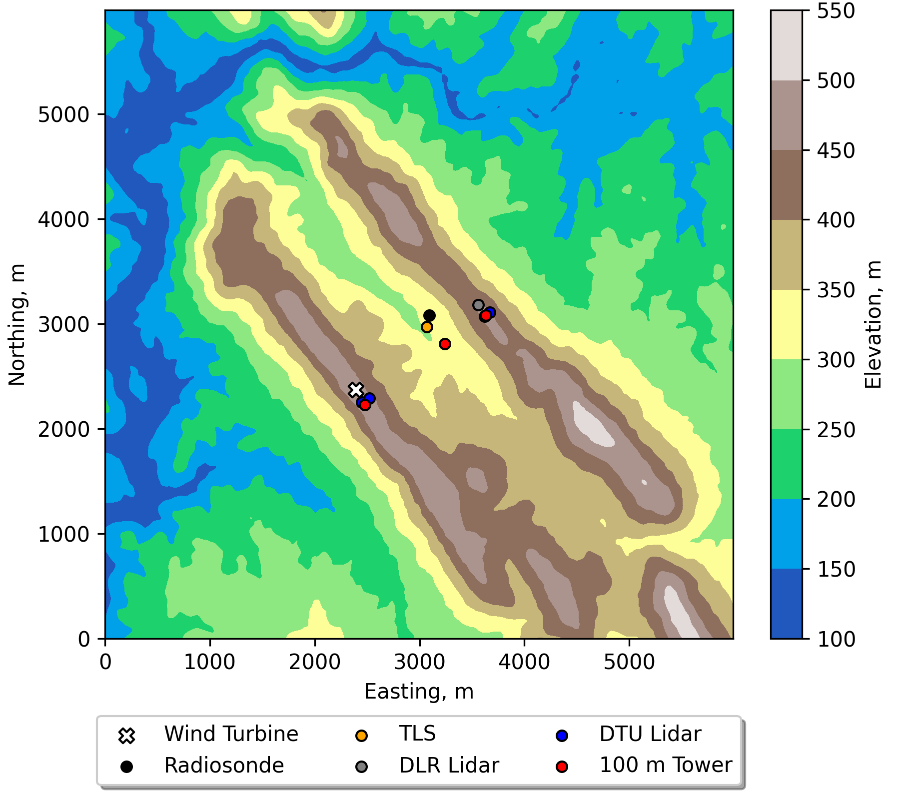
Presentation outline

- Brief description of the Perdigão site and instrumentation
- Observations and measurements of wind turbine wakes at Perdigão
- Semi-idealized model and preliminary results
- Real model setup, results, and comparisons with measurements
    - Stable case study
    - Convective case study

Perdigão field campaign

- Two parallel ridges with a wind turbine on the southwest ridge
- Intensive operation from May 1 to June 15, 2017
- Instrumentation
  - 100 m meteorological towers
  - Radiosonde
  - Lidars
  - Tether lifting system (TLS)



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Observations of wind turbine wakes at Perdigão

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Wakes deflect downwards in stable conditions and upwards in neutral and convective conditions

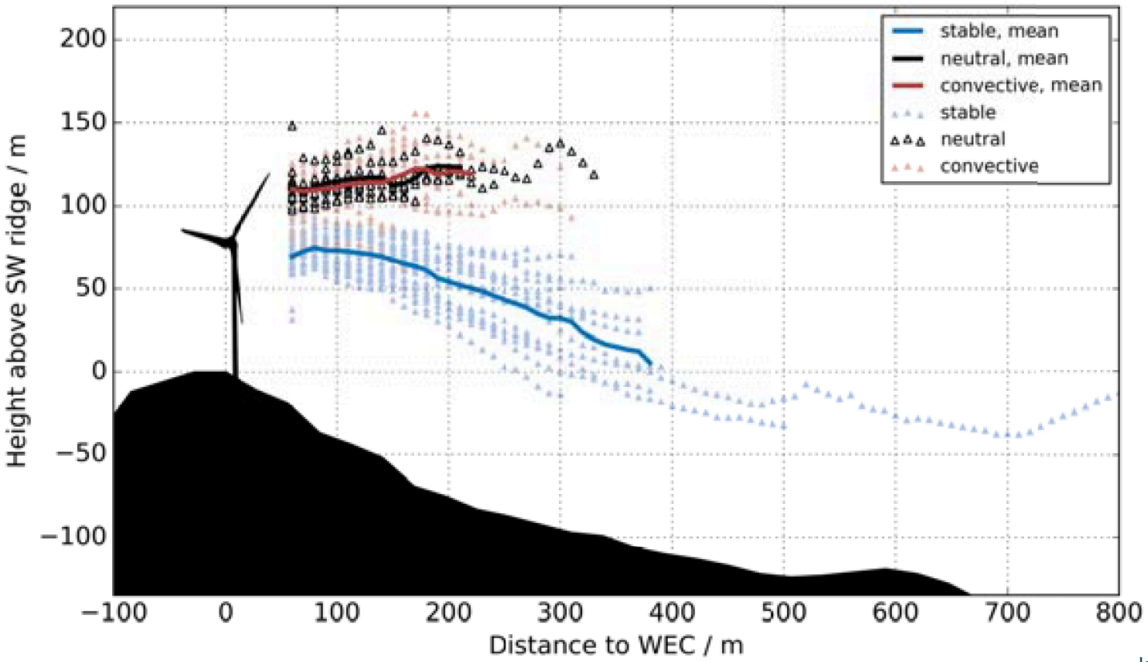
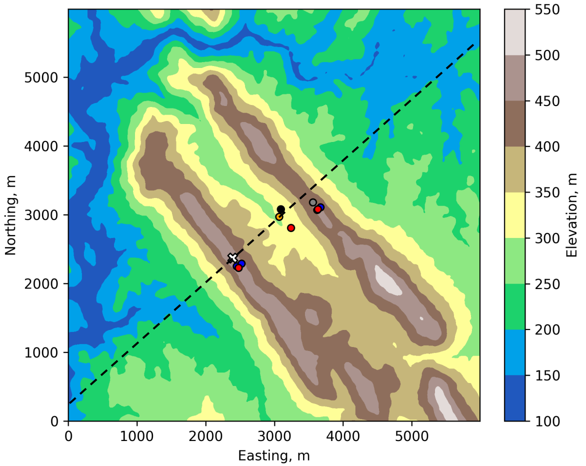


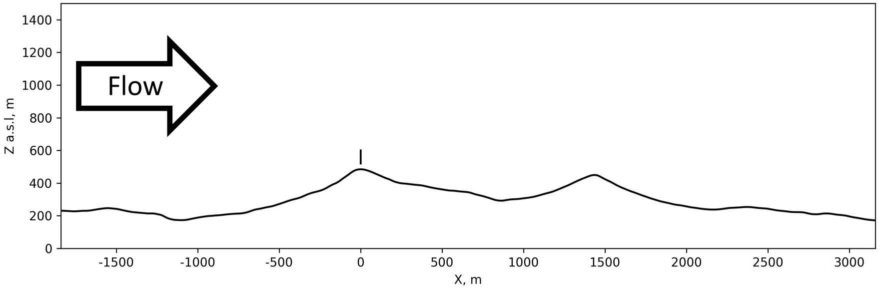
Image from Wildmann et al. 2018

Modeling Perdigão

Starting with a semi-idealized model as a proof of concept

- Periodic boundary conditions
- 2D cross-section
- Grid spacing of 10 m
- Surface roughness of 0.5 m





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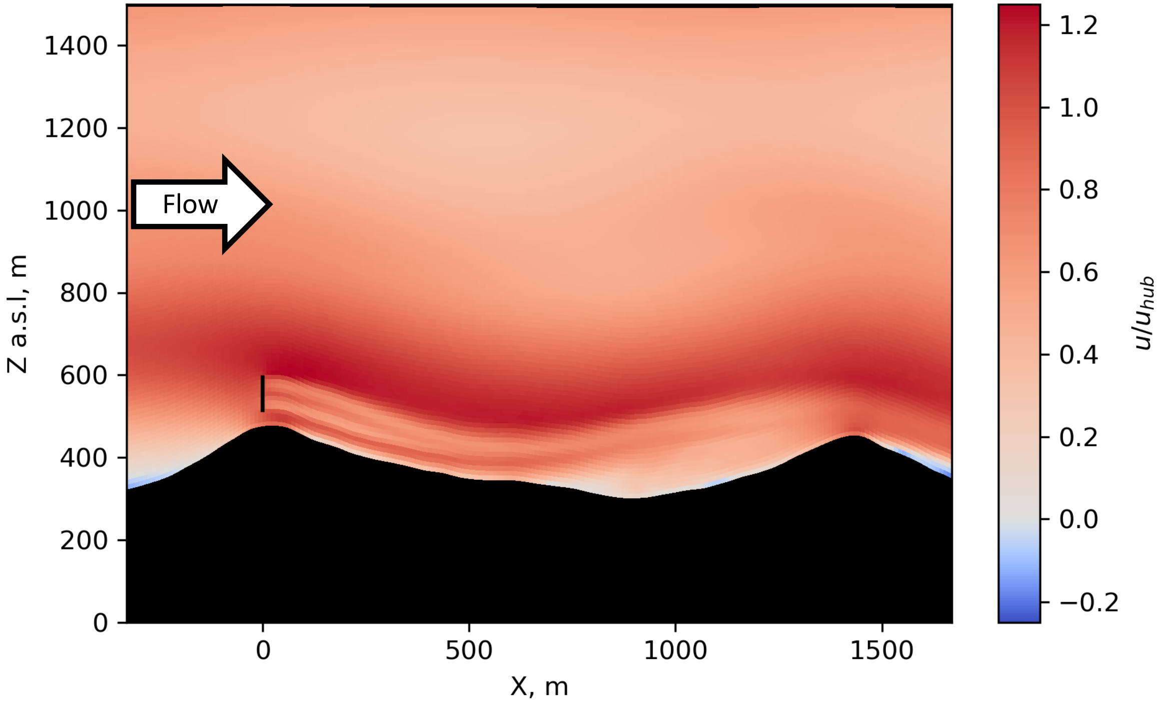
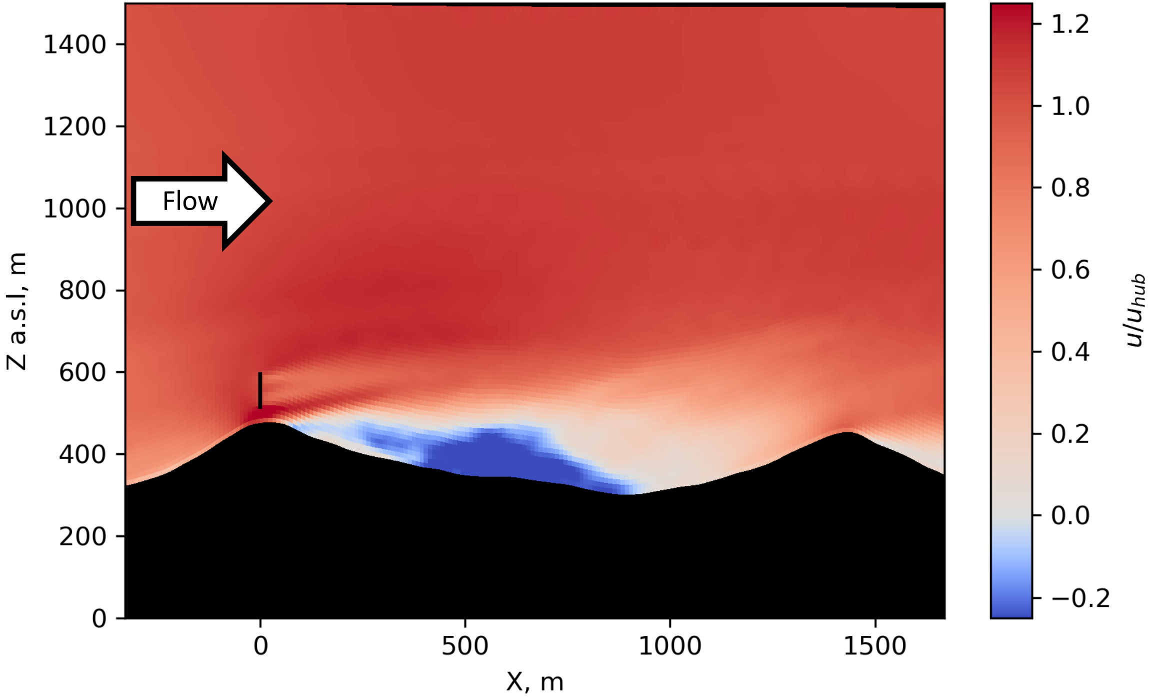
Semi-idealized model results match well with observed wake behavior for stable conditions



Semi-idealized model results match well with observed wake behavior for convective conditions



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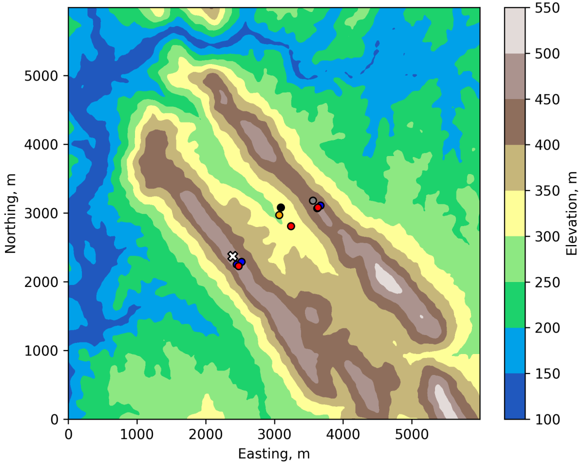
Real model setup

Domain	1	2	3	4	5
Closure	2.5-level MYNN		TKE 1.5		
dx	6750 m	2250 m	150 m	50 m	10 m
dz_{min}	60 m	60 m	30 m	30 m	8 m
n_x x n_y	141 x 141	181 x 181	271 x 271	271 x 271	601 x 601
nz	81	81	101	121	161
dt	30 s	10 s	0.5 s	0.0833 s	0.0167 s

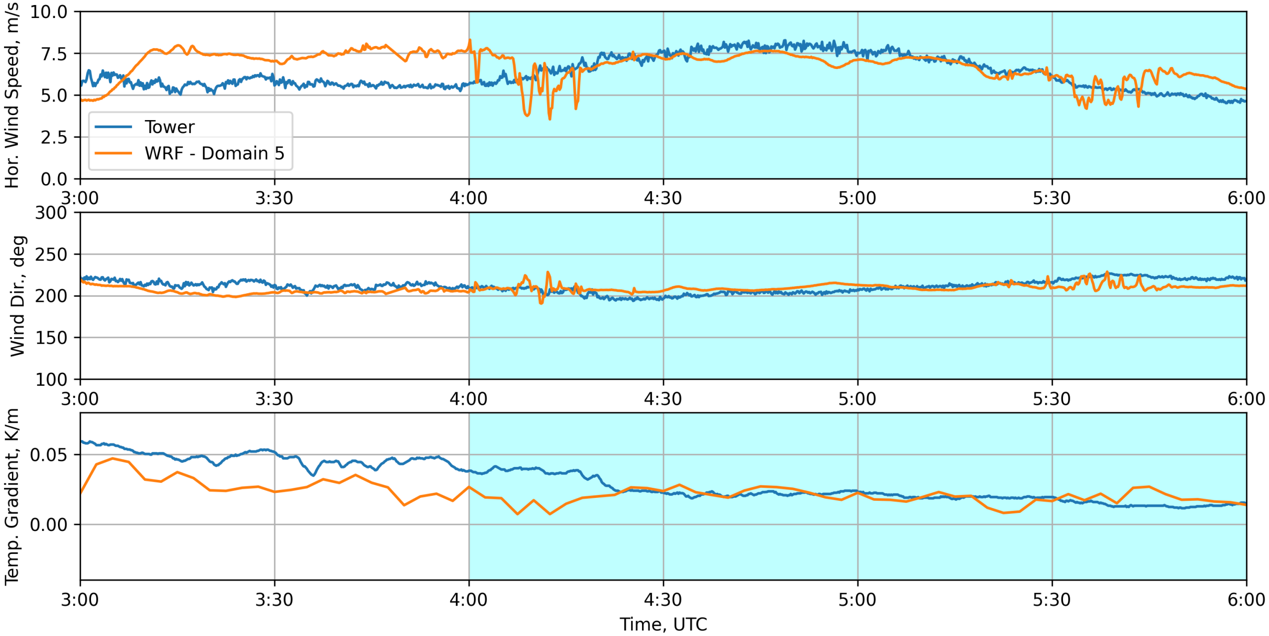


- Forcing: GFS 0.5^{o} Lat/Lon
- High resolution 10 m topography and land-use

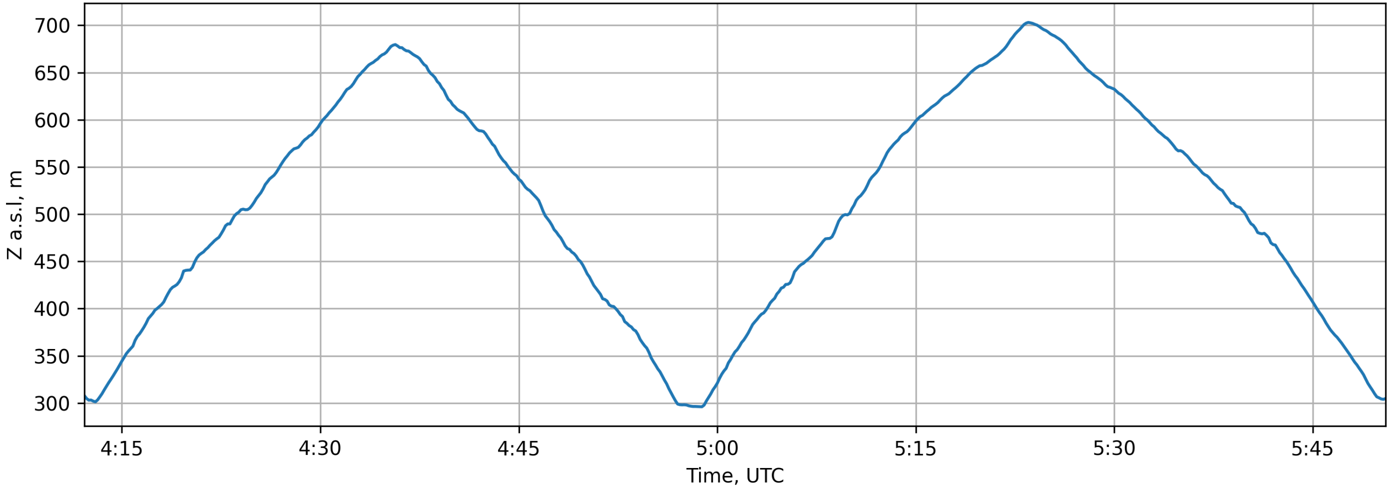
Stable Case Study:
June 14, 03:00-06:00 UTC

The real model compares well with met tower data

	Bias	RMSE
Wind Speed	−0.09 m/s	0.79 m/s
Wind Dir.	−0.1°	7.7°
Temp. Grad	−0.003 K/m	0.011 K/m



Reminder: The TLS is a device that moves up, down, and drifts



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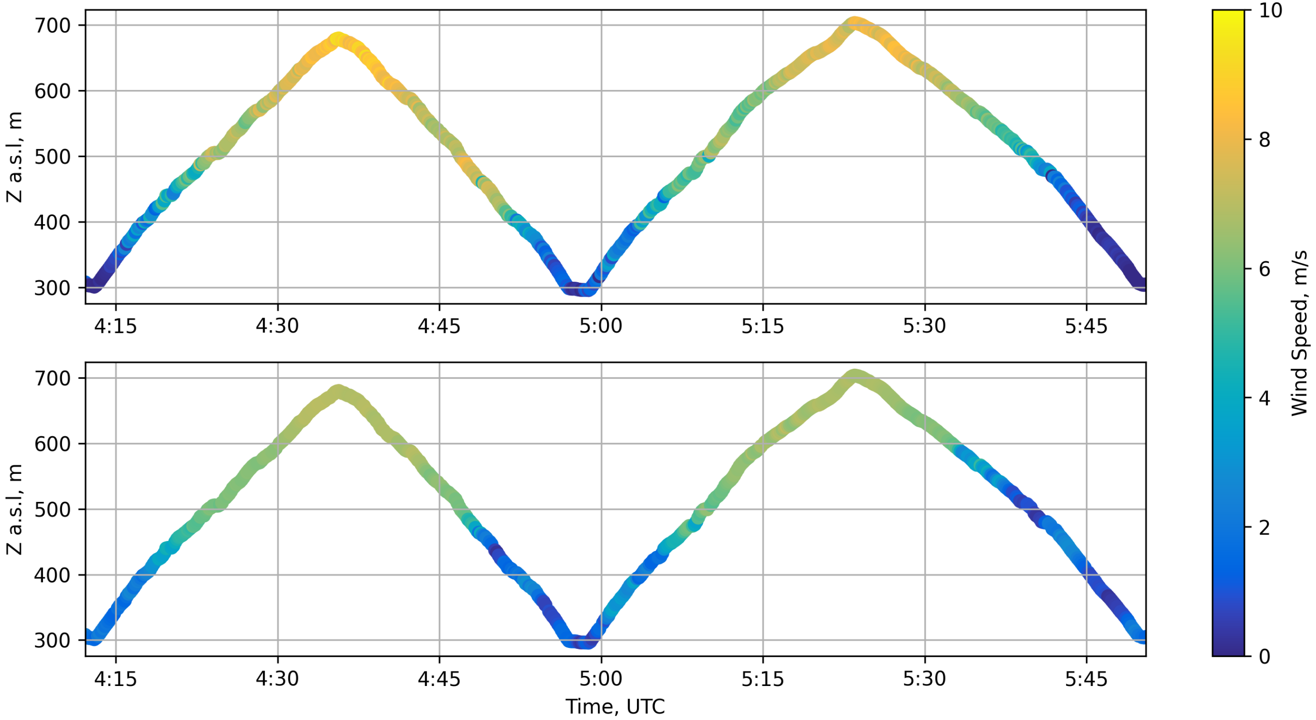
A ‘virtual TLS’ compares well with the actual TLS

TLS

WRF



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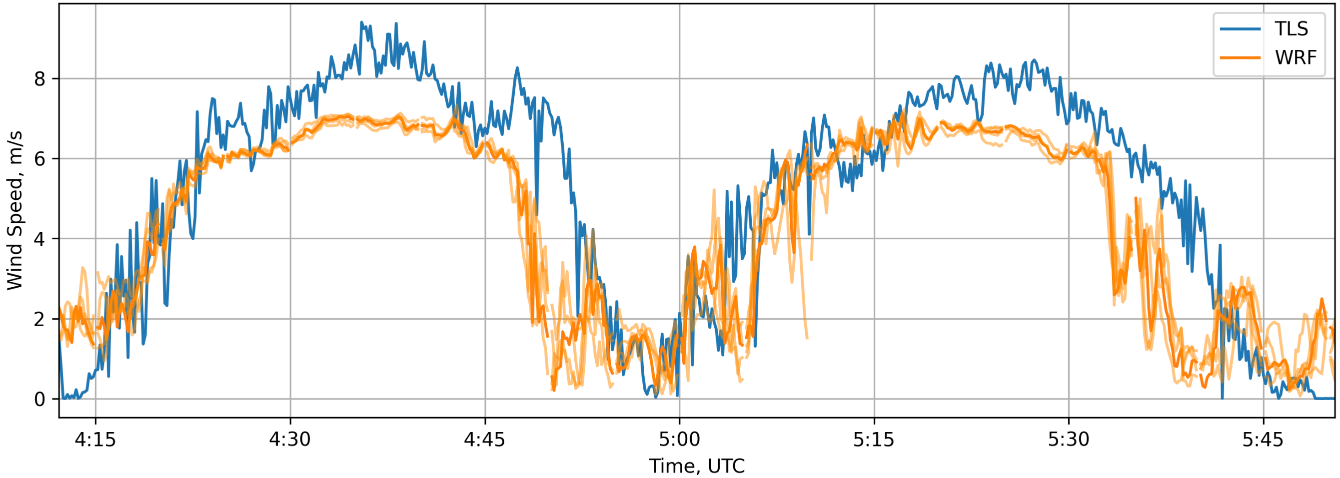
But the model underestimates the strength of the jet

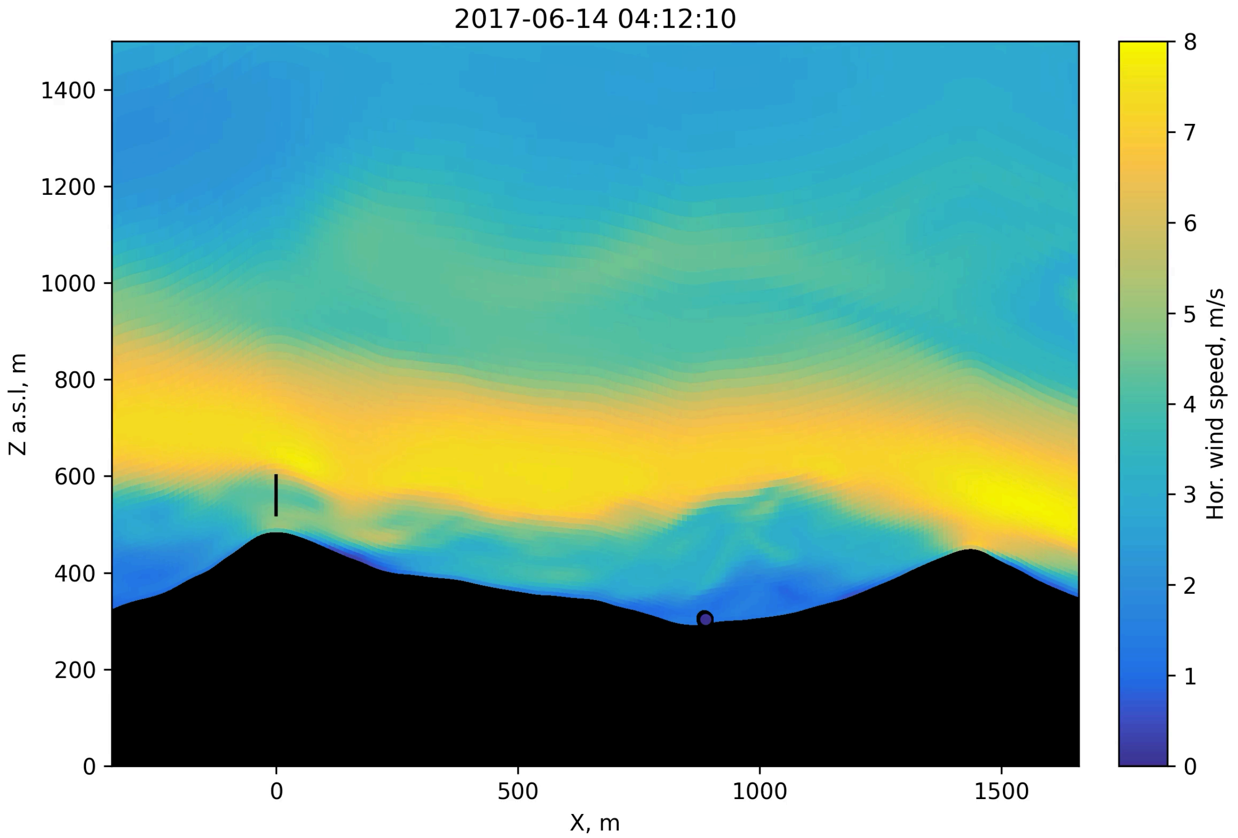
	Bias	RMSE
Wind Speed	-0.83 (m/s)	1.74 (m/s)



The wake deflects downward into the valley

$$Fr = \frac{U/h}{N} \approx 1.1$$

$$N = \left(\frac{g}{\theta_{10\mathrm{m}}} \frac{\theta_{100m} - \theta_{10m}}{100 - 10}\right)^{\frac{1}{2}}$$



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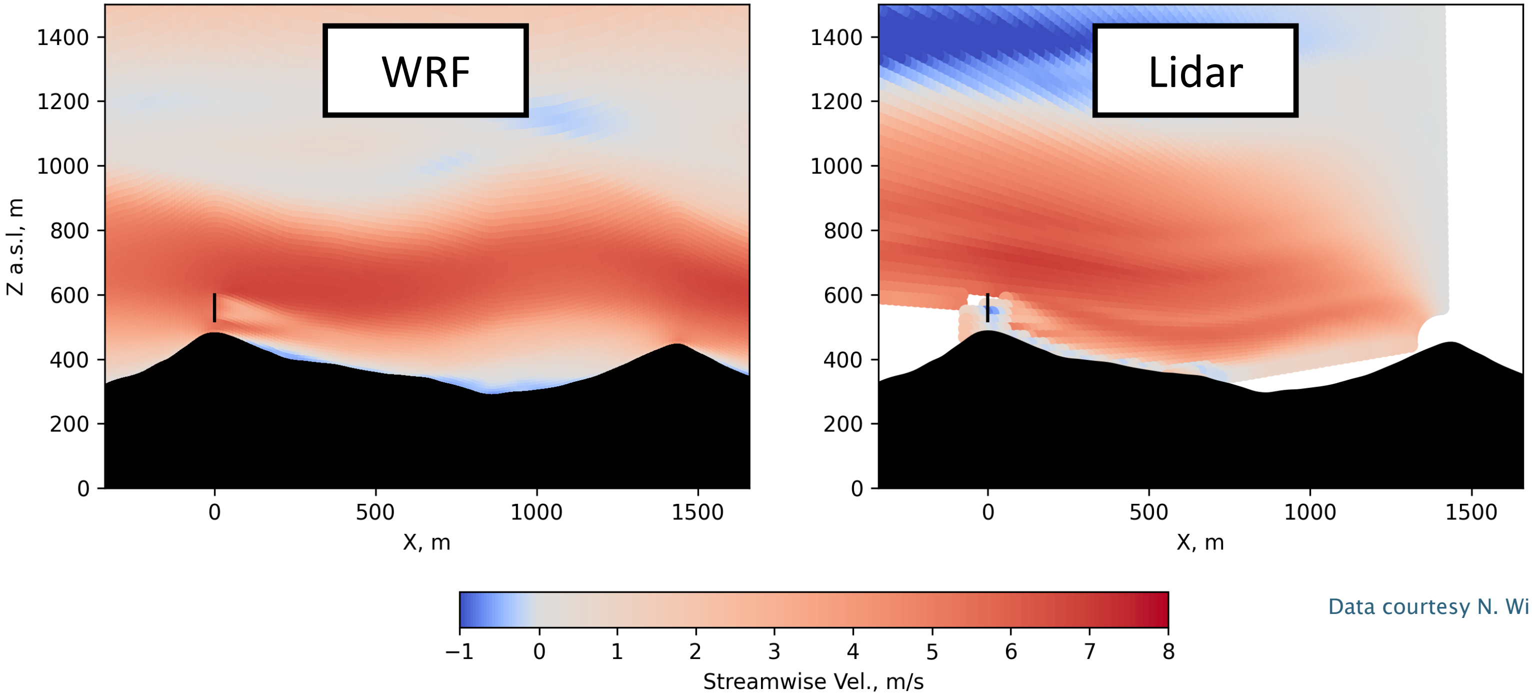
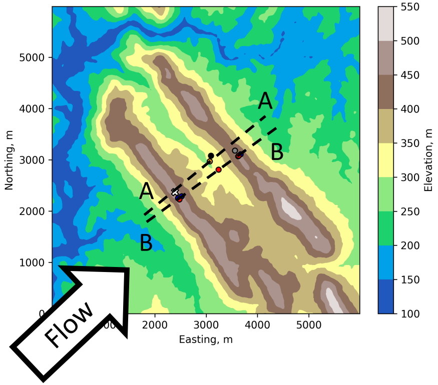
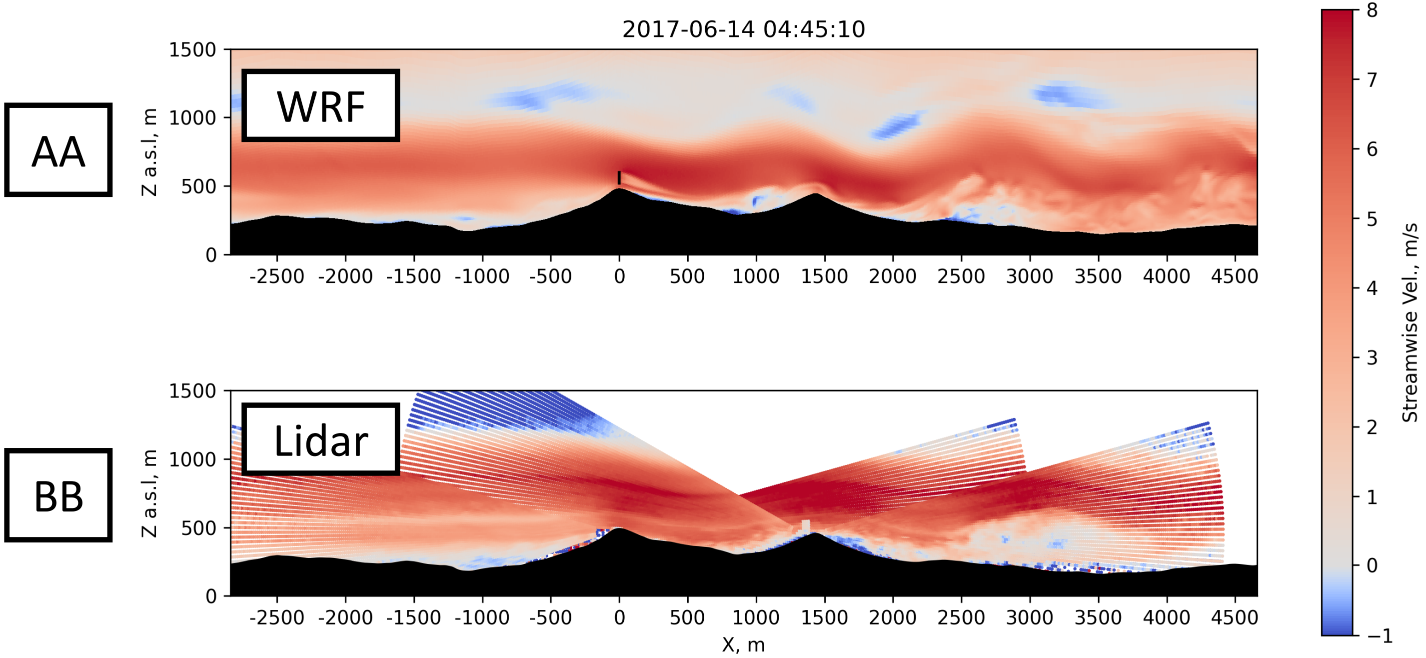


Data courtesy N. Wildmann, DLR

The model captures the hydraulic jump in the lee of the second ridge





Data courtesy R. Menke, DTU

Convective Case Study: May 13, 12:00-14:00 UTC

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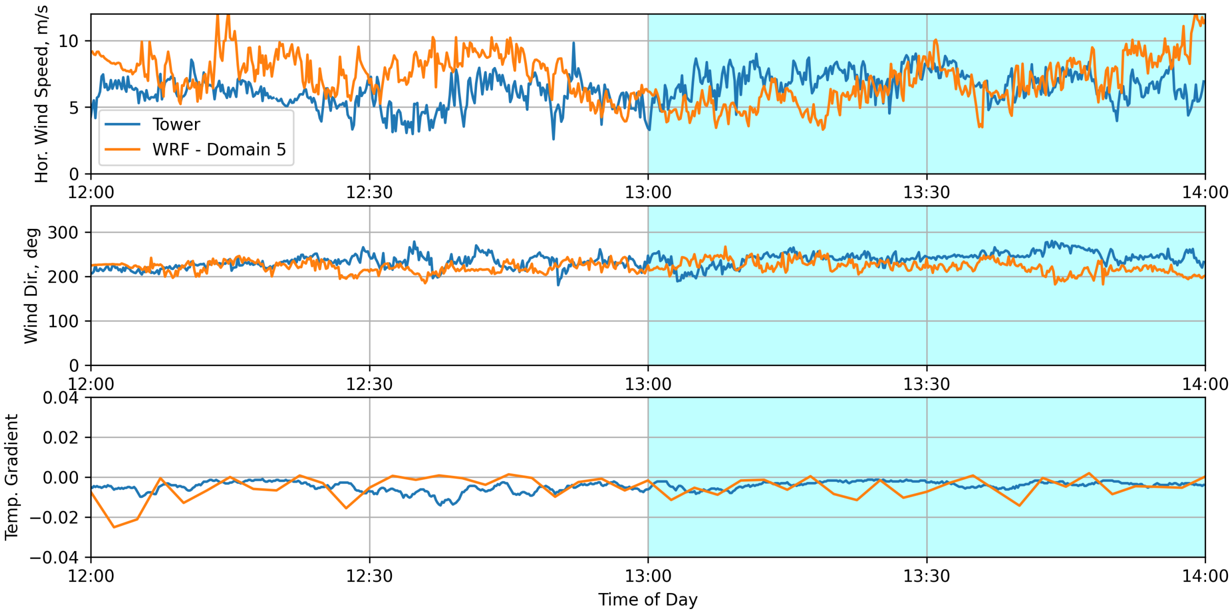
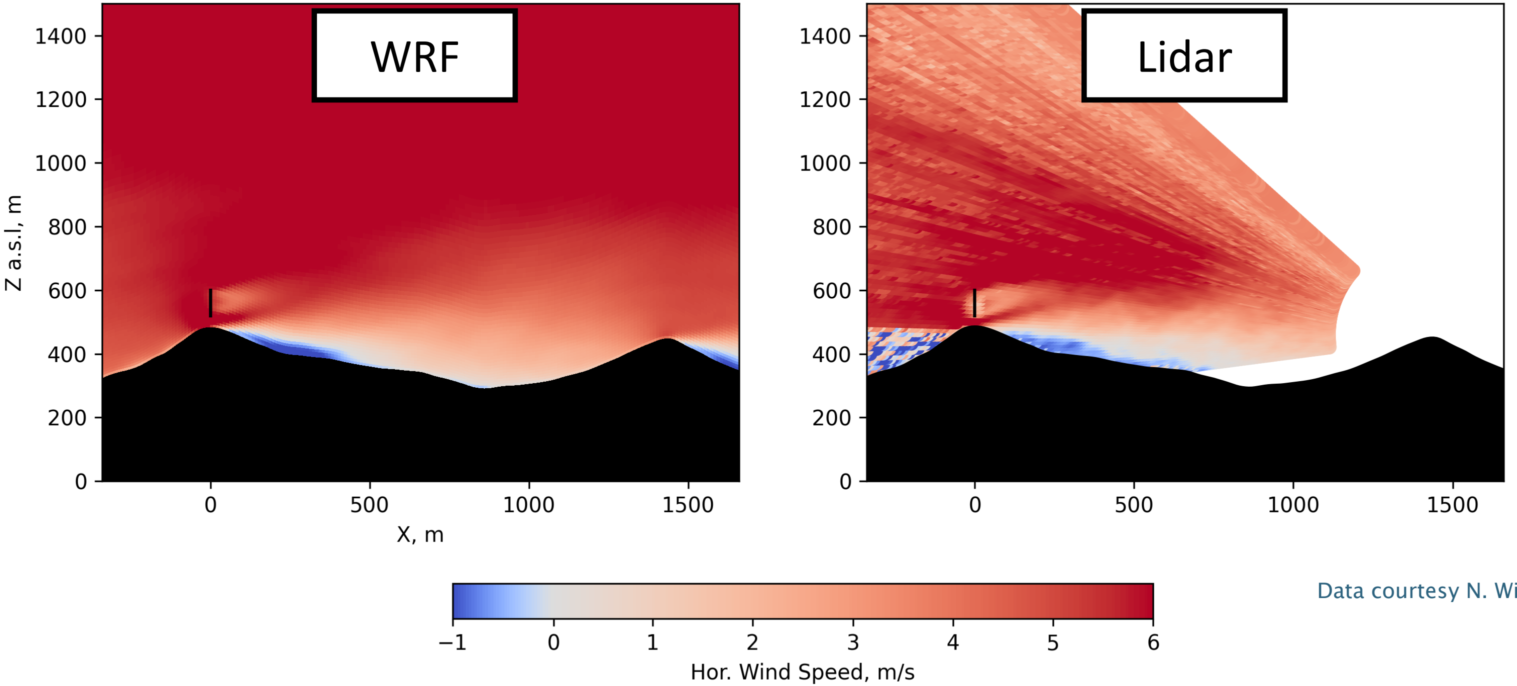
The real model compares well with met tower data

	Bias	RMSE
Wind Speed	−0.83 m/s	1.74 m/s
Wind Dir.	−20.0°	31.5°
Temp. Grad	−0.002 K/m	0.005 K/m



The wake deflects upwards above the recirculation zone



Data courtesy N. Wildmann, DLR

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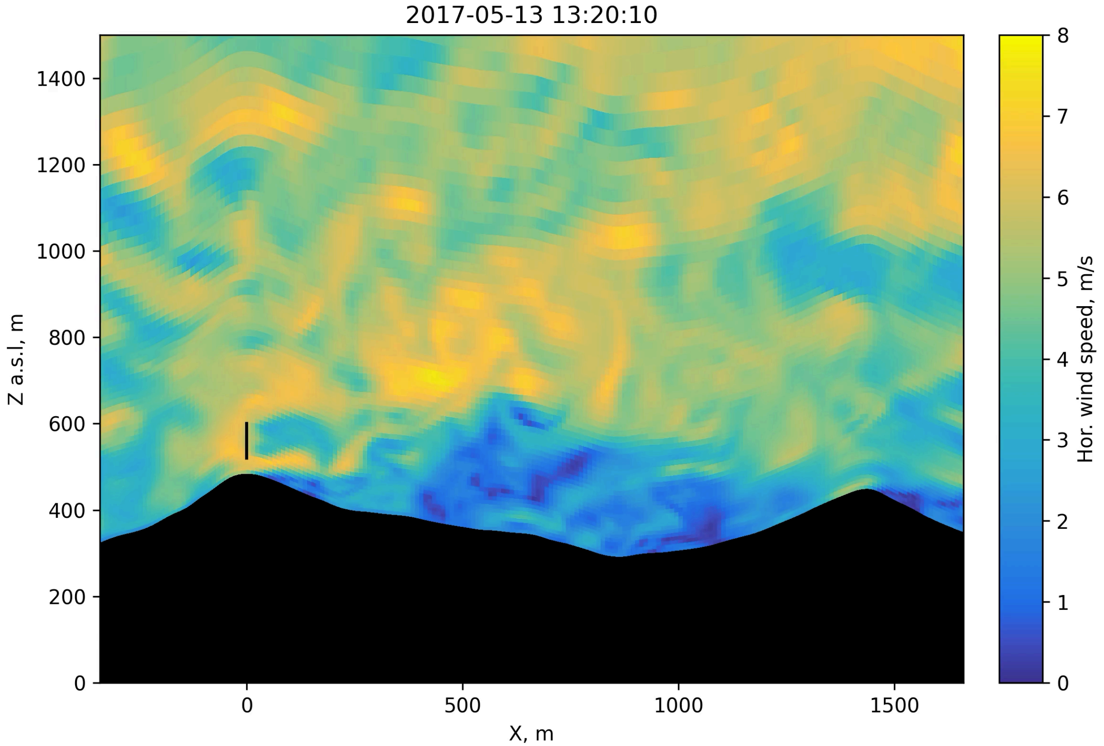

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Conclusions

- WRF-LES captures microscale features present in complex Perdigão terrain

- The GAD model accurately captures wake interaction with terrain-induced features

- Wake deflects downwards in the stable case and upwards in the convective case

Conclusions

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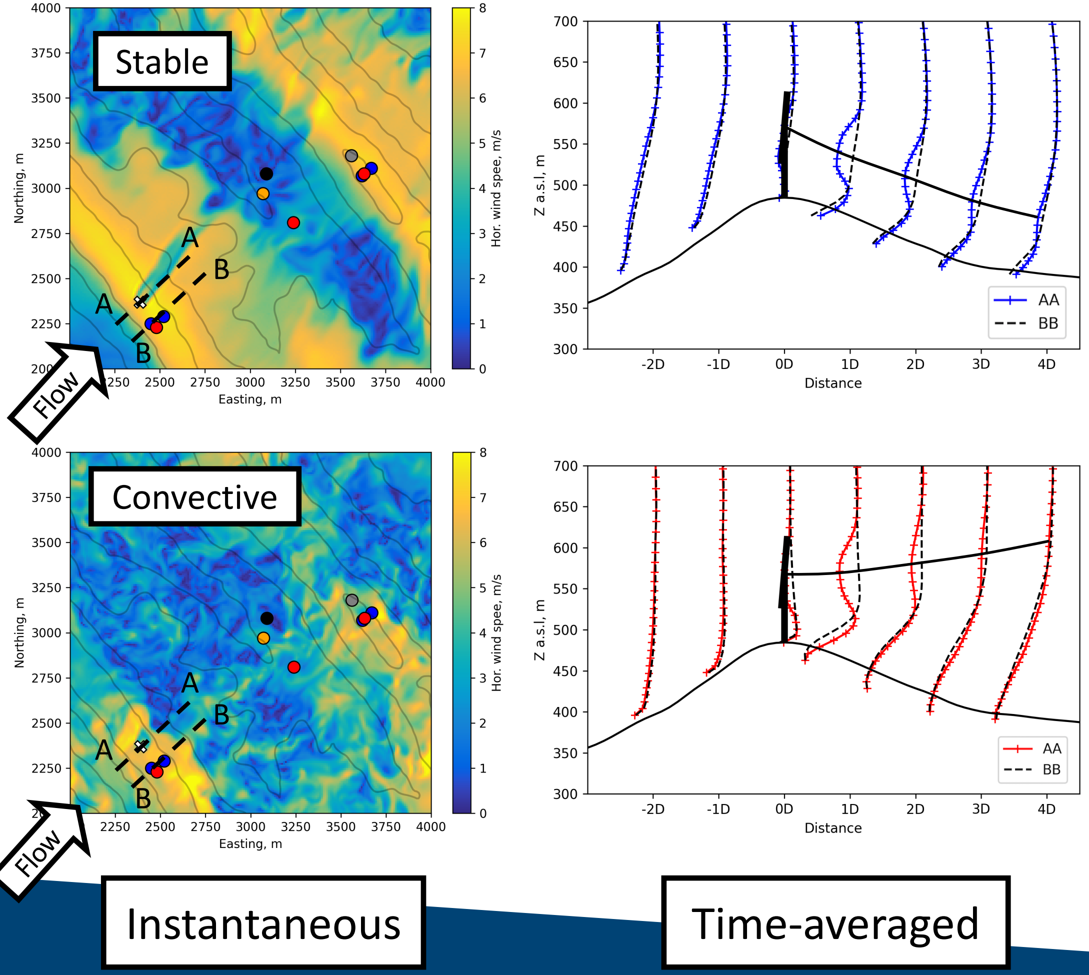

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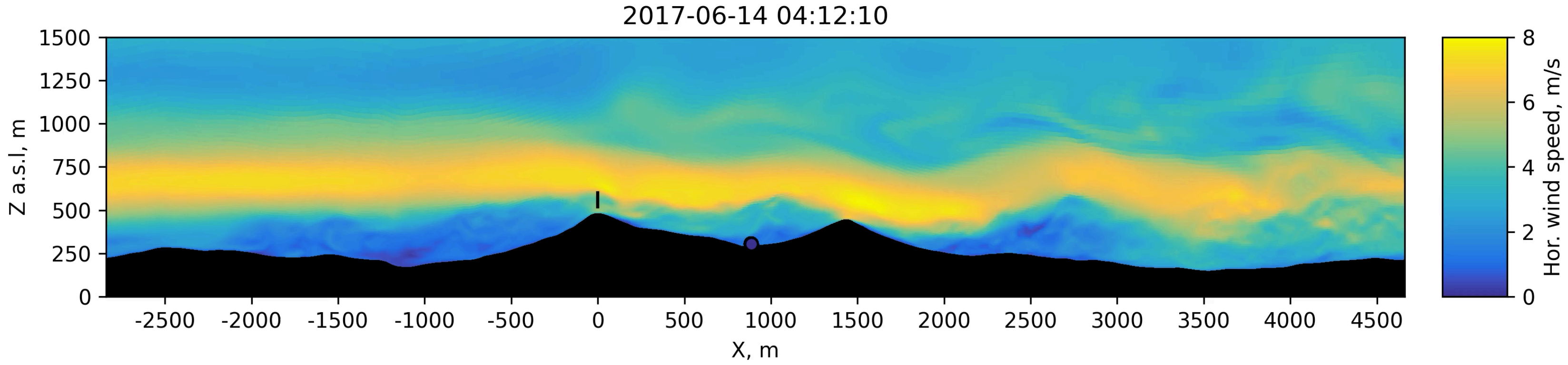
Thank You!



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- ASW is funded by an NSF Graduate Research Fellowship

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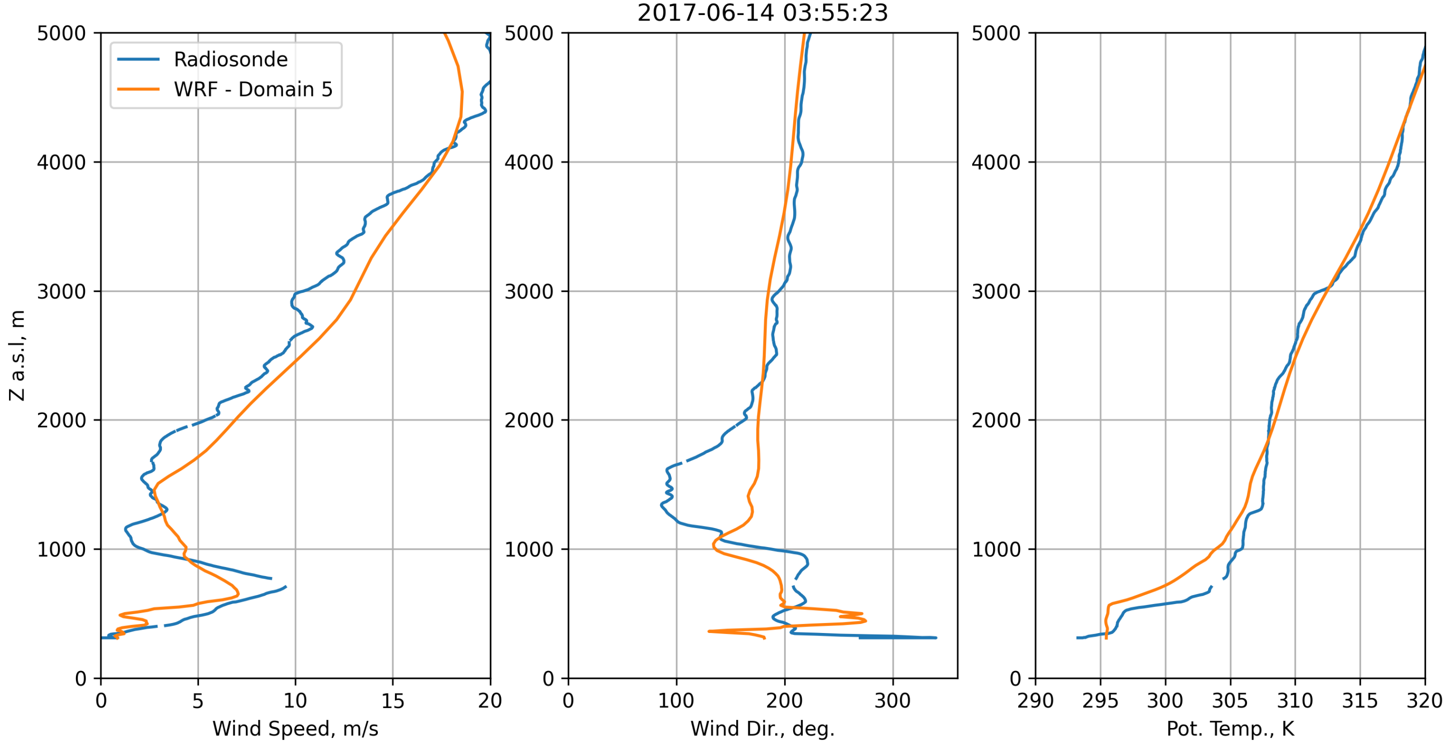
Backup

The model compares well with soundings but underestimates the strength of the jet



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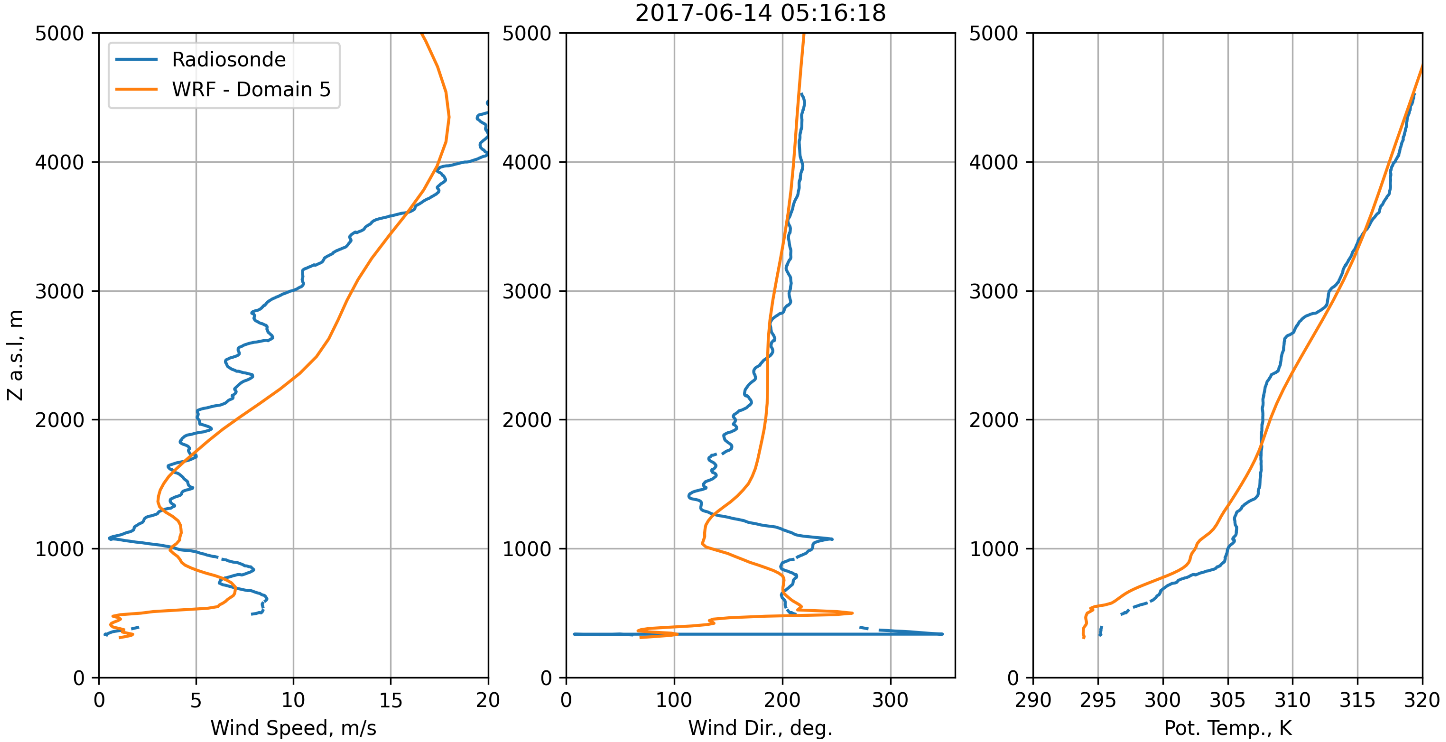
The model compares well with soundings but underestimates the height of the jet



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