ENERCON

IDENTIFYING AND MANAGING RECIRCULATION ZONES FOR WIND ENERGY APPLICATIONS

May 2025

Agenda

0 I Introduction

1 I Round Robin

2 I Identification

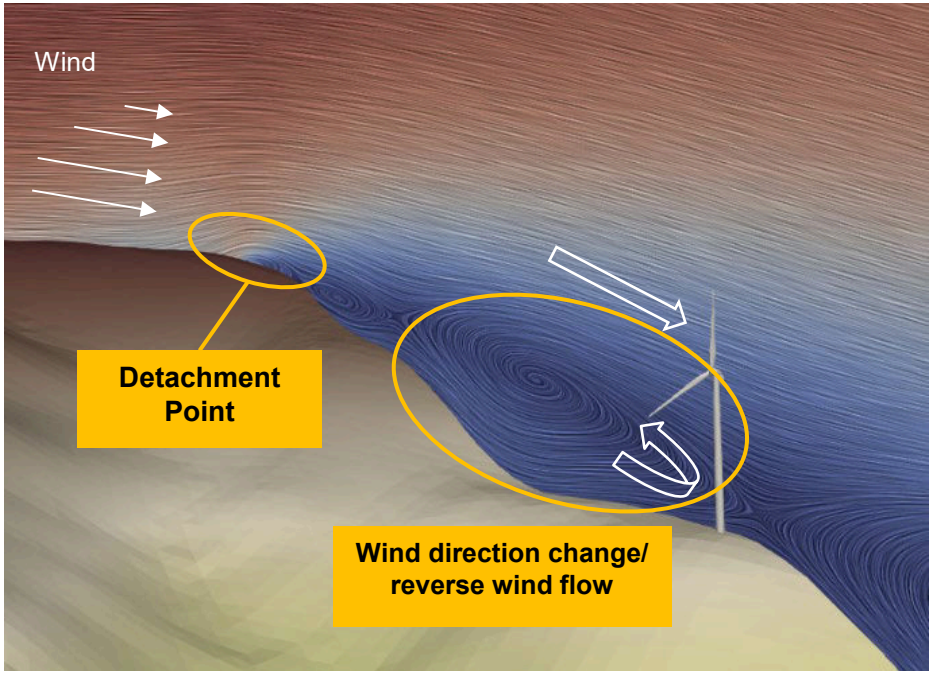
3 I Simulation Assessment, Validation and Data Representativeness

4 I Summary

0 - Introduction

- Wind Recirculation zones
  Areas with flow separation or presence of reverse flow.

  - Common in Complex terrain.
  - Significally lower Wind Speeds / Direction changes / High turbulence and shear

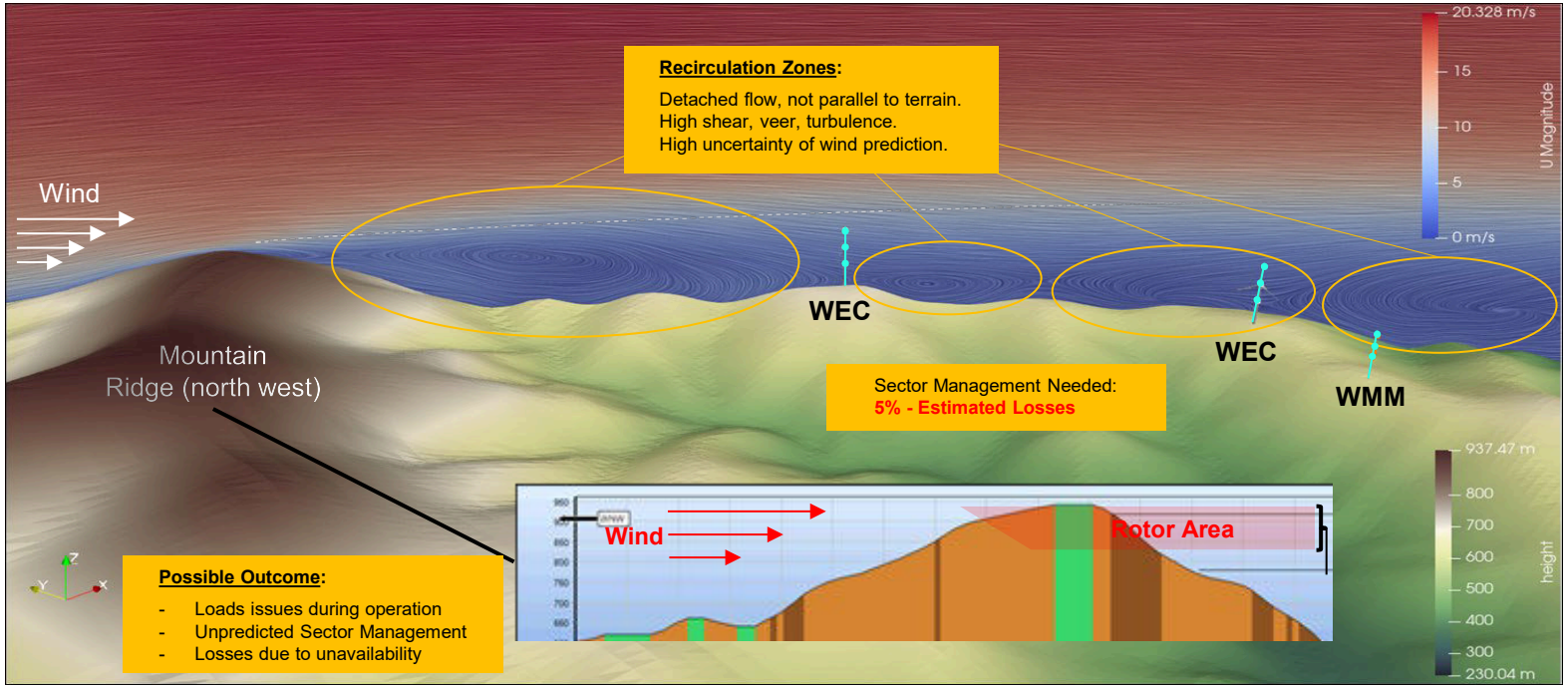


Why?

- Increased loads on wind turbines
- Potential need for sector management (SM)
- Potential for unexpected losses during operation

1 - Round Robin

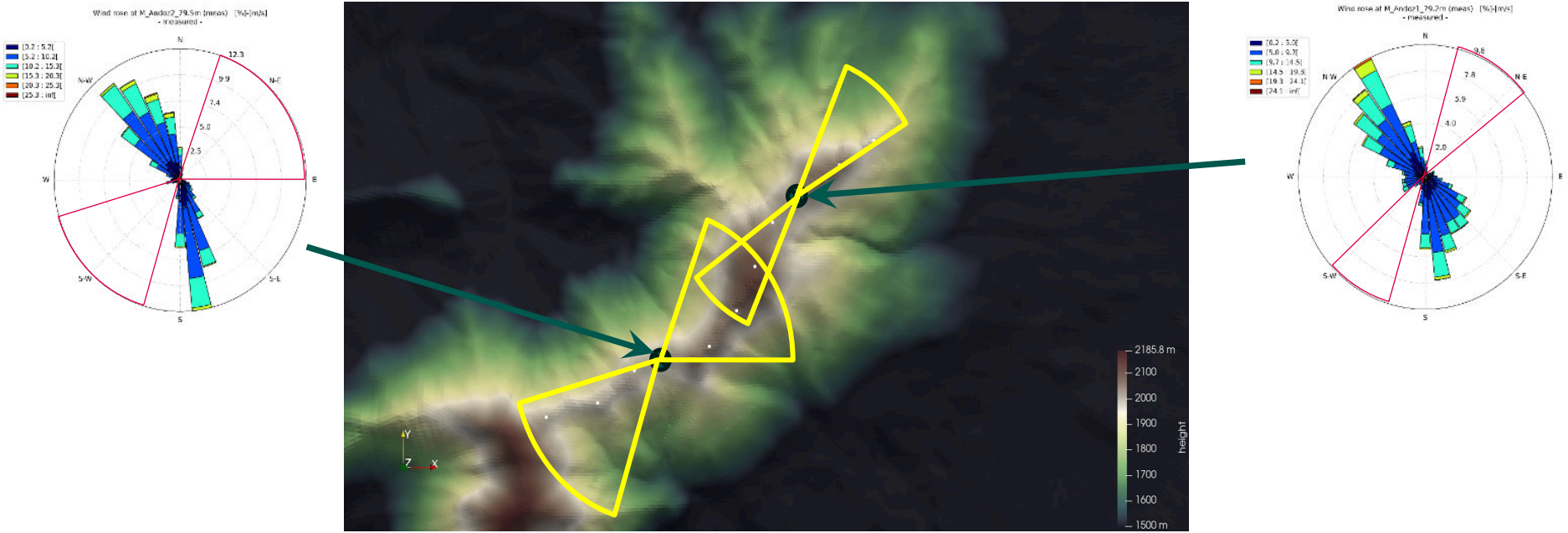
- Site suitability analyzed by consultant using linear model.



Stream Lines [GWD=330°]

2 - Identification

- During Input check
  Terrain effect on Measurement data.



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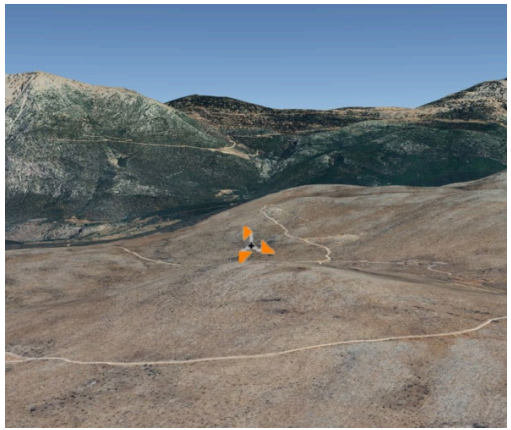
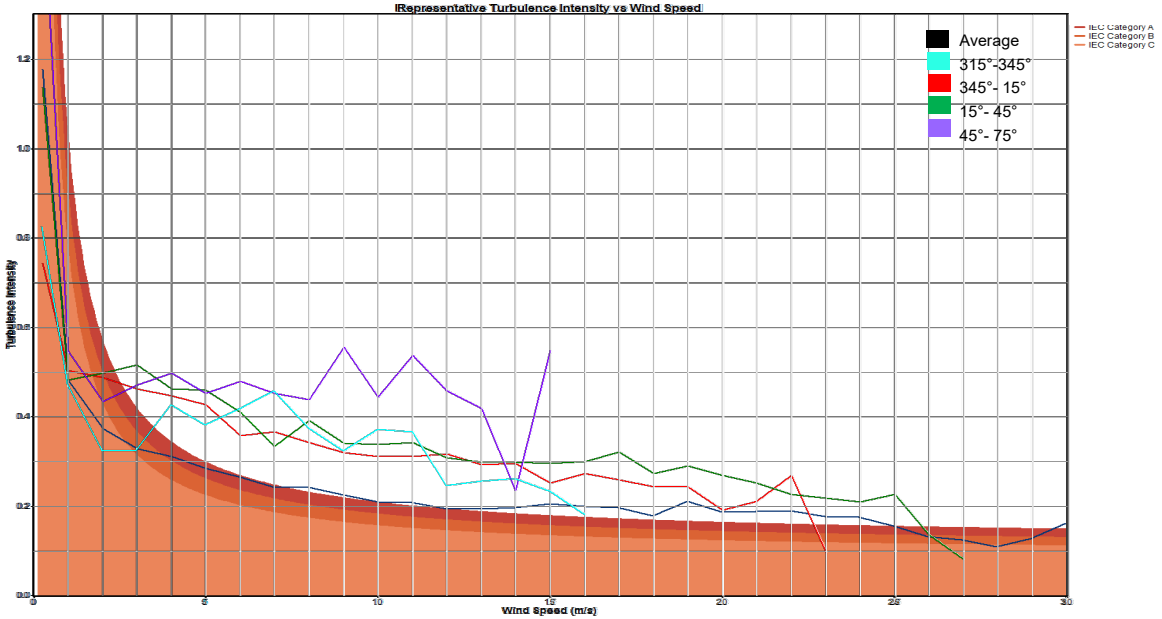
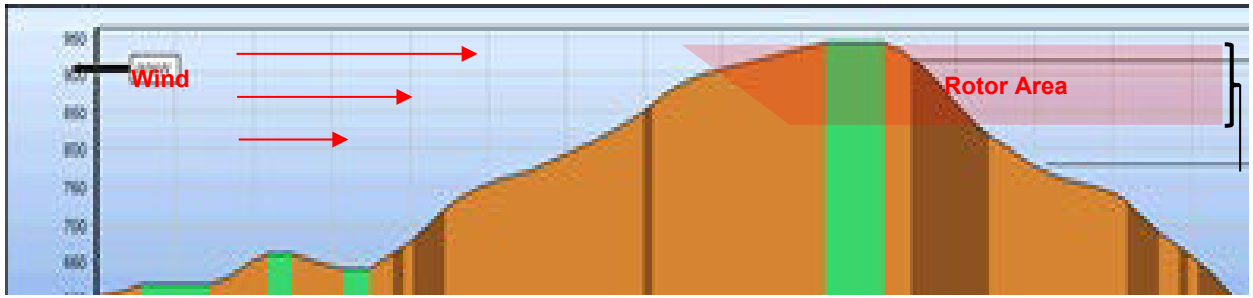
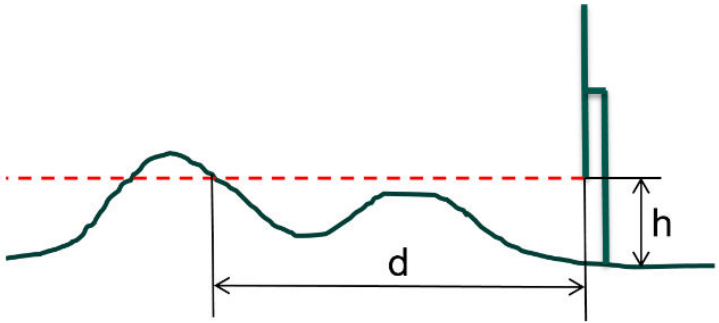




2 - Identification

- During Input check
  Terrain check around points of interest.





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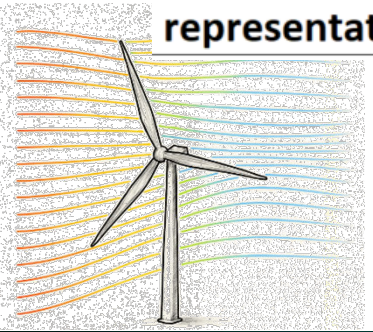
2 - Identification

- During Prediction

  Directions with exceeding and noticeable wind parameters differences through the rotor area.

Direction	140	150	160	240	250	260	270	280	290
avg. WS (HH)	7.12	8.683	9.93	3.492	3.54	3.633	2.955	2.264	2.79
avg. WS (LT)	6.428	8.142	9.593	2.736	2.525	2.285	1.529	0.801	0.676
avg. shear	0.064	0.034	0.01	0.195	0.267	0.364	0.508	0.775	1.019
avg. veer	3.361	4.744	6.291	12.38	10.7	9.6	5.199	12.02	28.88
representative TI (HH)	0.208	0.194	0.171	0.274	0.273	0.334	0.468	0.772	0.813
representative TI (LT)	0.245	0.245	0.222	0.433	0.522	0.794	1.255	2.292	3.223

Extreme values of veer and shear

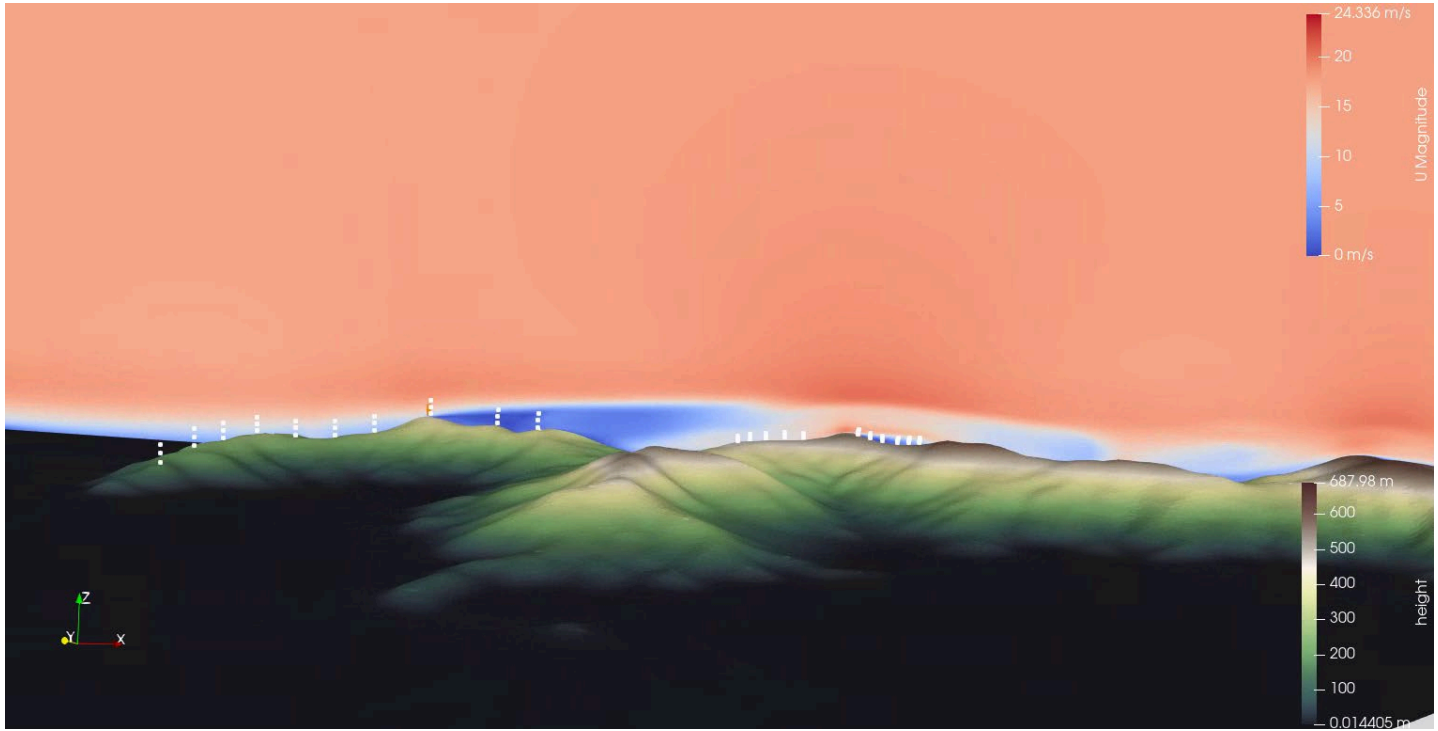


Turbulence difference from LT to HH

2 - Identification

Flow visualization - > ParaView

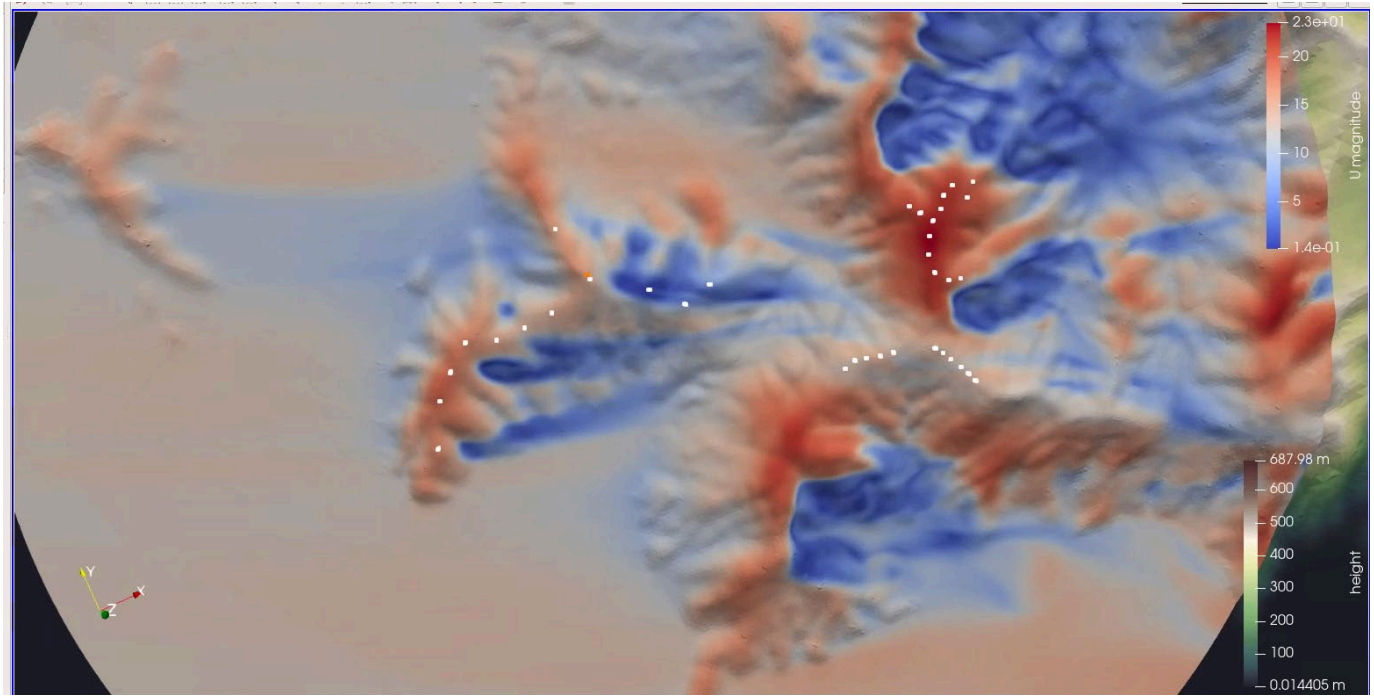
Flowslice



2 - Identification

Flow visualization - > ParaView

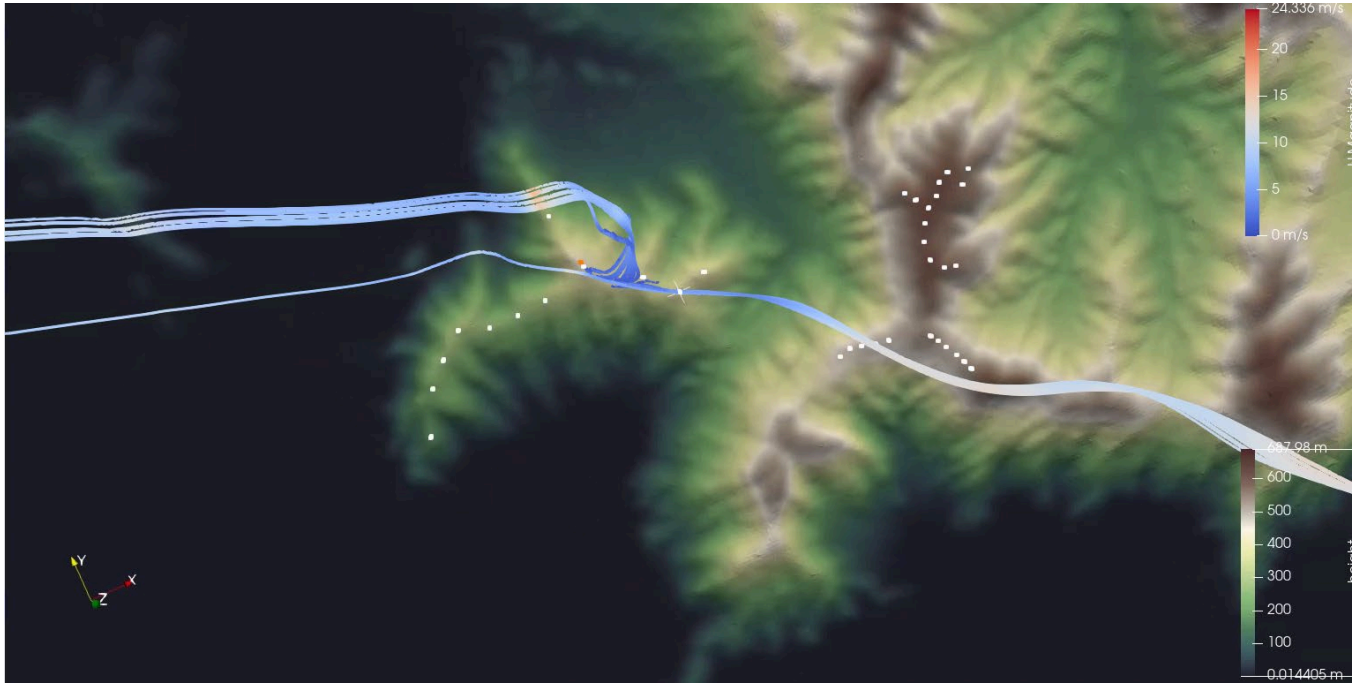
Slice at constant height



2 - Identification

Flow visualization - > ParaView

Streamlines



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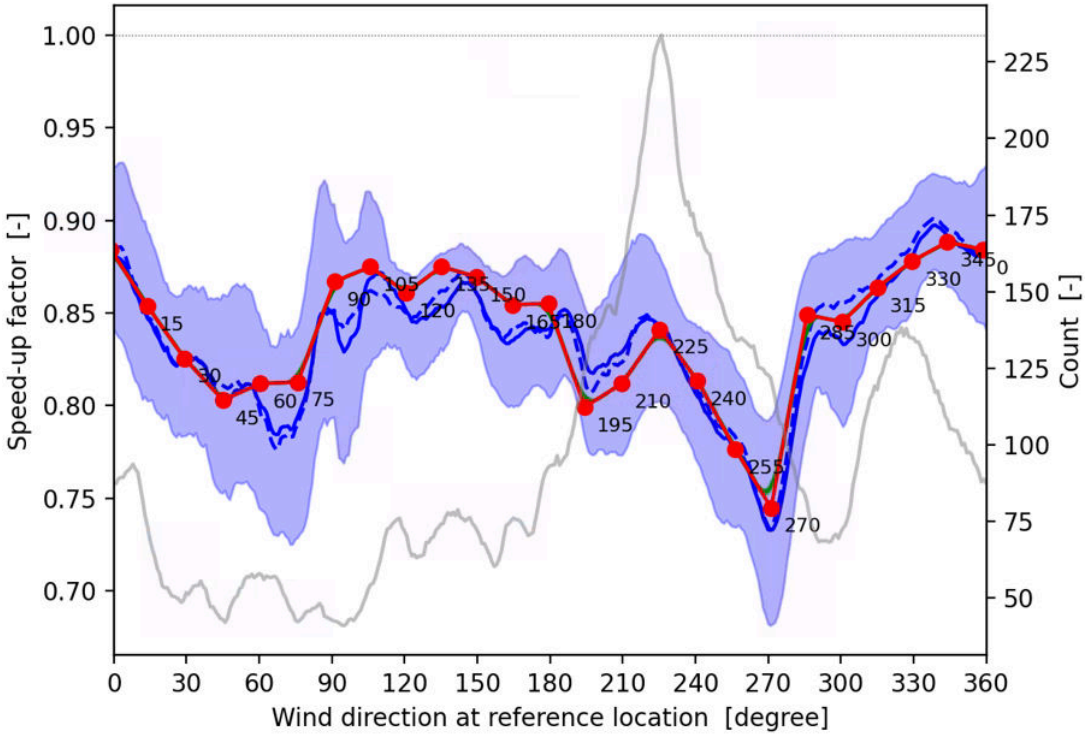
3 – Simulation Assessment, Validation and Data Representativeness

Problematic sector were identified, what now?

- Model validation
- Problematic sectors analysis
- Horizontal cross prediction

WD_Calibration_WS



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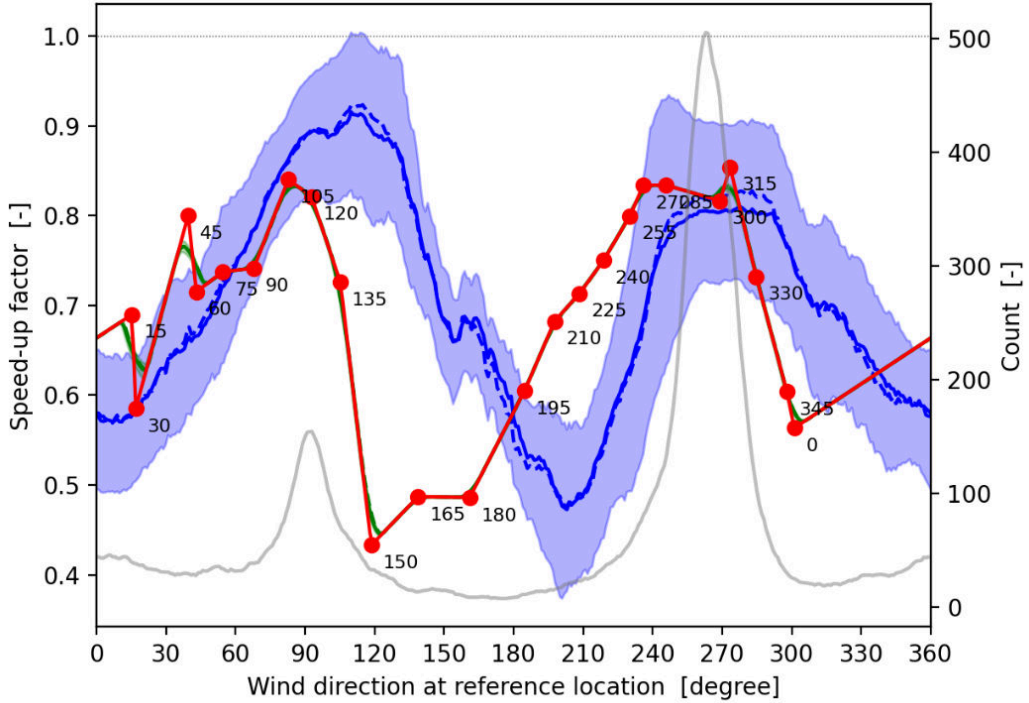
Representative Measurement!!

WD_Calibration_WS



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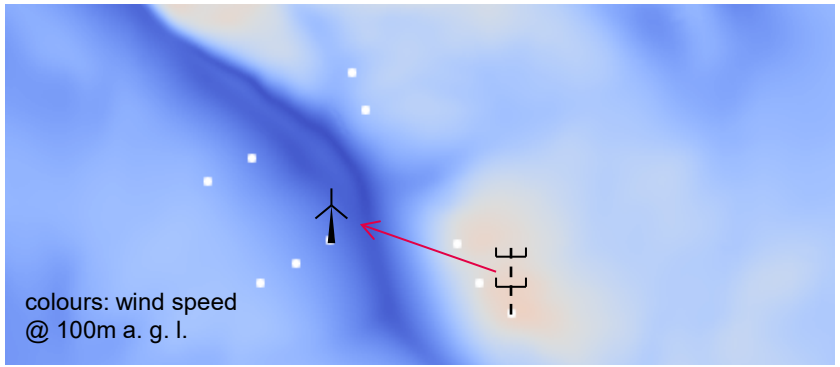
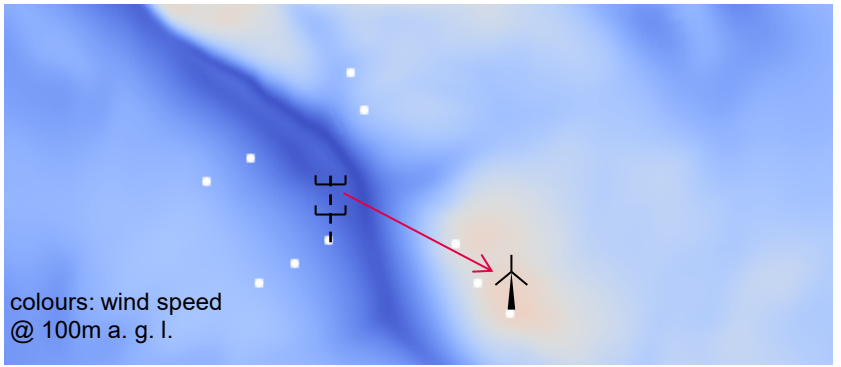
3 – Simulation Assessment, Validation and Data Representativeness

Recirculation scenarios



Turbine in recirculation region:

- potentially high turbulence load
- ambient TI and extreme events can be under-estimated by wind model
- **risky turbine location**
  → to be mitigated!



Met mast in recirculation region:

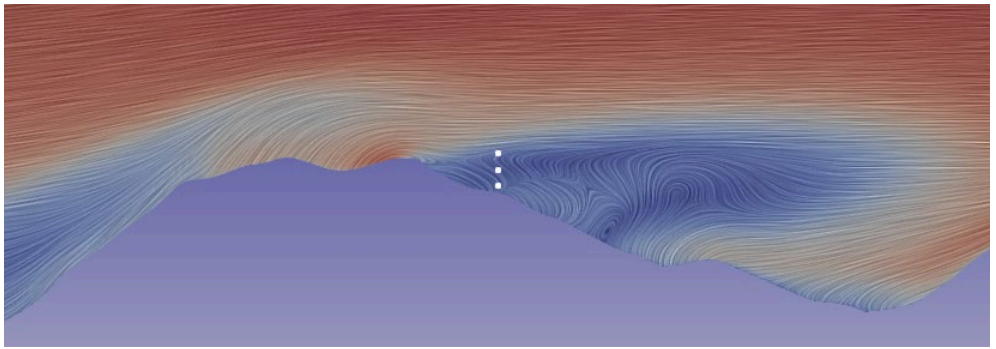
- high speed-up factor between mast and turbine, large errors in prediction
- very high wind speed predicted at turbine
- **prediction is *likely* to be wrong**

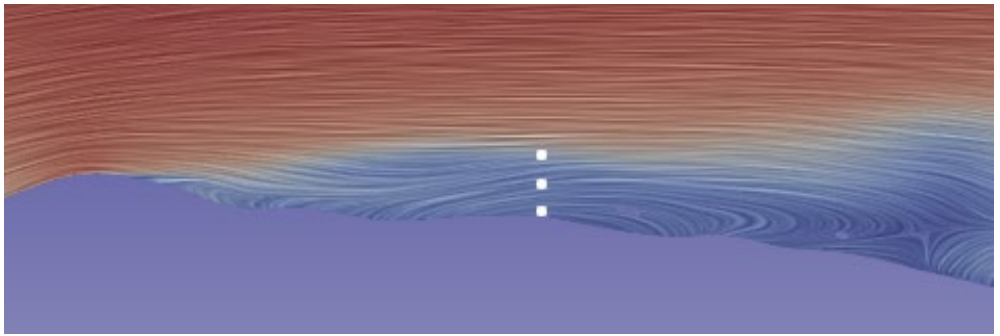
4 - Summary

Most Likely Problematic

- Recirculation at turbine position

  Noticible decrease in wind speeds, reverse flow, detachment points.

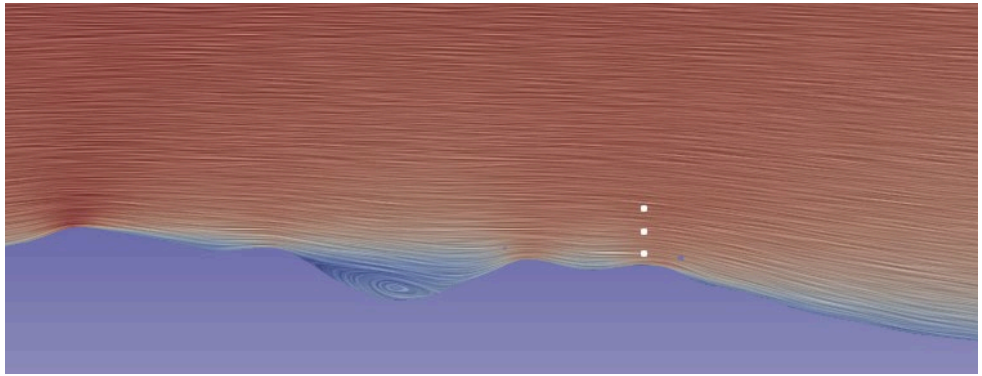


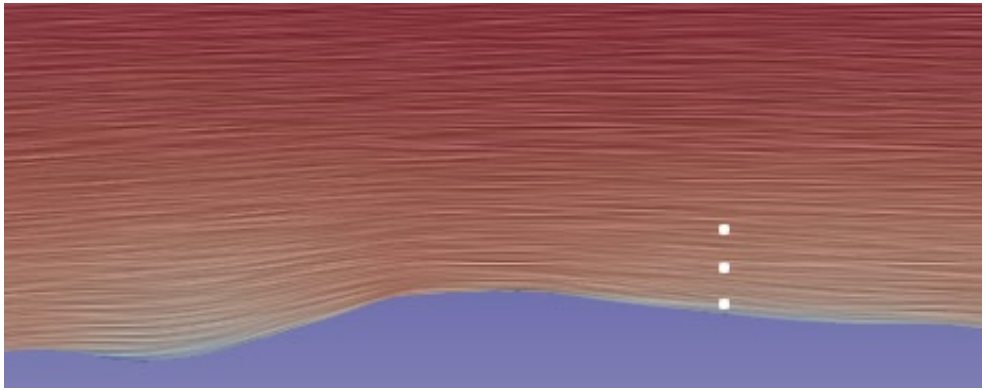


4 - Summary

Potentially not Problematic

- Flow not separating / not steep enough.
- Recirculation not reaching the turbine position.
- Turbine located on hill top.

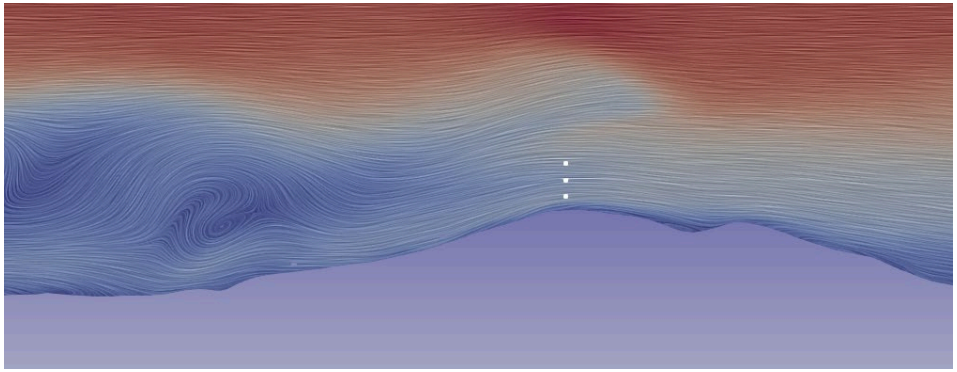


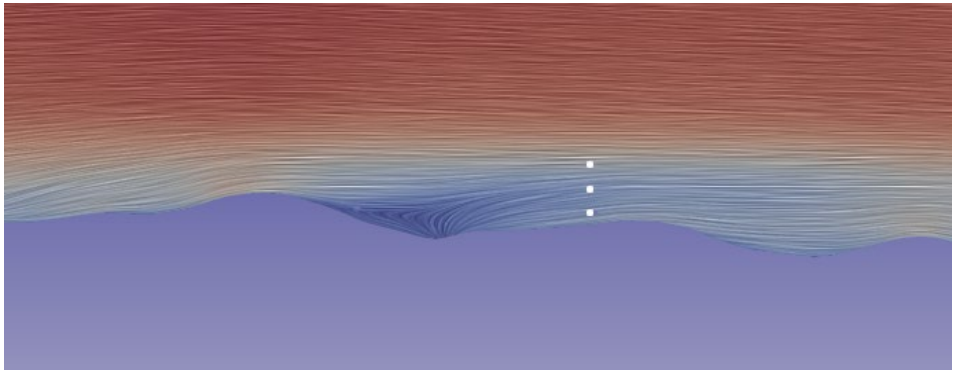


4 - Summary

Potentially Problematic

- Recirculation present but near dissipated.
- Not straight forward.
  Case by case dependent.
- Check if more than a single parameter is exceeding.
- Check frequency of the sector.
- In case of doubt – Mitigate / Validade by measurement.





4 - Summary

- Recirculation areas are common in complex terrain.

  It could lead to turbine loads issues and potential damages.

- Recirculation check shall start at early stages of development.

  Avoid placing turbines in recirculation areas.

- A single exceeding parameter is not enough to identify as recirculation.

  Pragmatic assessment is required, considering different parameters & inputs.

- Model robustness and validation is necessary.

  Focus on representative measurement. High resolution maps can help.
  Linear Models are not suitable to investigate recirculation areas.

- Risk assessment → Load Mitigation

THANK YOU FOR YOUR ATTENTION!

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