A Holistic Approach to Designing Dual Doppler Scanning LiDAR Site Assessment Measurement Campaigns

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DTU Wind Energy
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Introduction

Designing a wind resource assessment measurement campaign is a complex problem.

Campaign cost and expected energy yield assessment uncertainty are often competing objectives:

- *How many locations to measure? And where?*
- *What measurement technology to deploy?*
- *How to long to measure?*

Long range scanning LiDAR has the potential to deliver significantly reduced energy yield assessment uncertainty by measuring at many locations simultaneously (including in complex terrain).

However, there are barriers preventing the use of the technology in commercial settings:

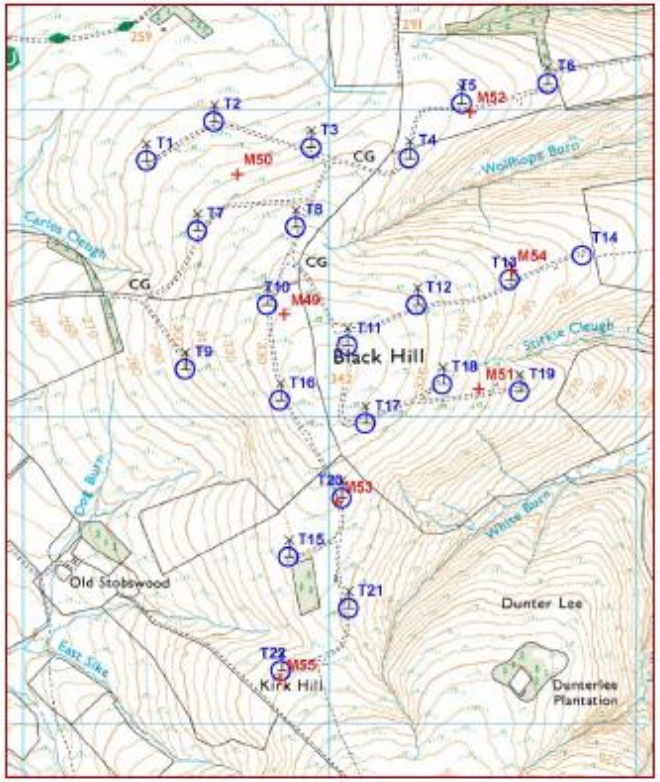
- *Cost of the technology*
- *Industry experience and acceptance*
- *Specialist expertise required to plan campaigns*

RECAST is delivering tools that enable scanning LiDAR campaign planning without specialist expertise.
RES is leading a demonstration work package to apply these tools in practice.

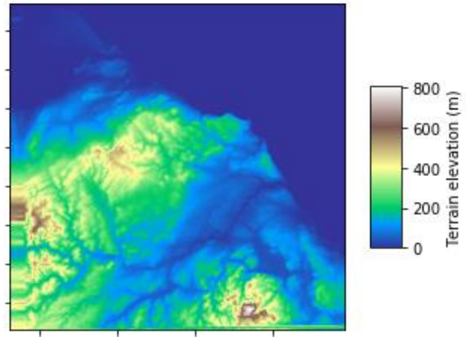
We demonstrate a workflow using these tools to design scanning LiDAR campaigns and compare against conventional measurement technologies.

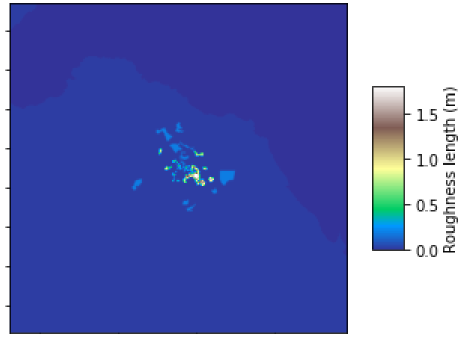
Case Study

Data from a RES developed operational wind farm, previously used in the CREYAP assessment, was used as case study to demonstrate the tools and workflows:

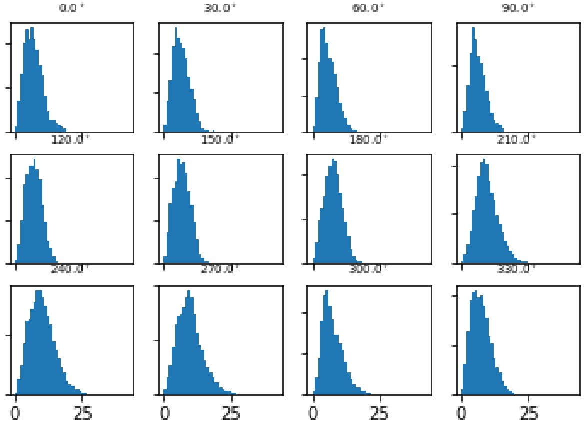


22 turbines, 47 m hub height, 1.3 MW rated power





Flow modelling performed using a pre-release version of *pyWAsP*



Wind climate estimated from original site assessment mast used for AEP modelling (also using *pyWAsP*)

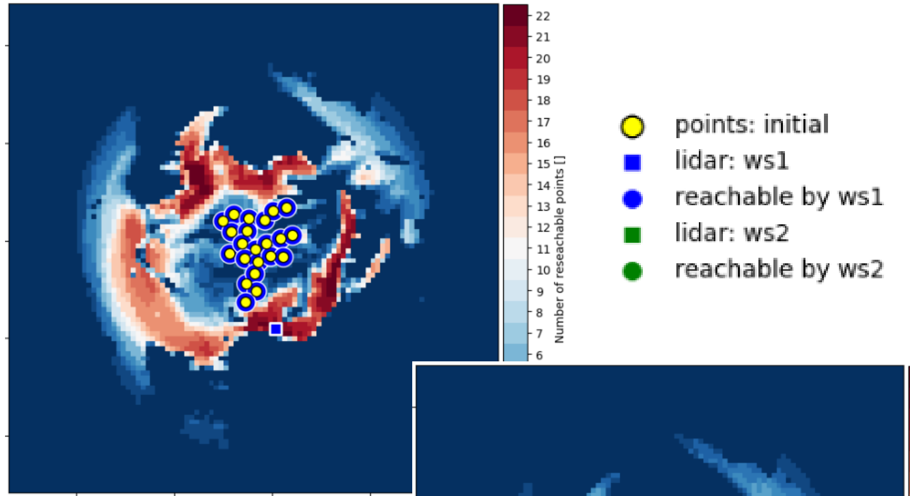
https://www.wasp.dk/

Mortensen, N. G., & Ejsing Jørgensen, H. (2013). Comparative Resource and Energy Yield Assessment Procedures (CREYAP) Pt. II. EWEA Technology Workshop: Resource Assessment, Dublin, Ireland, 26 June.

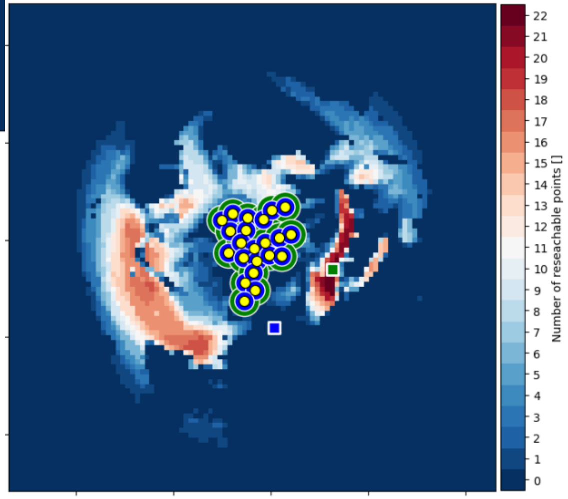
Scanning LiDAR Campaign Design

The Python-based open source *Campaign Planning Tool* (CPT) uses publicly available terrain and land cover data to find LiDAR deployment locations achieving clear line of site to desired measurement locations.

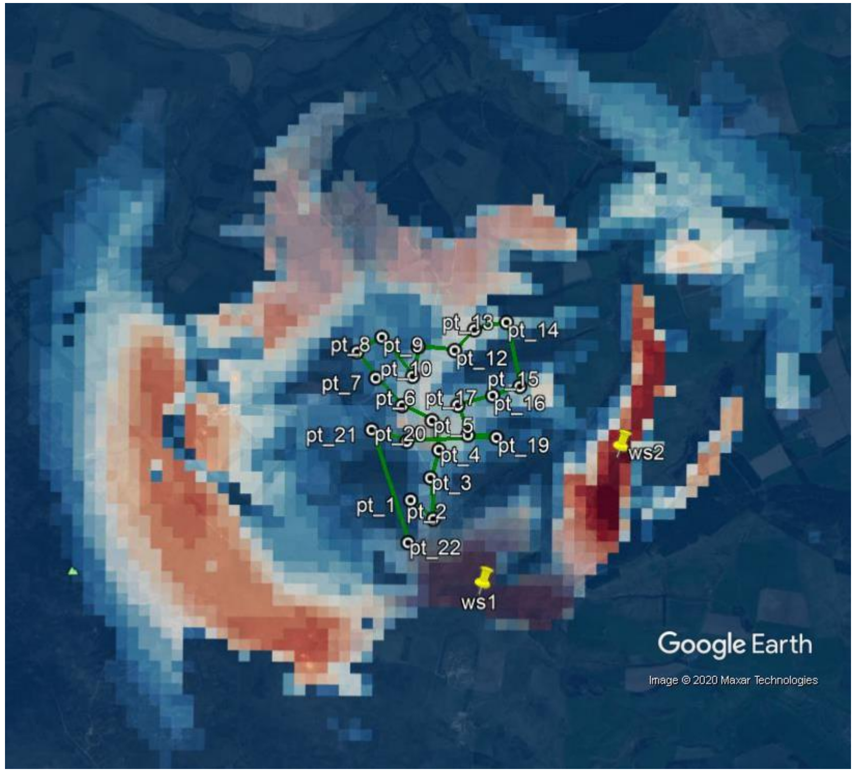
Step 1: Line of site analysis



Finding valid locations for first LiDAR (top) … and second LiDAR given the location of the first (bottom)



Step 2: Kinematic analysis



Calculate the scanning head movement for each LiDAR to maximise time spent at measurement locations

Step 3: Export the scanning pattern and upload to WindScanner system for deployment

Nikola Vasiljevic. (2019, August 28). campaign-planning-tool v0.1.3, Zenodo. http://doi.org/10.5281/zenodo.3462049

https://github.com/niva83/campaign-planning-tool

Scanning LiDAR Wind Speed Uncertainty Estimate

The open source Python package, *YADDUM*, is used to model the uncertainty in wind speed measurement for each measurement location based on the LiDAR positions identified using CPT.

Horizontal wind speed measurement uncertainty varies between measurement positions (e.g. due beam angles, range, etc.), and with atmospheric conditions.

YADDUM models uncertainty as a function of:

Atmospheric conditions

Wind speed
Wind direction
Flow inclination angle
Power law shear exponent

LiDAR system uncertainties

Radial velocity measurement
Azimuth angle
Elevation angle
Resolve range

Campaign design

LiDAR locations (x, y, z)
Measurement locations (x, y, z)

We use *YADDUM* to model uncertainty for each measurement point at a range of conditions relevant to our site:

Turbine / WDir	0	30	60	90	120	150	180	210	240	270	300	330
T1	1.7%	1.8%	2.0%	1.7%	1.2%	1.5%	1.7%	1.8%	2.0%	1.7%	1.2%	1.5%
T2	1.4%	1.6%	1.8%	1.6%	1.3%	1.3%	1.4%	1.6%	1.8%	1.6%	1.3%	1.3%
T3	1.6%	1.6%	1.8%	1.7%	1.3%	1.4%	1.6%	1.6%	1.8%	1.7%	1.3%	1.4%
T4	1.7%	1.7%	1.7%	1.7%	1.4%	1.4%	1.7%	1.7%	1.7%	1.7%	1.4%	1.4%
T5	1.9%	1.9%	1.9%	1.9%	1.4%	1.4%	1.9%	1.9%	1.9%	1.9%	1.4%	1.4%
T6	2.2%	2.2%	2.2%	2.2%	1.5%	1.6%	2.2%	2.2%	2.2%	2.2%	1.5%	1.6%
T7	2.6%	2.6%	2.6%	2.6%	1.7%	1.8%	2.6%	2.6%	2.6%	2.6%	1.7%	1.8%
T8	3.0%	2.9%	2.9%	3.0%	1.9%	2.0%	3.0%	2.9%	2.9%	3.0%	1.9%	2.0%
T9	2.9%	2.9%	2.8%	3.0%	2.1%	1.8%	2.9%	2.9%	2.8%	3.0%	2.1%	1.8%
T10	2.3%	2.4%	2.3%	2.4%	1.7%	1.6%	2.3%	2.4%	2.3%	2.4%	1.7%	1.6%
T11	2.5%	2.7%	2.5%	2.6%	2.0%	1.6%	2.5%	2.7%	2.5%	2.6%	2.0%	1.6%
T12	2.2%	2.6%	2.3%	2.3%	1.9%	1.4%	2.2%	2.6%	2.3%	2.3%	1.9%	1.4%
T13	2.2%	2.8%	2.6%	2.5%	2.2%	1.4%	2.2%	2.8%	2.6%	2.5%	2.2%	1.4%
T14	2.0%	2.9%	2.8%	2.5%	2.3%	1.5%	2.0%	2.9%	2.8%	2.5%	2.3%	1.5%
T15	1.7%	2.1%	2.0%	1.8%	1.6%	1.2%	1.7%	2.1%	2.0%	1.8%	1.6%	1.2%
T16	1.8%	2.0%	1.8%	1.8%	1.5%	1.3%	1.8%	2.0%	1.8%	1.8%	1.5%	1.3%
T17	1.9%	2.0%	1.8%	1.8%	1.5%	1.4%	1.9%	2.0%	1.8%	1.8%	1.5%	1.4%
T18	1.7%	1.7%	1.6%	1.6%	1.4%	1.3%	1.7%	1.7%	1.6%	1.6%	1.4%	1.3%
T19	1.6%	1.6%	1.5%	1.5%	1.4%	1.3%	1.6%	1.6%	1.5%	1.5%	1.4%	1.3%
T20	1.9%	1.9%	2.1%	1.9%	1.4%	1.6%	1.9%	1.9%	2.1%	1.9%	1.4%	1.6%
T21	2.3%	2.3%	2.5%	2.2%	1.4%	1.8%	2.3%	2.3%	2.5%	2.2%	1.4%	1.8%
T22	1.7%	2.0%	2.0%	1.5%	1.2%	1.6%	1.7%	2.0%	2.0%	1.5%	1.2%	1.6%

Horizontal wind speed uncertainty for each measurement location and wind direction for at site mean wind speed and shear exponent of 0.2.

System assumptions: 0.1 m/s uncertainty in radial wind speed measurement, 0.1° uncertainty in elevation and azimuth angle, 1 m resolve range.

Nikola Vasiljevic. (December 2019). YADDUM v0.20.0, Zenodo. https://zenodo.org/record/3580749

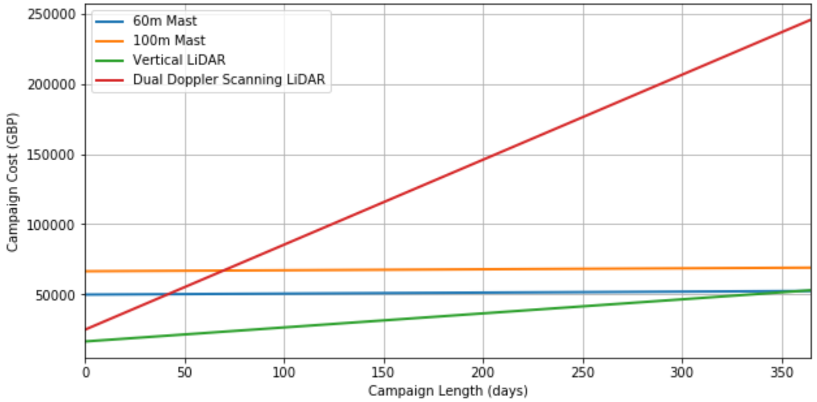
https://github.com/niva83/YADDUM

Campaign Evaluation and Comparison Method

Having designed a dual Doppler scanning LiDAR campaign and estimated wind speed measurement uncertainty, we can compare scanning LiDAR campaigns to conventional campaigns in terms of cost and expected energy yield uncertainty.

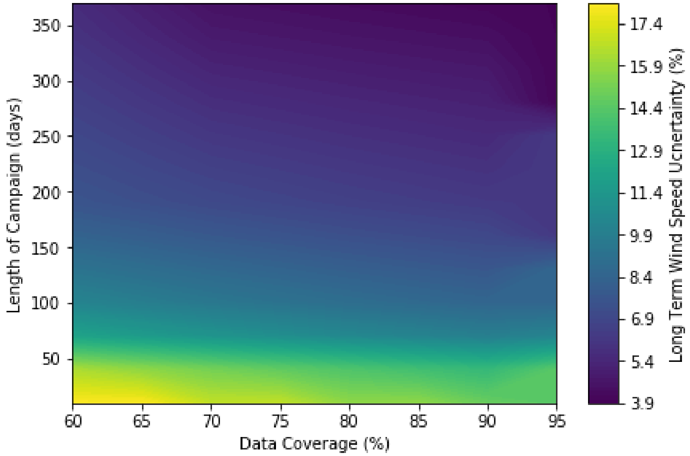
Generic campaign cost model

Based on RES' experience with different measurement technologies.
LiDAR costs expected to decrease in the future.



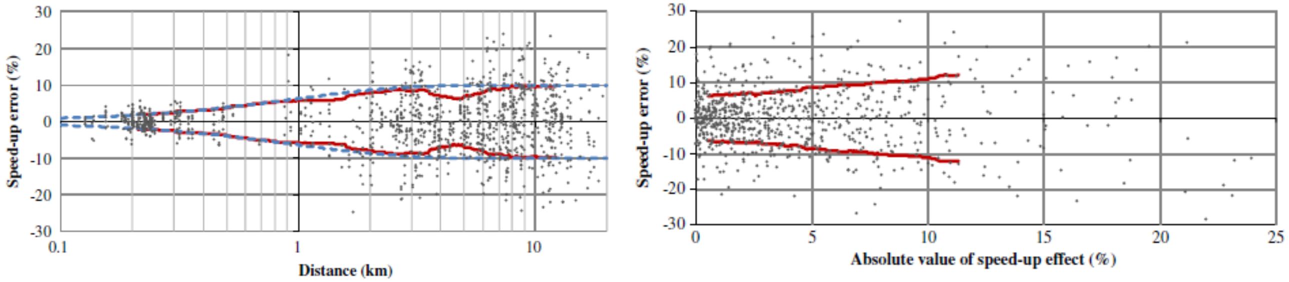
Uncertainty from wind climate long term extrapolation

Based on RES LTE (incl. MCP and IAV) uncertainty model.
Covers single and multi-measurement campaigns (i.e. incl. 2 step MCP).



Horizontal extrapolation uncertainty

Using the empirical method of Clerc et al (2012).



Other assumptions

Measurement uncertainty for masts and vertical LIDAR of 1.6% and 2% respectively.

Engineering model for vertical extrapolation uncertainty.

5% AEP uncertainty due to other sources (availability, wakes, power curve, etc.).

Multi-measurement combination using inverse uncertainty.

AEP uncertainties combined assuming independence.

Clerc, A., et al., A systematic method for quantifying wind flow modelling uncertainty in wind resource assessment, J. Wind Eng. Ind. Aerodyn. 111 (2012) 85-94

Campaign Comparison Results and Conclusions

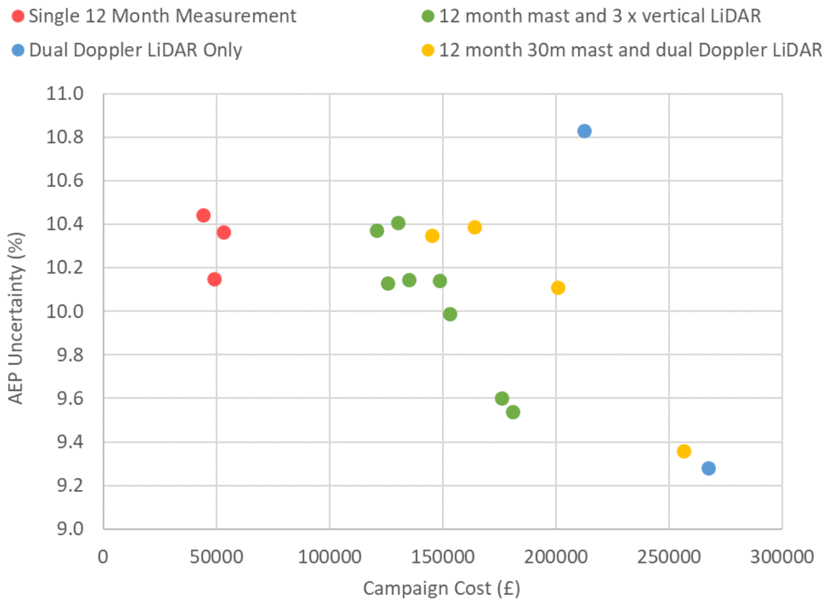
Cost and AEP uncertainty estimated for different campaign designs:

Single 12 month measurement
Hub height (47m) or 30m mast.
Vertical LiDAR.

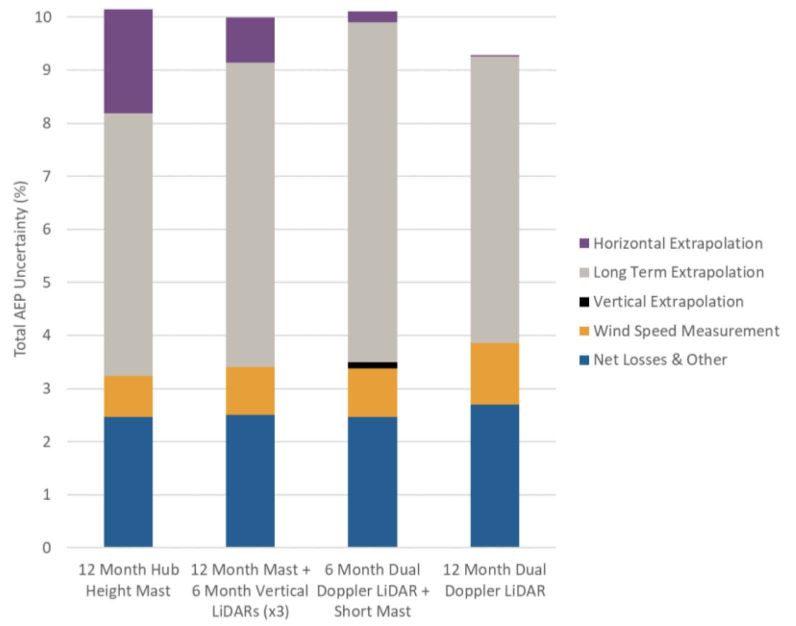
12 month mast + 3 x vertical LiDAR
Hub height (47m) or 30m mast.
3, 4, 6 and 9 month LiDAR deployment length.

Dual Doppler LiDAR only
3, 4, 6, 9 and 12 month LiDAR deployment length.

12 month 30 m mast + dual Doppler LiDAR
3, 4, 6 and 9 month LiDAR deployment length.



AEP uncertainty vs campaign cost for different campaign designs.
(Uncertainty > 11% for dual Doppler LiDAR only campaign with 3, 4 & 6 month duration)



AEP uncertainty breakdown for selected cases

Scanning LiDAR can reduce uncertainty, however, cost is prohibitive *for this site (hub heights lower than typical modern turbines)*.

Mast costs will increase significantly with hub height and number of measurements, making scanning LiDAR more attractive comparatively.

Scanning LiDAR potentially more attractive on sites with high hub height and large flow variation (e.g. large and/or complex sites).

Estimated LTE uncertainty is high for campaigns utilising sub-year measurement periods (even for 2 step MCP with a 12 month met mast).

As costs are high for long campaigns, methods to reduce uncertainty for short measurement periods, or use scanning LiDAR to augment flow models with measured speed-ups (e.g. mast for long term resource measurement, short term SL for spatial variation) may be beneficial.

WindScanner Demonstration Campaign

A dual Doppler scanning LiDAR demonstration campaign at a RES development wind farm in Northern Ireland is planned for 2020.

Scanning LiDAR deployment using the DTU WindScanner system.

Scanning LiDAR deployment at land owner's property and a nearby RES operated operational wind farm.

80m tubular mast on site for verification of LiDAR measurements and hard target reference.

Vertical LiDAR deployment at north east of the site planned to coincide with scanning LiDAR campaign.

The campaign has been designed using tools developed in RECAST.

Site visit and detailed planning complete.

Scanning LiDAR (WS1 and WS2), met mast (M1) and vertical LiDAR (L1) deployment locations for the planned campaign.

The proposed wind turbine locations for the development site are also marked (T1 – T9).

WindScanner ...making wind visible

Thank you!

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