

Bandpass Adjusted Turbulence (BAT)

Vestas



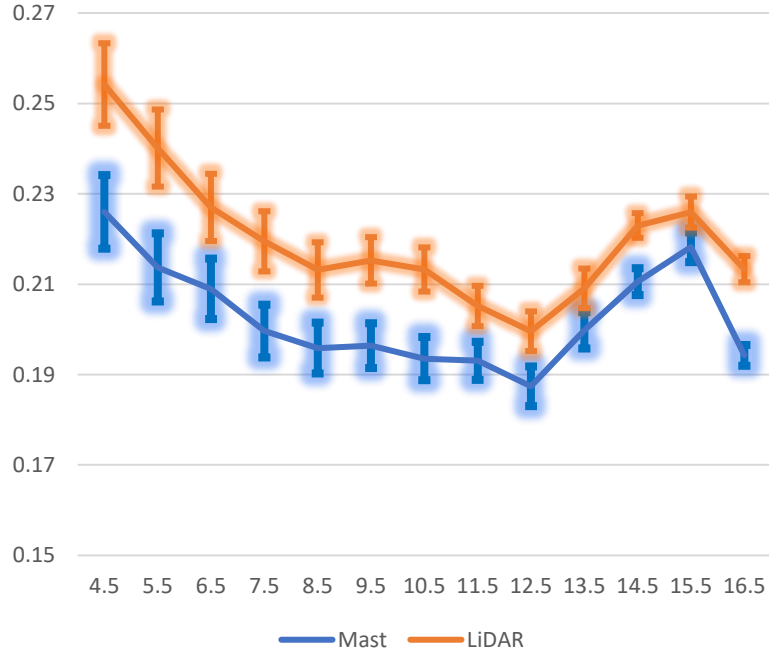


Outcome

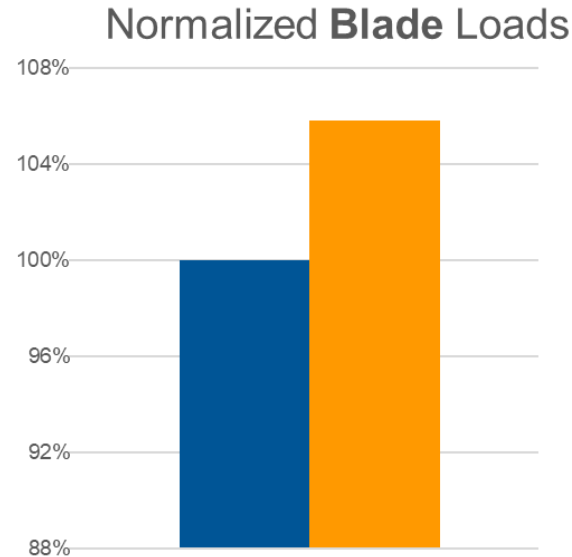
- Some challenges of turbine suitability assessment with LiDARs
- A potential method to overcome it
- Performance
- Next Steps

| | |
|---------------------------------|-------|
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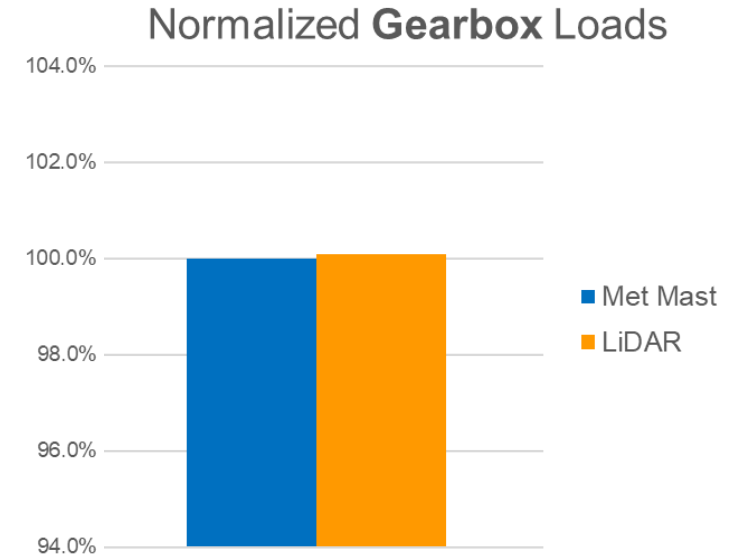
Problem definition



- Semi-complex terrain
- With forest
- inland



Turbulence driven loads*



Wind Speed driven loads

Turbine siteability vs Wind resource assessment

Mismatch

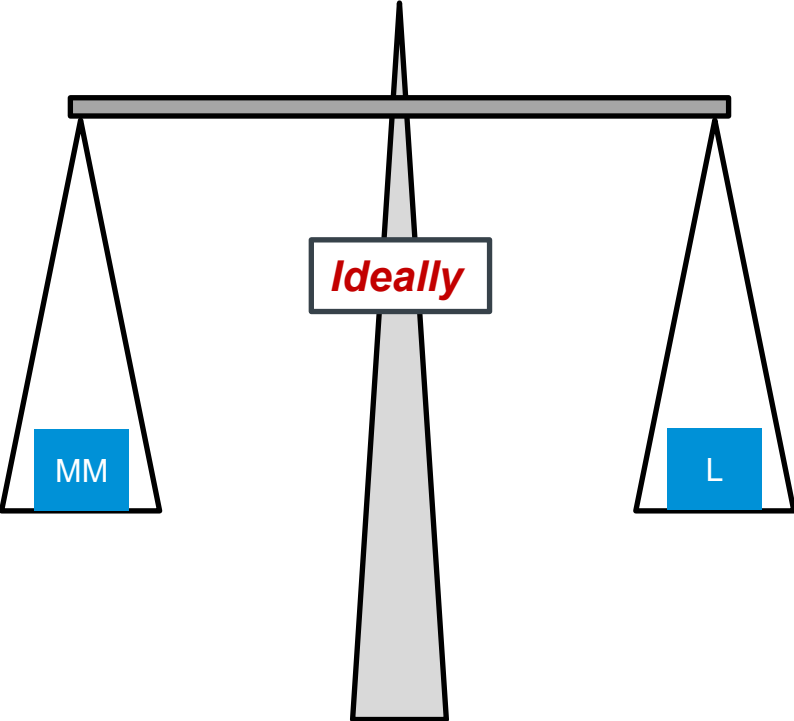
Problem Definition

*Loads are simulated loads using certified load models

Problem Definition

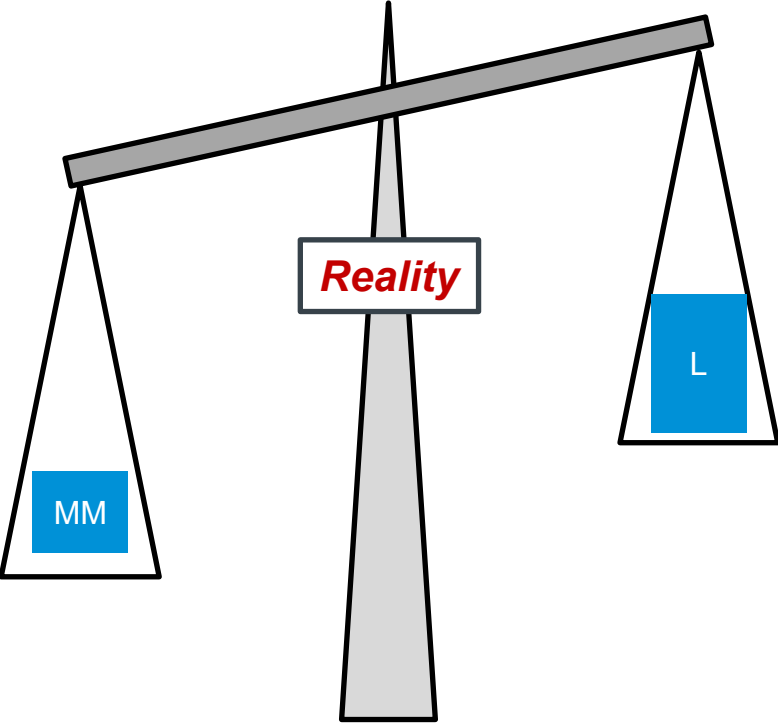
Summary

Turbine Loads Evaluation

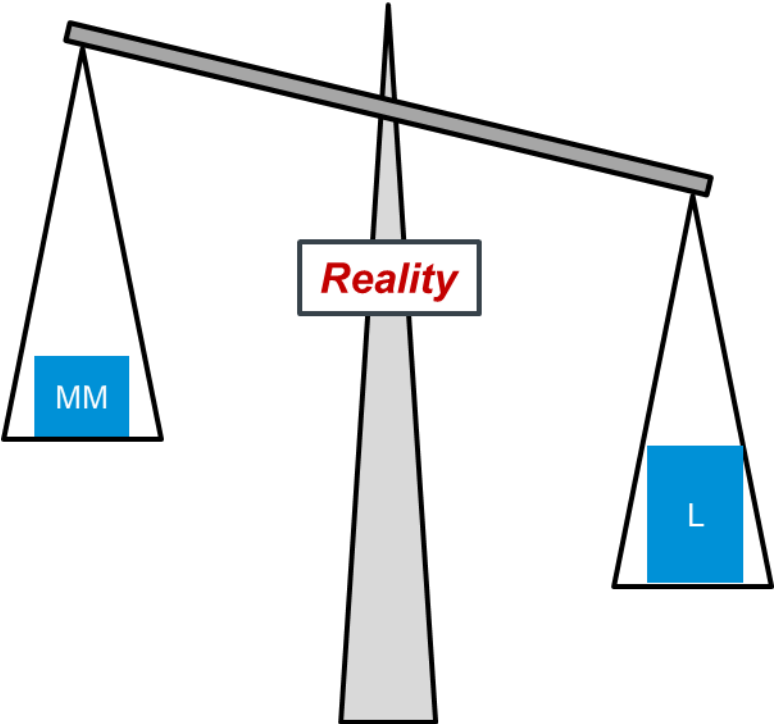


Problem Definition Summary

Turbine Loads Evaluation



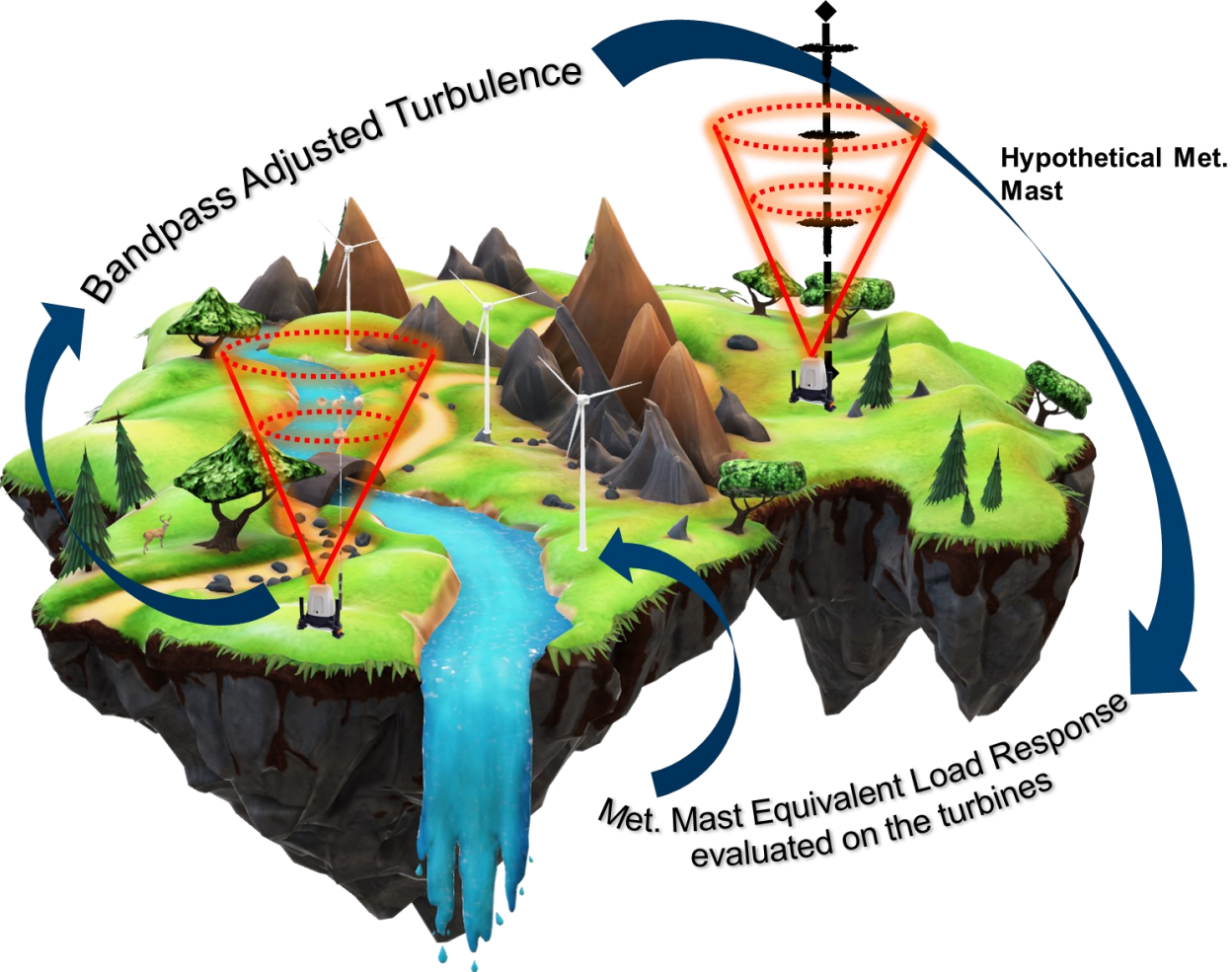
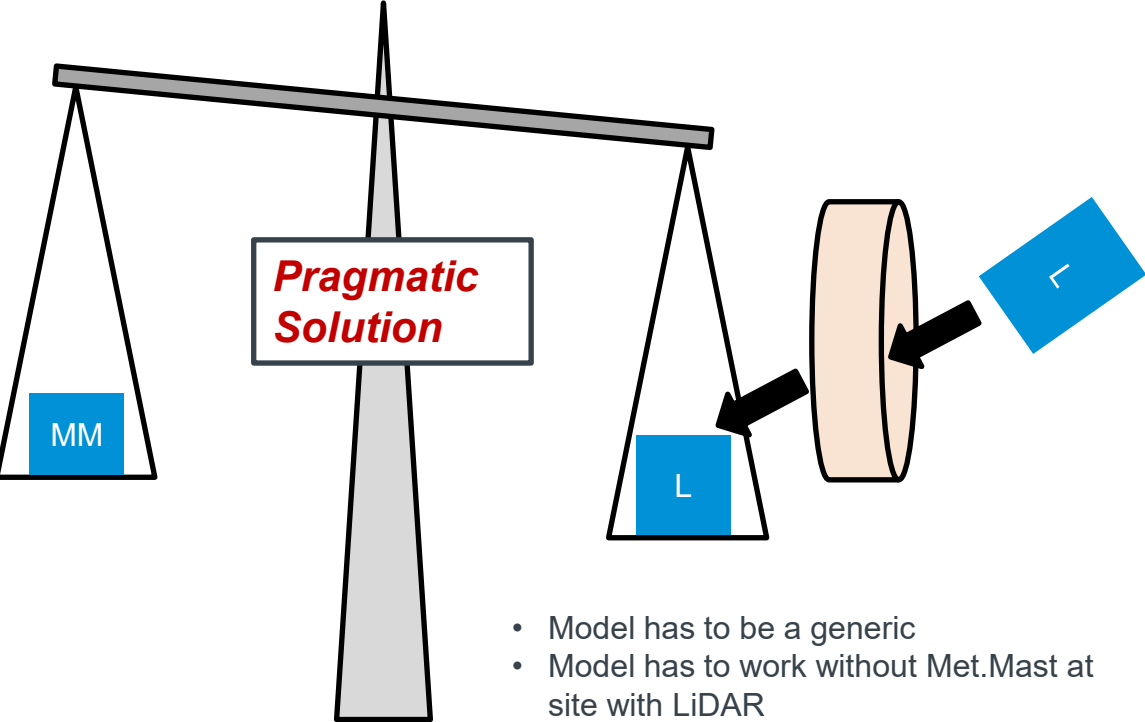
Turbine Loads Evaluation



Problem Definition Summary

Pragmatic Solution : Met. Mast Equivalent

Turbine Loads Evaluation

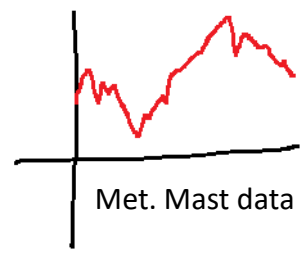


Methodology

... a BAT in detail

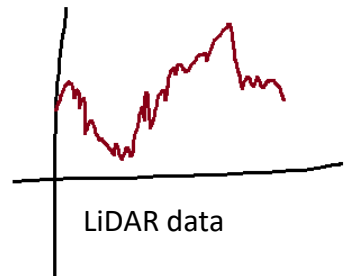
The green box – is the User Interface, which will not require Met Mast in the long term
 The grey box – is the Model validations – which requires Met Mast data for now
 The orange box – is the BAT Model builder – updated when needed

Plenty of ...



Met. Mast data

Inputs

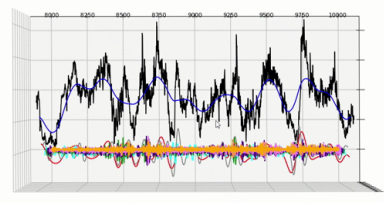


LiDAR data

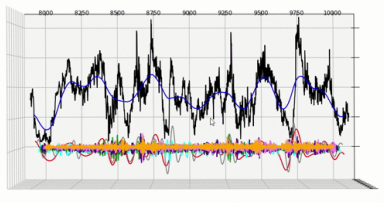
- Collocated and Concurrent
- 1y duration
- High availability
- 10min-avg WS, StDev, TI

for Each in Collocated Pairs:

Met. Mast data



vs



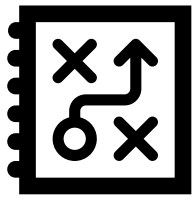
LiDAR data

- Decomposition
- Frequency-band based comparison

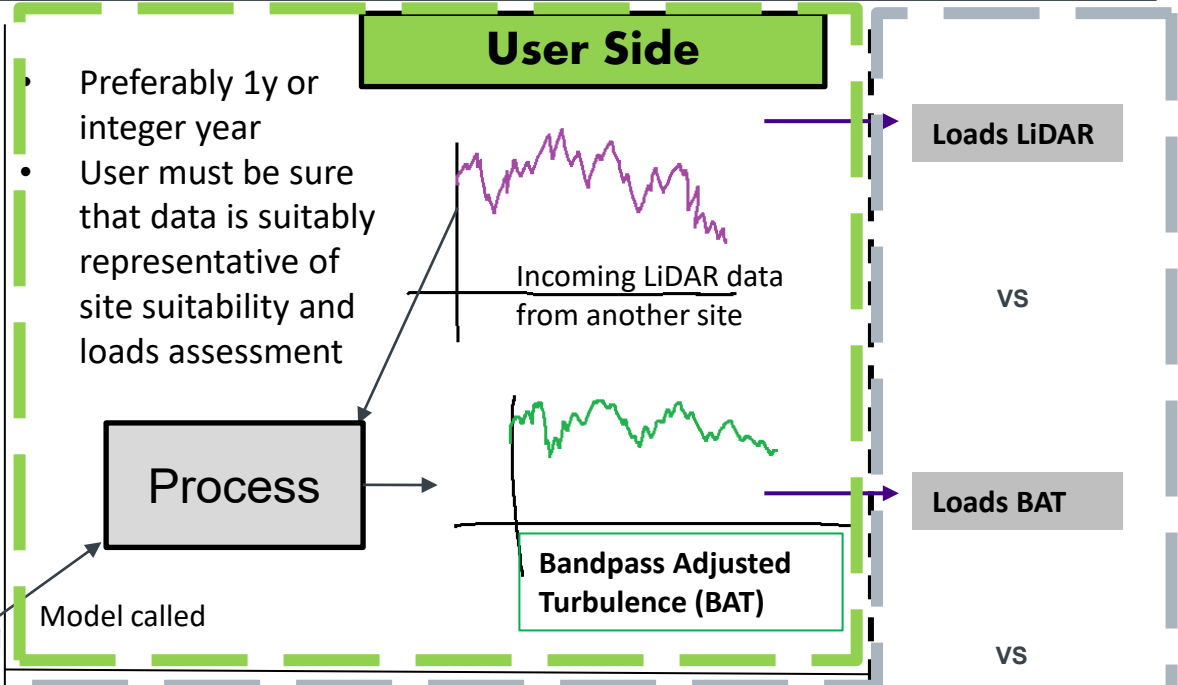
Model Builder - BATMoB

Transformation Model

Information from all the Collocated pairs – aggregated and stored



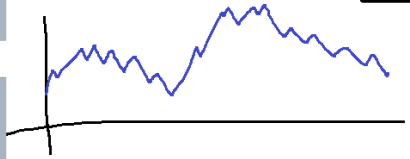
| Index | WSGain | WSOffset | STDGain | STDOffset |
|-------------|------------|--------------|------------|--------------|
| Component0 | 0 | 0 | 0 | 0 |
| Component1 | 1.03595 | -0.008551995 | 0.898079 | -0.000170753 |
| Component2 | 1.00949 | 0.000397437 | 0.859821 | 2.83299e-05 |
| Component3 | 0.956115 | 0.000259187 | 0.773841 | 1.29903e-05 |
| Component4 | 0.871057 | 8.7082e-06 | 0.674264 | -7.71268e-06 |
| Component5 | 0.795558 | -4.30029e-06 | 0.606604 | -2.59205e-05 |
| Component6 | 0.678431 | 3.10187e-05 | 0.511543 | -1.88281e-06 |
| Component7 | 0.556591 | -2.95832e-05 | 0.409564 | -1.43455e-05 |
| Component8 | 0.421635 | -6.84698e-06 | 0.294131 | -1.03444e-05 |
| Component9 | 0.288214 | 8.99707e-06 | 0.154607 | 5.95555e-06 |
| Component10 | 0.0968977 | -2.46251e-05 | 0.0674476 | 4.86239e-06 |
| Subgroup1 | -0.458872 | -1.2769e-05 | -0.268372 | 4.47362e-06 |
| Subgroup2 | -0.0886704 | -4.24632e-06 | -0.0468174 | -3.17859e-06 |
| Subgroup3 | -0.0784178 | -9.36095e-07 | 0.0516817 | 2.15759e-06 |
| Subgroup4 | 0.136699 | 2.01822e-06 | -0.0537133 | 1.26928e-06 |



- Preferably 1y or integer year
- User must be sure that data is suitably representative of site suitability and loads assessment

Model called

For Model Validations

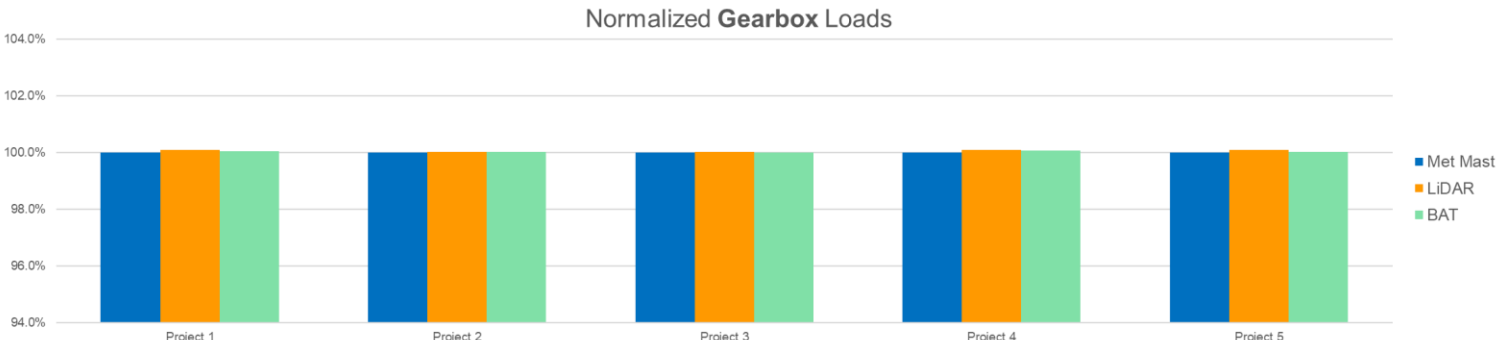
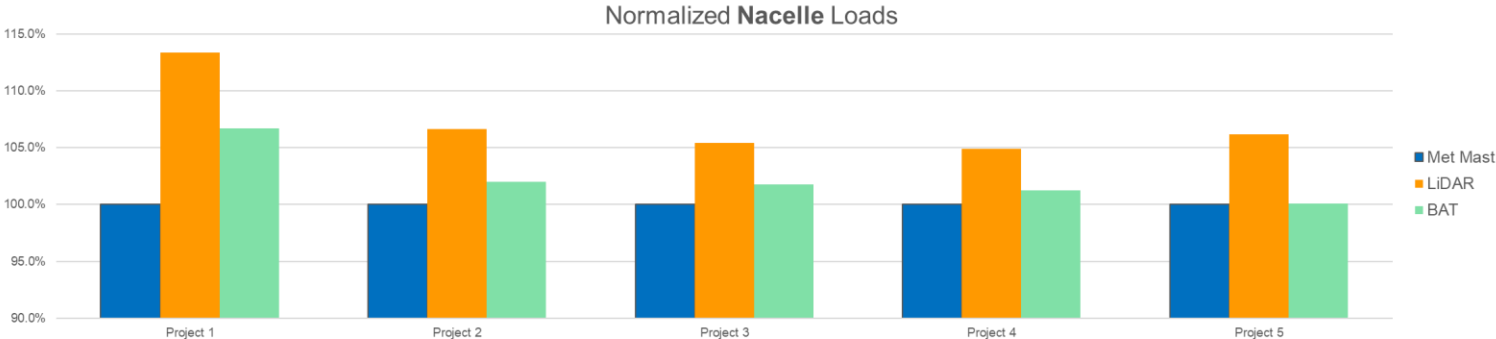
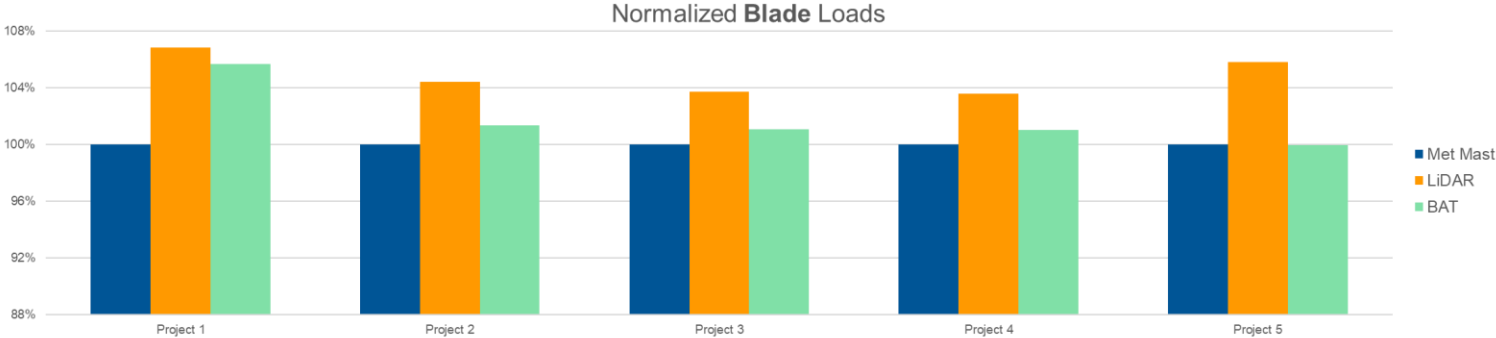


... With probably a Met. Mast nearby...

- Preferably same /overlapping timestamps as LiDAR
- Maybe different timestamps & durations

Validations

Met Mast Equivalent Load response



TI driven loads adjusted with BAT are closer to the loads calculated directly from Met.Mast data

Wind speed driven loads remain unchanged when adjusted with BAT

Total 52 independent site validations (next slides)

Validations

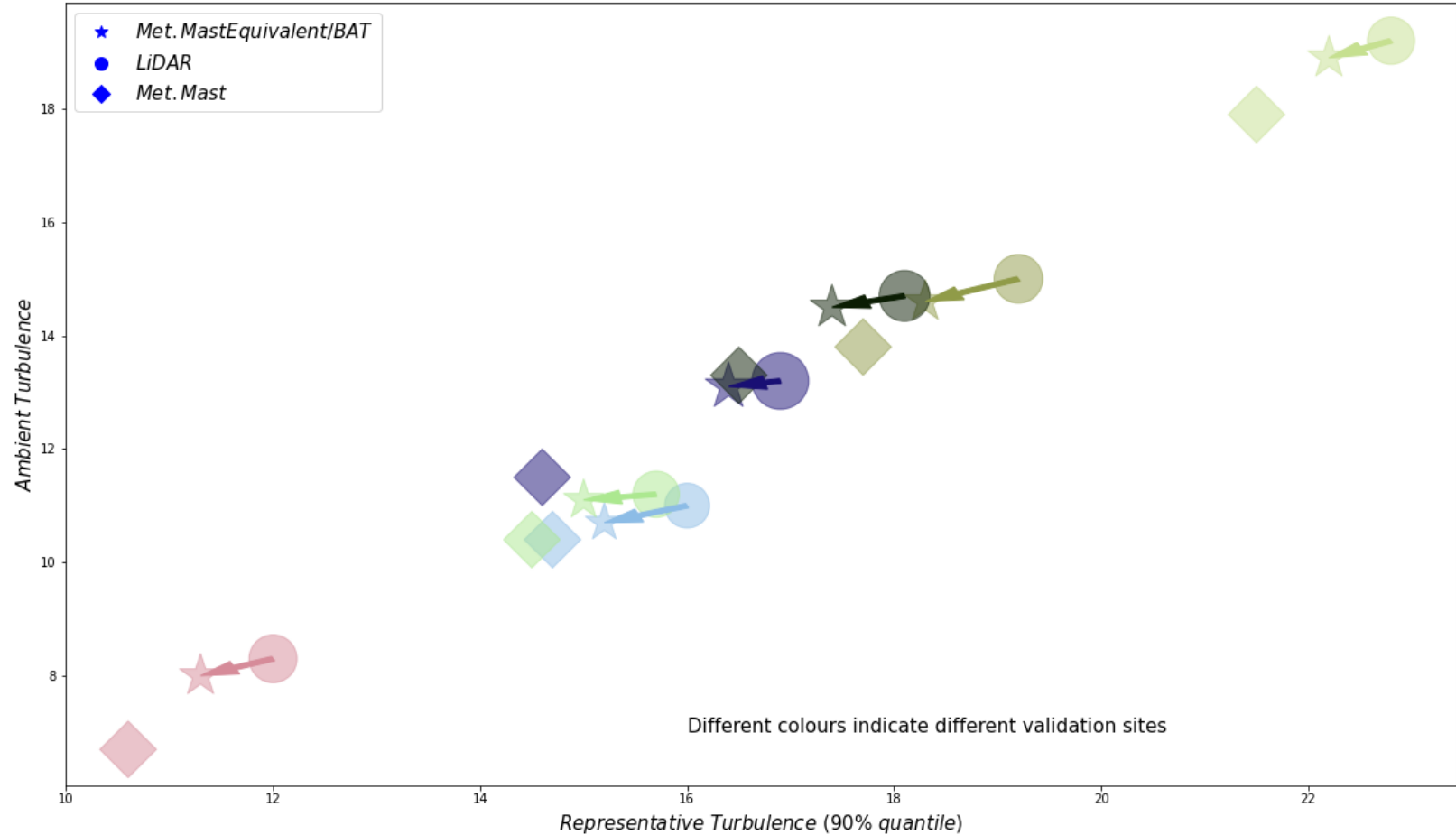
Met Mast Equivalent Climatic



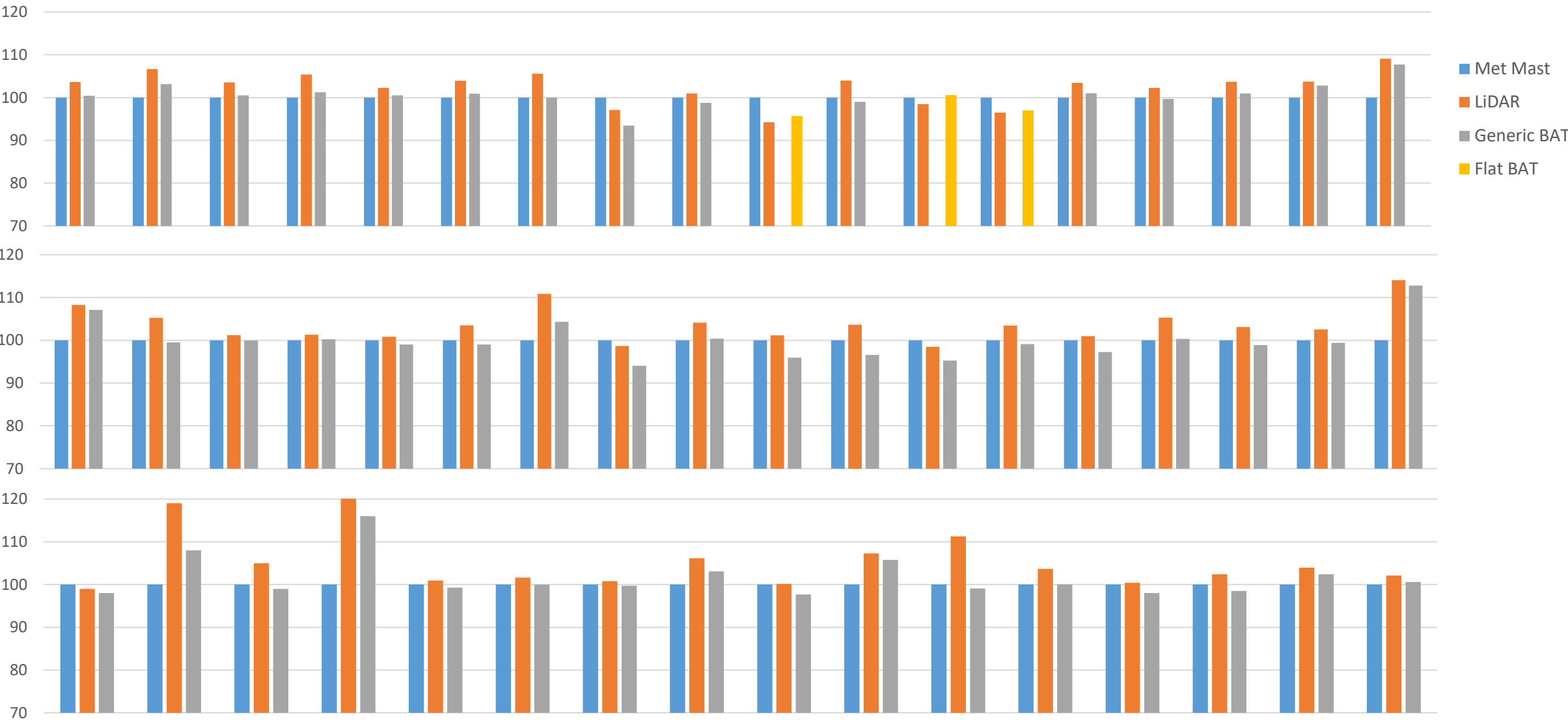
The aim of the project was to find Met. Mast equivalent Load response, but the binned TI vs WS comparison also shown for industry benchmarking

Notable observations:

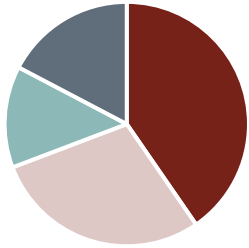
- BAT follows the LiDAR on average TI
- Major difference observed in Std Dev of TI
- Hence, impact on Representative TI (mean + 1.28 Std dev), which drives Fatigue loads



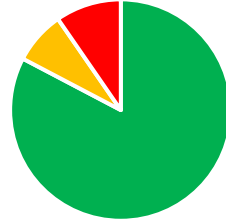
Normalized Blade Loads – as representative for turbulence-driven component



Normalized Blade Loads – Validation conclusions



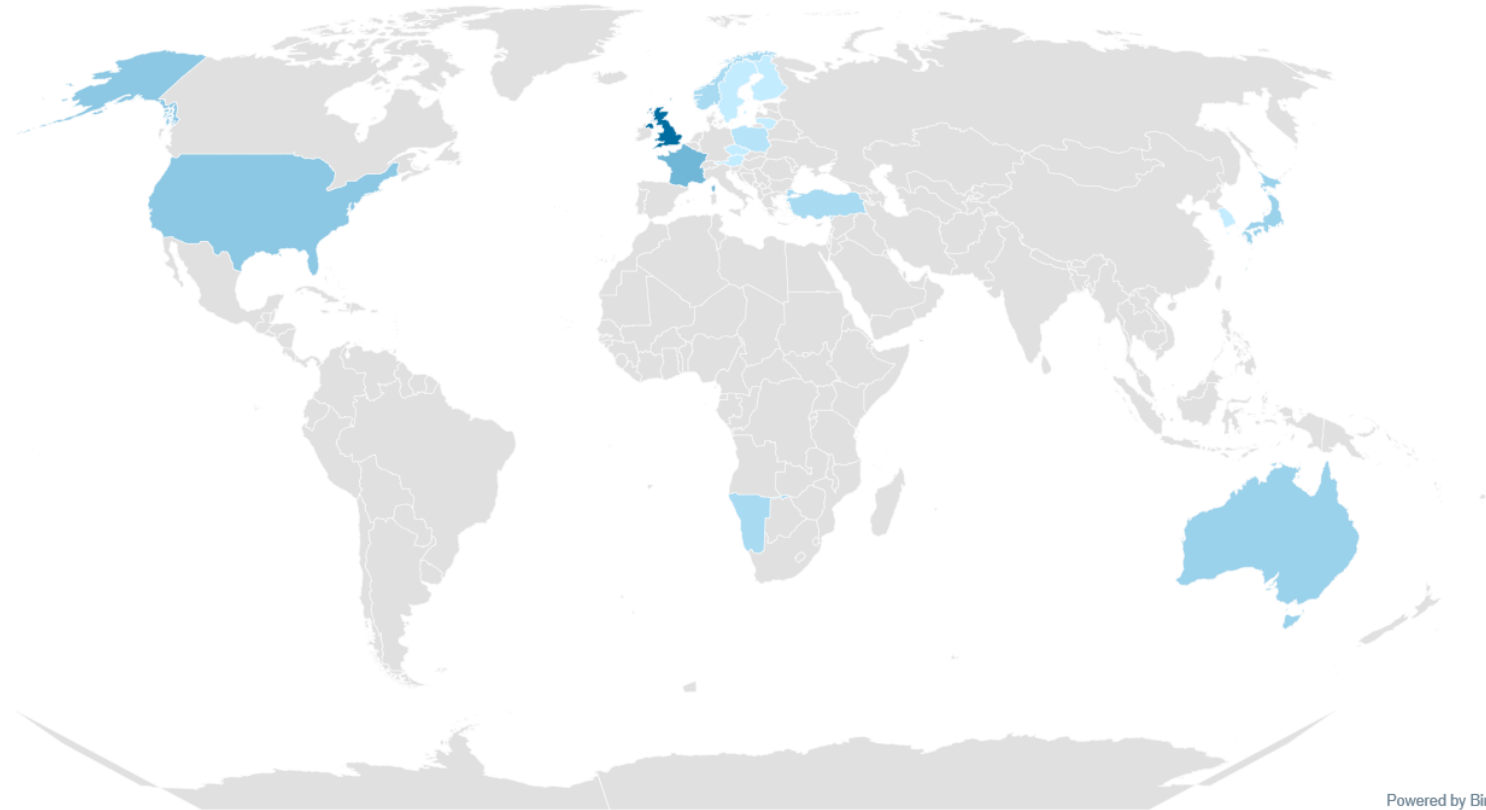
- Complex
- Semi-complex
- Flat Forested
- Flat



- Acceptable and Conservative transformation
- Within uncertainty buffer
- Under-conservative transformations

Validation locations

- 52 independent sites build the basis for validation – with good mix of geography and orographic conditions
- 47 sites show acceptable and conservative load levels after transformation
- 5 sites show under-conservative load levels, meaning the BAT-transformed loads are lower than Met.Mast-loads and exceed uncertainty buffer.
- Out of the above 5 sites, 4 are known to be flat sites and have not yet been tested with FLAT BAT – and all have below 6 months of data



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So have we solved it all?

NO – it's under validation

Can we site turbines with LiDAR after today?

***No – its under additional validation
but, we have an internal process to hand-
carry project specifics***

Short Duration LiDAR measurements??

***Effective duration and availability – current standard best
practices of site representativeness still apply***

***LiDAR data must be representative of the turbine locations
in terms of climatics and height of measurement***

***This methodology cannot make an unsuitable dataset suitable, for siteability – it can ONLY adjust
volume to point measurements***

Next Step

...begins here

| | |
|--------------------------------------|-------|
| Offshore | GC000 |
| Flat, No Forestry, Nearshore | GC001 |
| Flat, No Forestry, Inland | GC002 |
| Flat, Forestry, Nearshore | GC011 |
| Flat, Forestry, Inland | GC012 |
| Semi Complex, No Forestry, Nearshore | GC101 |
| Semi Complex, No Forestry, Inland | GC102 |
| Semi Complex, Forestry, Nearshore | GC111 |
| Semi Complex, Forestry, Inland | GC112 |
| Complex, No Forestry, Nearshore | GC201 |
| Complex, No Forestry, Inland | GC202 |
| Complex, Forestry, Nearshore | GC211 |
| Complex, Forestry, Inland | GC212 |

Offshore discussion Ongoing

Out of everything, Flat sites need a closer look – probably a GC specific model

Conclusions

- First step towards LiDAR only siting – the algorithm seems to be robust and with potential - ongoing endeavours towards industry communication
- The BAT algorithm targets to adjust / transform the Std dev. of TI – to proceed to a Met. Mast Equivalent turbine loads

Summary

- Notable Collaborators



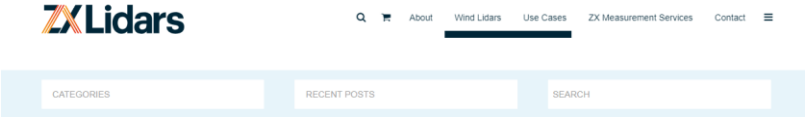
Thanks to all of them for their continued support, high quality data



- Complete engagement with CFARS



- Presented in Wind Europe Tech Workshop Brussels 2022, Lyon 2023; Wind Europe Copenhagen, 2023; ACP Conference USA, 2022



Vestas assesses turbine suitability with Lidar wind measurements

22 Jun 2022

Vestas releases details of assessing wind turbine suitability for projects with wind measurements from Lidar only, with ZX Lidars

Ahead of WindEurope's Wind Technology Workshop 2022, Brussels, wind turbine OEM Vestas has released details of "a way towards Lidar-Only Load Response Comparison" that shows a methodology that can potentially enable wind farm developers to conduct Lidar only measurement campaigns that will support turbine suitability for new projects in the future. The methodology, referred to as Bandpass Adjusted Turbulence (BAT), brings a novel methodology for using measurements solely from wind Lidars for evaluating the load response of wind turbines forward using the wind turbulence spectra from the Lidar measurements.

The work is being regarded as a step towards 'Wind Industry 2.0' – a world where met masts are no longer required for this final hurdle within wind farm development, and follows the general acceptance of Lidar data by wind consultants and the finance community since 2012, onshore and offshore.

A collaboration between Vestas, Fred. Olsen Renewables, Natural Power and ZX Lidars has resulted in this significant development for the wind energy industry as the community works towards Lidar wind measurements that can be safer, faster, cheaper and better when compared to traditional mast and cup anemometry.

Preview the full poster here: <https://windeurope.org/tech2022/programme/posters/PO067/>



Thank you

