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Wind. It means the world to us.™

Bandpass Adjusted Turbulence (BAT)

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Outcome

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

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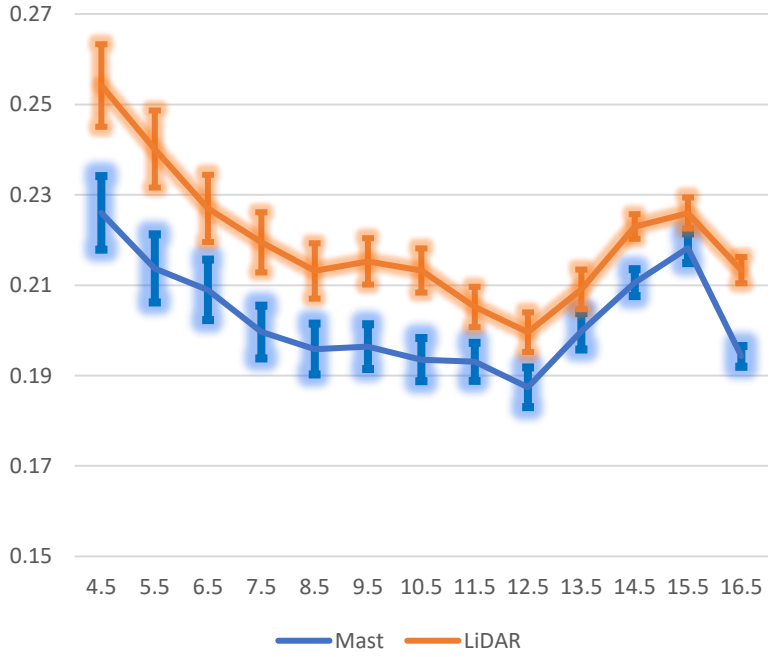
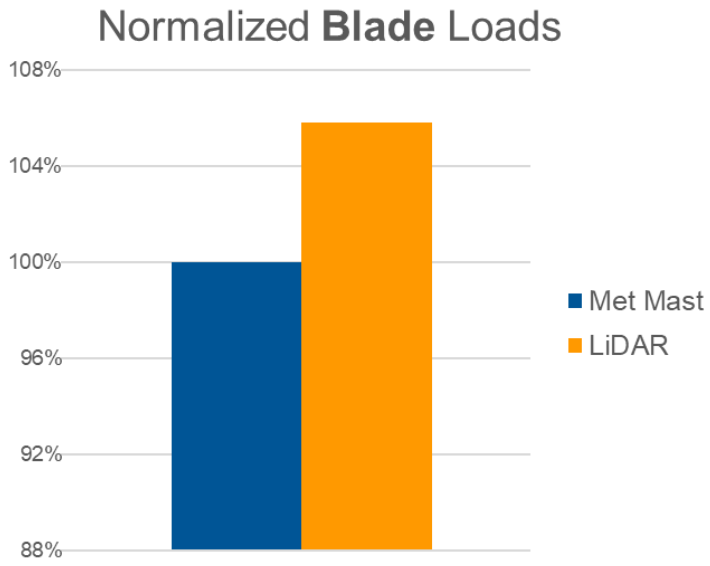
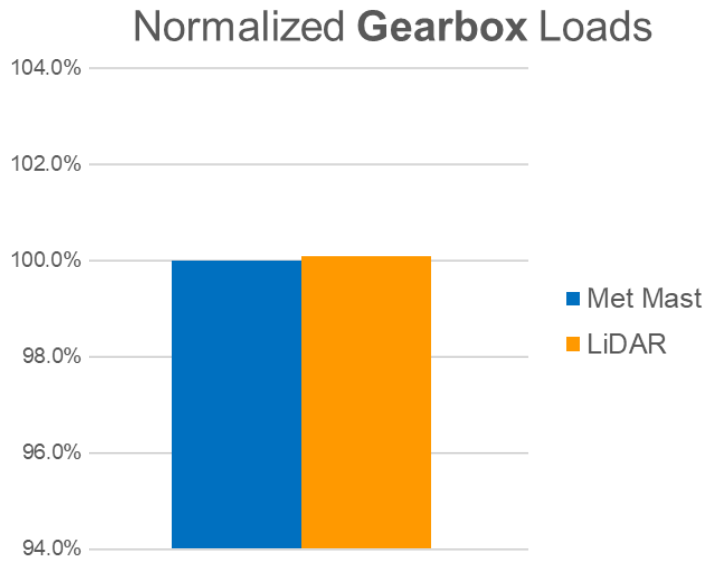
Problem definition



- 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

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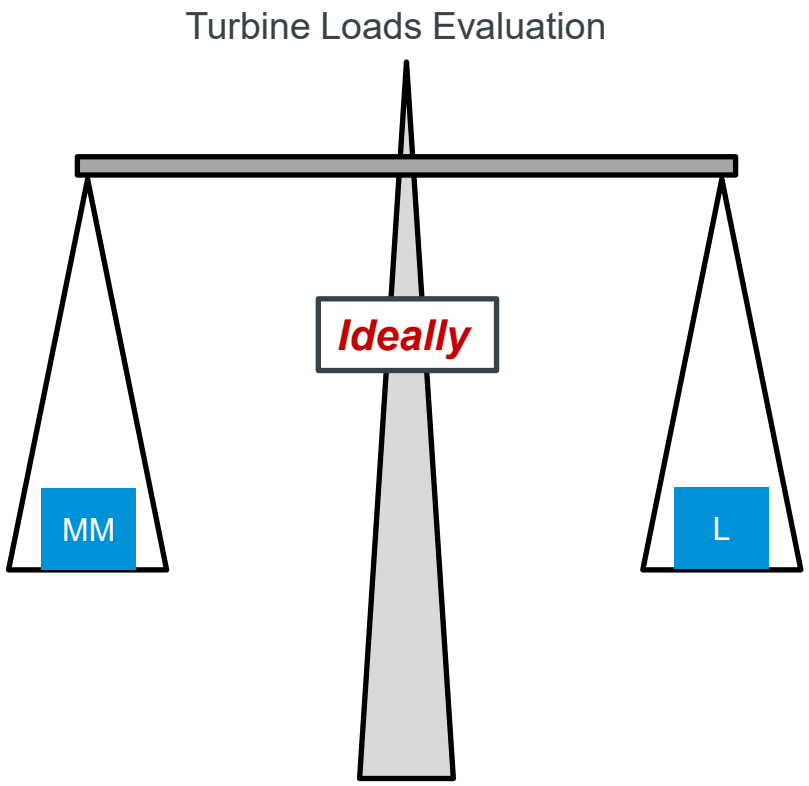
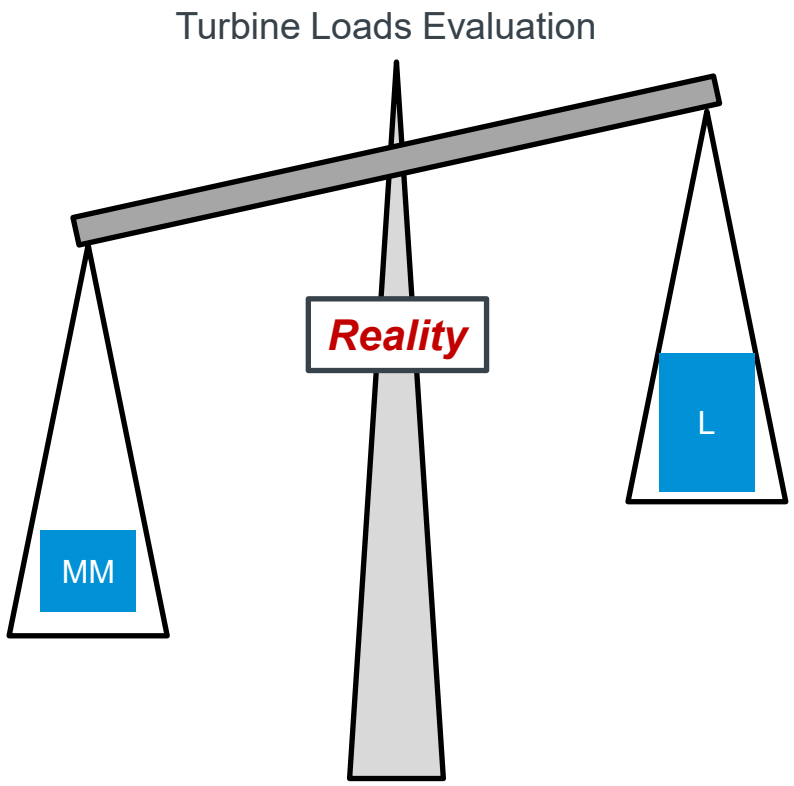
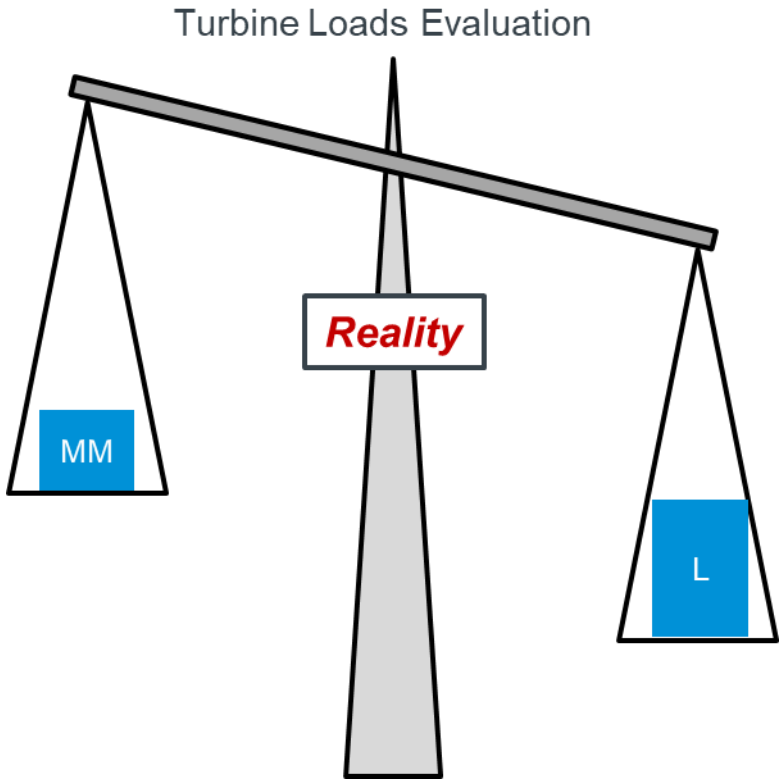
Problem Definition
Summary



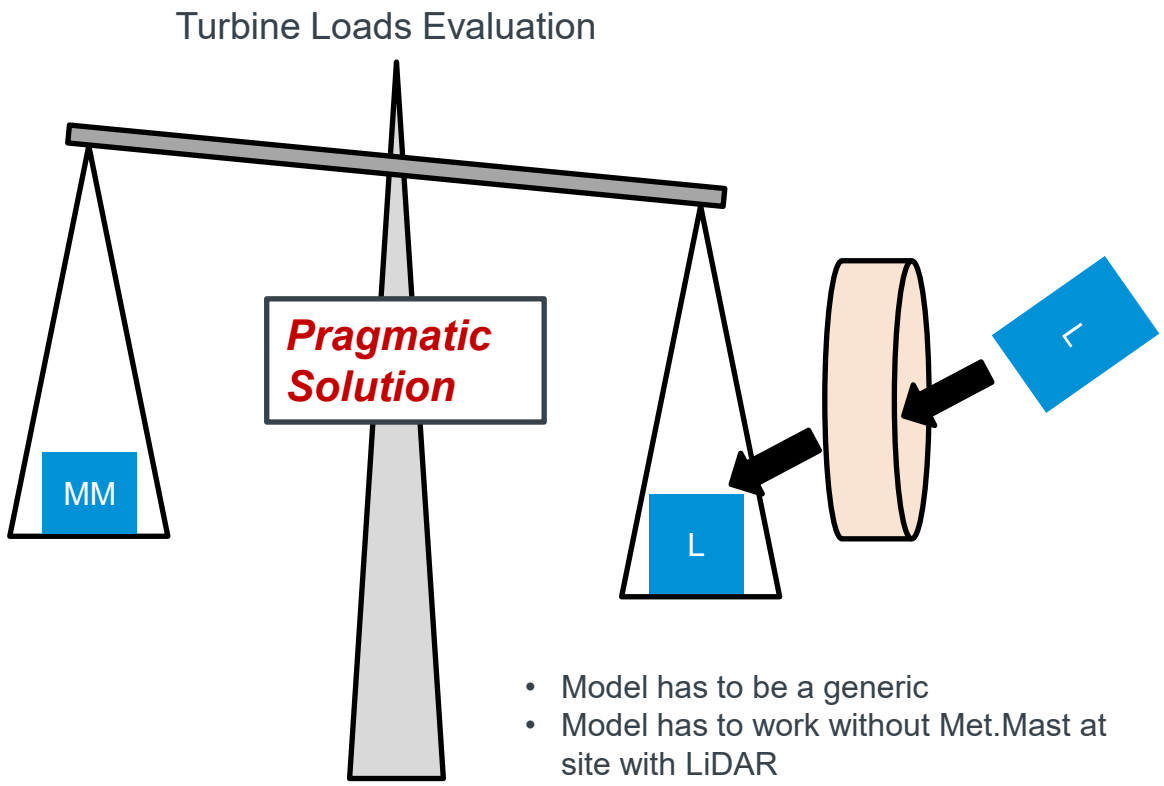
Problem Definition
Summary



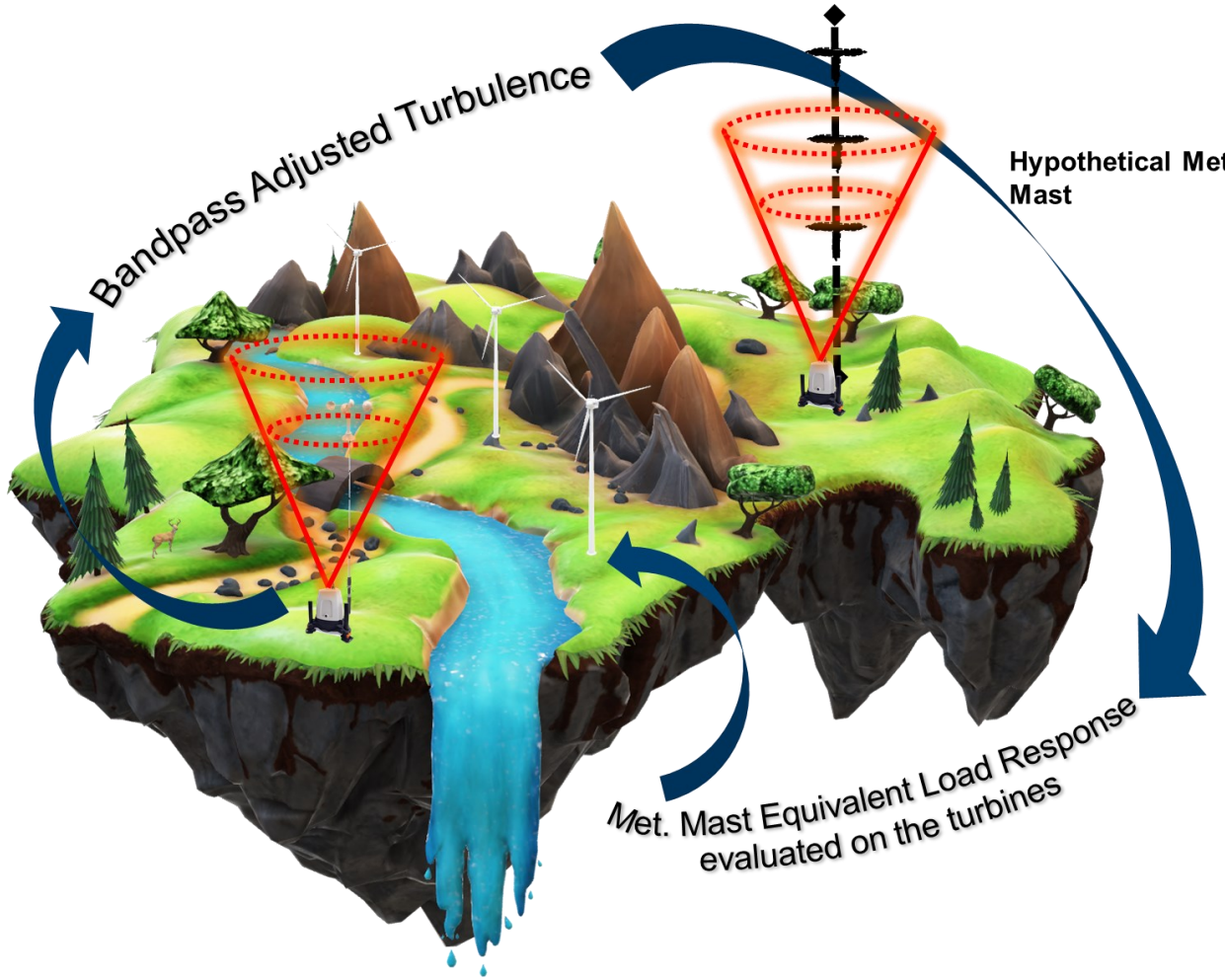


Problem Definition
Summary

Pragmatic Solution : Met. Mast Equivalent



- Model has to be a generic
- Model has to work without Met.Mast at site with LiDAR



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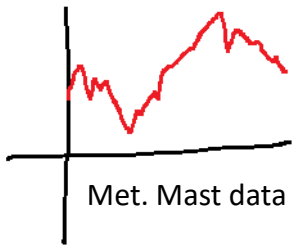
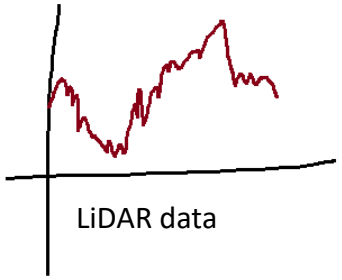
Methodology
... a BAT in detail

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



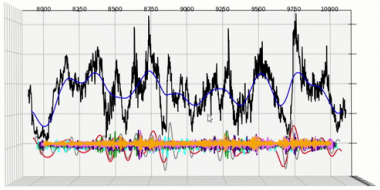
LiDAR data

Inputs

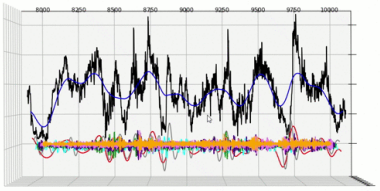
- Collocated and Concurrent
- 1y duration
- High availability
- 10min-avg WS, StDev, TI

for Each **in Collocated Pairs**:

Met. Mast data



VS

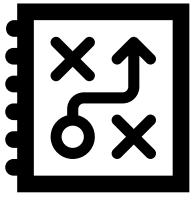


LiDAR data

- Decomposition
- Frequency-band based comparison

Transformation Model

Information from all the Collocated pairs – aggregated and stored



Index	WSGain	WSOffset	STDGain	STDOffset
Component0	0	0	0	0
Component1	1.03595	-0.000551995	0.890079	-0.000170753
Component2	1.00949	0.000397437	0.859821	2.83299e-05
Component3	0.956115	0.000259107	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	-2.95032e-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

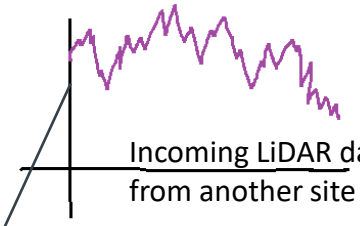
Model Builder - BATMoB

User Side

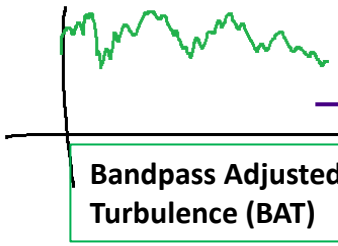
- Preferably 1y or integer year
- User must be sure that data is suitably representative of site suitability and loads assessment

Process

Model called



Incoming LiDAR data from another site



Bandpass Adjusted Turbulence (BAT)

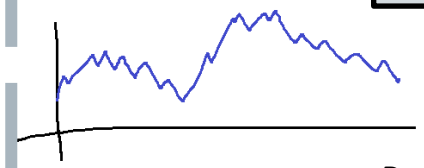
Loads LiDAR

VS

Loads BAT

VS

For Model Validations



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

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

Loads Met Mast

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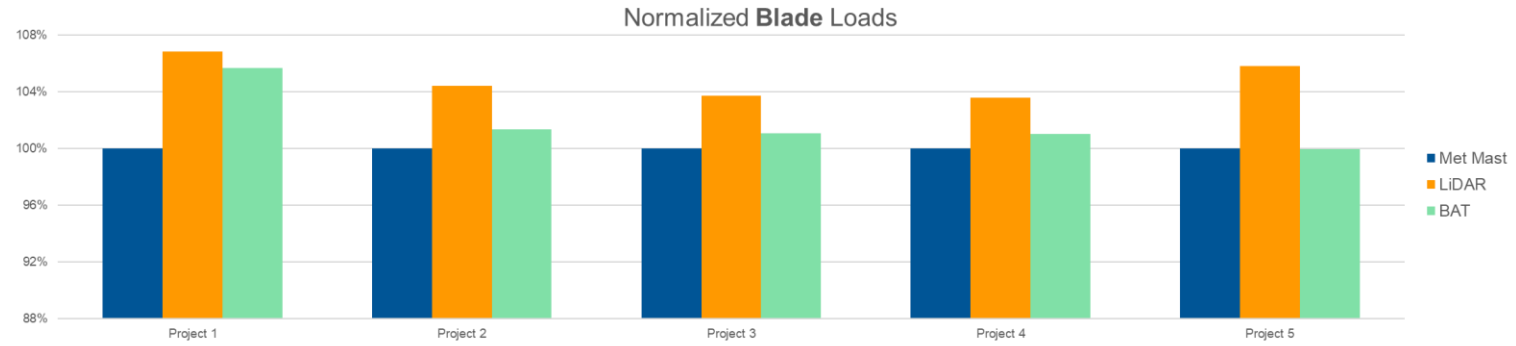
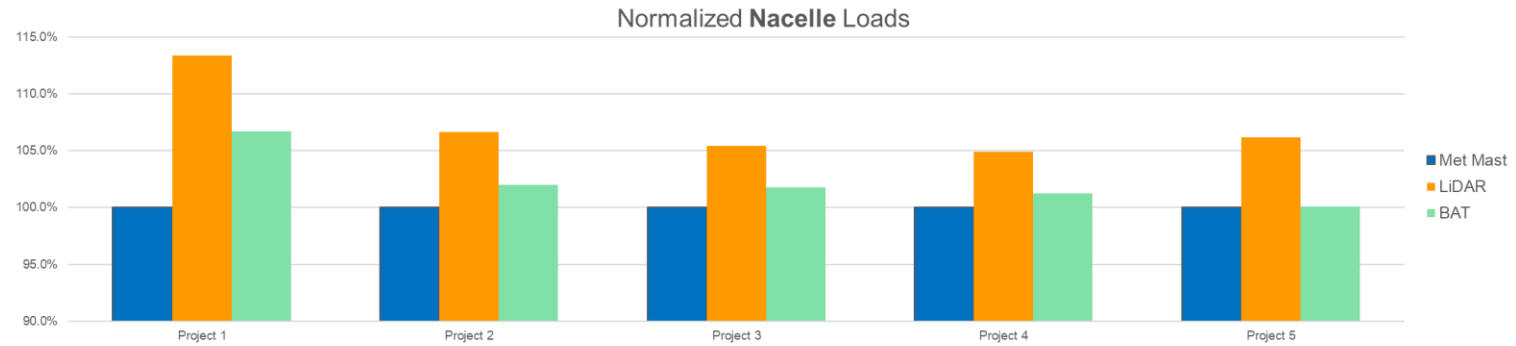
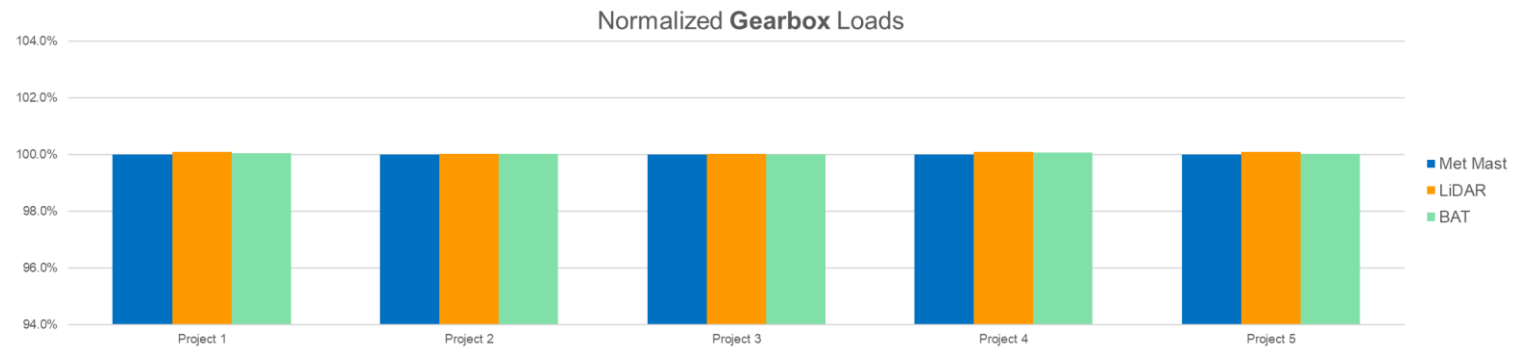
Validations
Met Mast Equivalent Load response







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)

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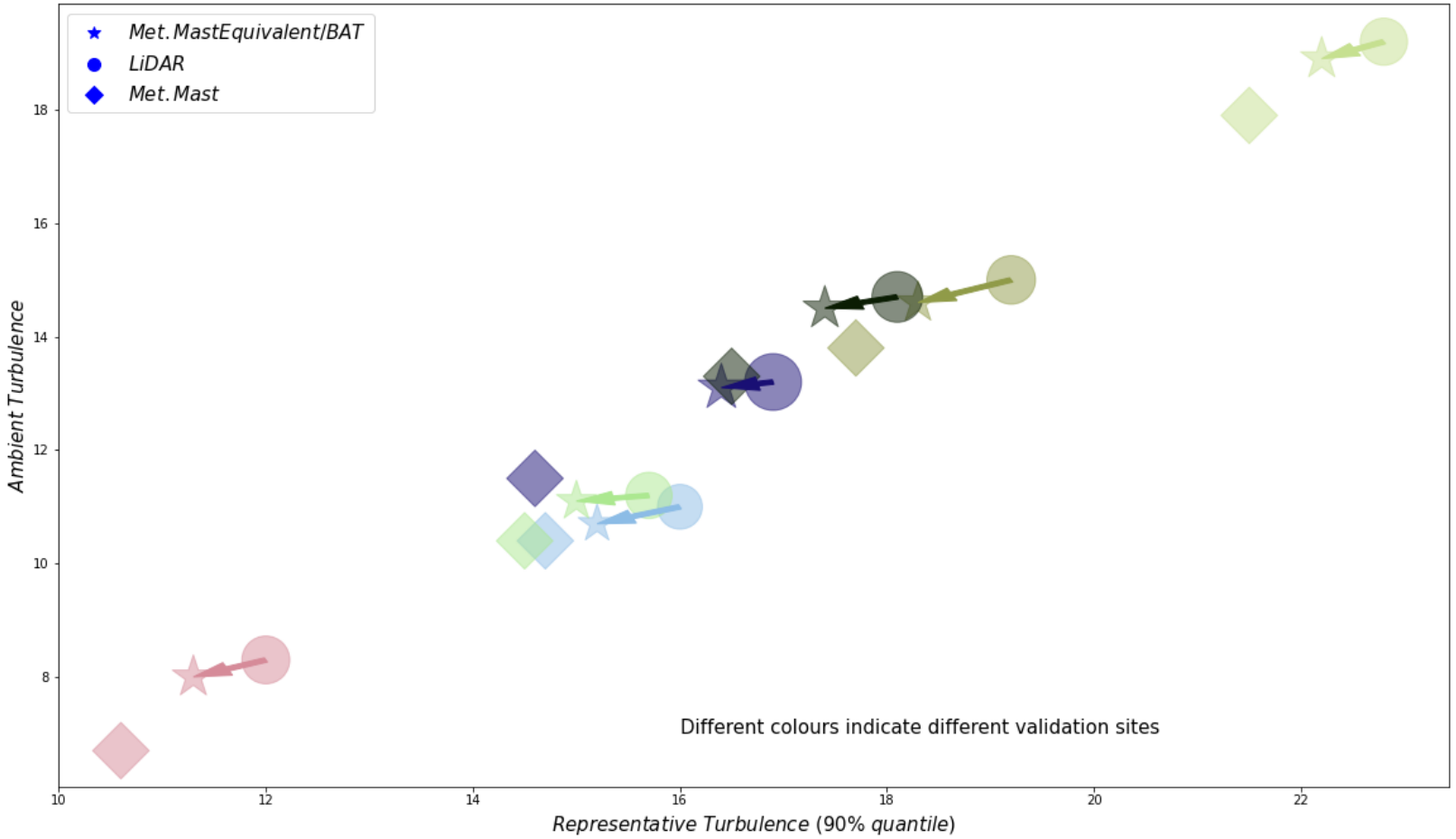
Validations
Met Mast Equivalent Climatics

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



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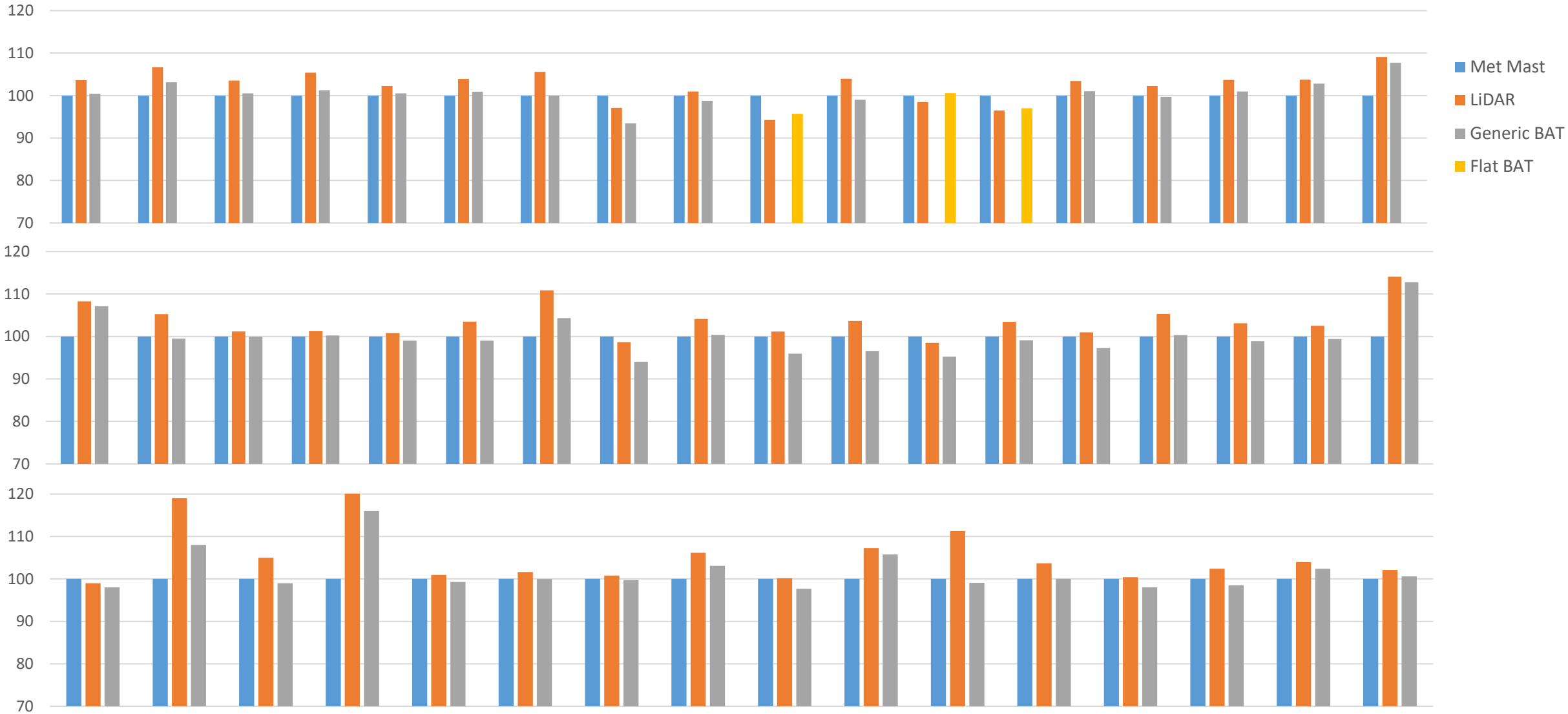
Normalized Blade Loads – as representative for turbulence-driven component



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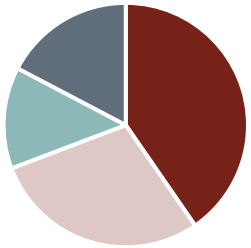
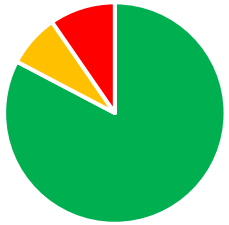
Normalized Blade Loads – Validation conclusions

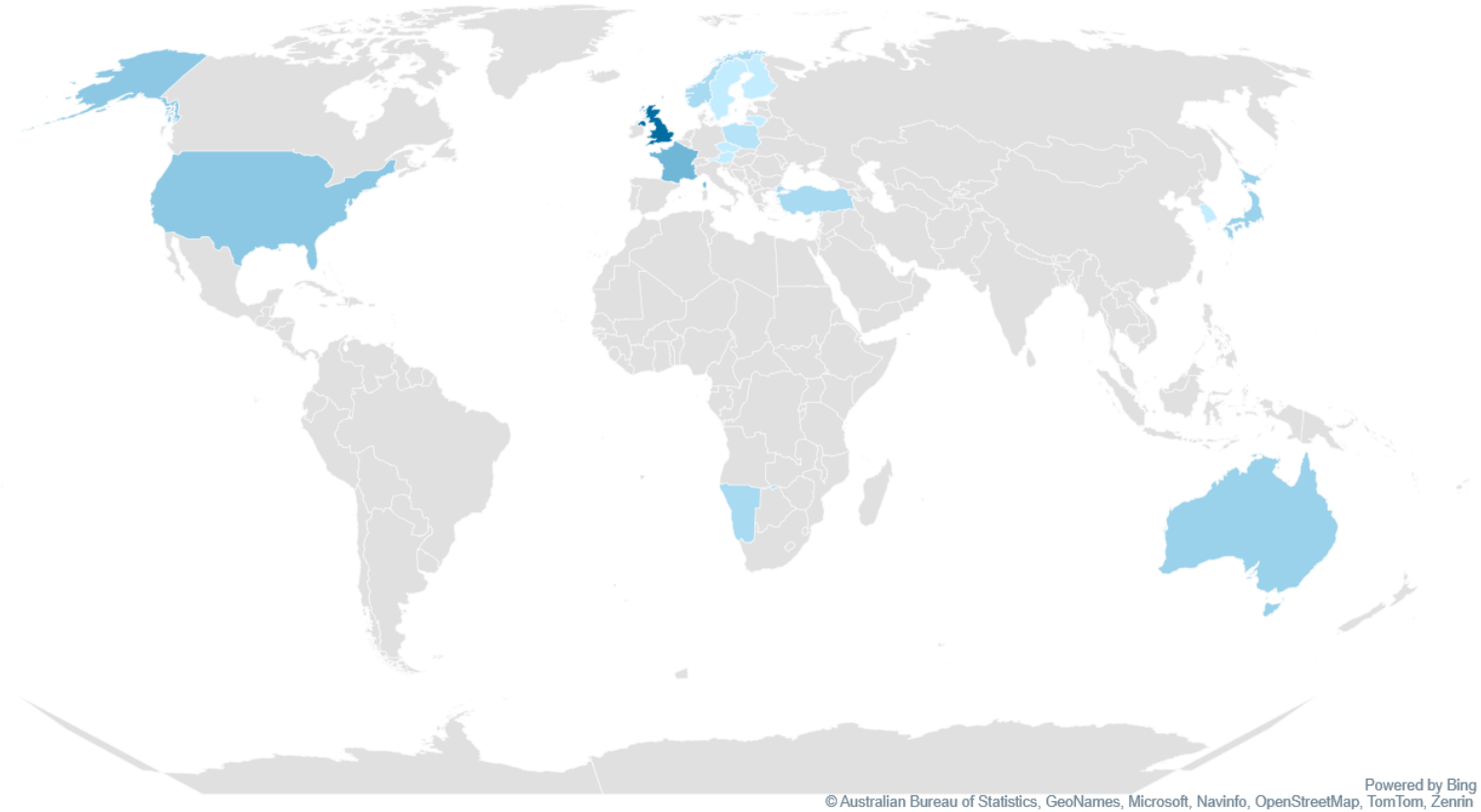


Complex
Semi-complex
Flat Forested
Flat



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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Validation
FAQs

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

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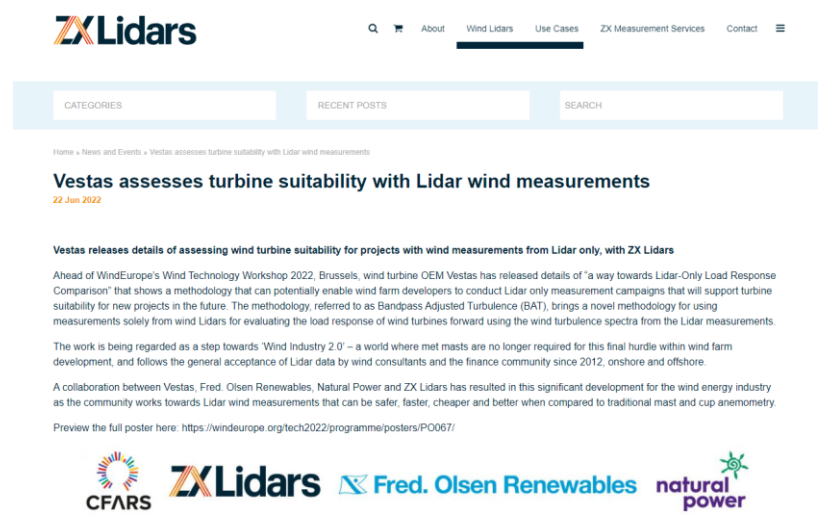
Summary

- 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




Thank you