

## **Increased Project Bankability : Thailand's First Ground-Based LiDAR Wind Measurement Campaign**

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As wind turbines size continue to grow with higher hub heights and larger rotor diameters, LiDAR wind measurements become necessary to improve the coverage of wind measurements at a site in all directions and to reduce the project investors risk. While traditional cup anemometers are today's standard measuring devices for wind speed measurements, LiDARs have proven to perform with IEC-class 1 accuracy level in order and can provide additional bankable data either used as a standalone measurement system or as a complement to a traditional met mast to reduce vertical and horizontal extrapolation uncertainties and increase the bankability of any given project.



The big advantage of LiDAR systems relies in their quick and easy deployment. This can be especially interesting at isolated and complex sites where high masts installation (>80 m height) can be very challenging (and expensive). WINDCUBE v2 LiDAR is the optimal choice for complex terrains as its Flow Complexity Recognition (FCR) feature ensure the measured data is IEC-class 1 accurate even in the most complex terrains.

The FCR technology is essentially an online correction system, which is paired with WINDCUBE v2 LiDAR. WINDCUBE v2 LiDAR is equipped with five beams; four beams are inclined vertically 30° in each direction (0°, 90°, 180°, 270°, and 360°). The inclined beams measurements are used to calculate the horizontal component of the wind speed. The fifth beam (shooting light pulses vertically upwards with 0° inclination) helps in measuring the vertical wind component so the impact of terrain complexity on the measurements can be factored.

MeteoPole have been appointed as LiDAR Engineering Consultant for a proposed 64 MW wind farm in Thailand. The proposed wind farm is located in the central part of Thailand, in an undulating terrain with complex roughness land cover. The wind farm covers a relatively wide area as the maximum distance between two WTGs is 8 km. The proposed wind farm hub height is 120 m with a swept diameter of 110 m. Three masts are measuring at a height of 85 m.

Extrapolation of 85m wind measurement to 120 m prospective hub height can be highly uncertain and so it increases project's financial risks. In addition, to ensure smooth operations throughout project lifetime, it is essential to assess the load acting over the swept area of each WTG. High wind shear and turbulence intensity values might reduce the turbine lifetime and increase the maintenance cost. LiDAR wind measurement is the only possible solution to accurately assess the wind shear and turbulence intensity across rotor diameters with 12 programmable measurement heights from 40m to 200m. As a result, MeteoPole recommended the project owner to

perform a LiDAR wind measurement campaign as a complement to the ongoing met mast measurement campaign.

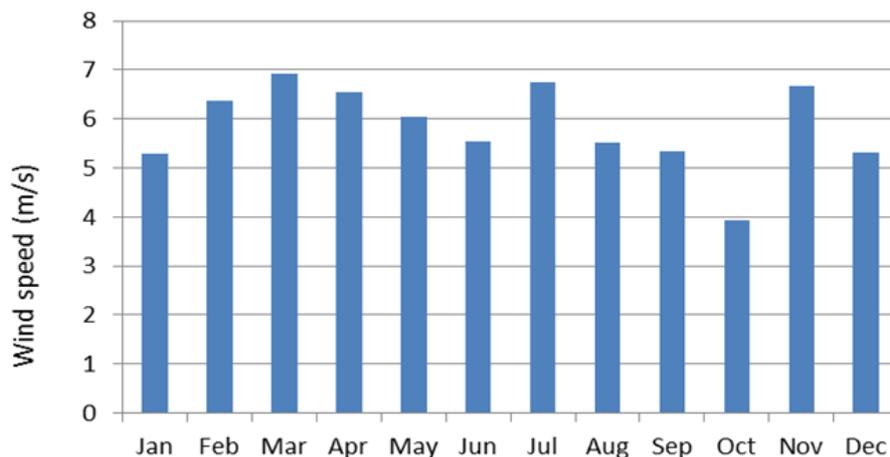
Due to the roughness complexity and the undulating terrain, the main objective of the LiDAR wind measurement campaign is to reduce the vertical and horizontal extrapolation uncertainties. To do so, the LiDAR measurements should be made at hub height (to bring the vertical extrapolation uncertainty down to zero) and at as many as possible locations (to reduce as much as possible the horizontal extrapolation uncertainty).

In order to reduce the uncertainty in wind measurement, it is necessary to choose an optimal measurement location. The optimal wind measurement location should have the following characteristics:

1. Good agreement between synoptic and measured directions;
2. No over-speeding zone;
3. Minimum wind inflow angle;
4. Low turbulence zone.

Considering the representative area covered by the met mast, terrain complexity and prospective turbine clusters, four LiDAR measurement locations were proposed including three existing met masts along with one extra location proposed by MeteoPole. LiDAR measurement at the mast locations will be used to remove the vertical extrapolation uncertainty and the extra proposed location will be used to reduce both horizontal as well as vertical extrapolation uncertainties.

MeteoPole has used the data from three on-site masts to understand the local wind climate. To understand and to validate the mast location choice based on the criteria mentioned above, Computation Fluid Dynamics (CFD) simulations were performed using the industry standard CFD code *ZephyrCFD*. CFD simulation results ensured that existing masts location and proposed LiDAR locations are in accordance with the foresaid criteria.



It can be seen from the above monthly wind speed variations plot that the LiDAR has to capture the seasonal variations at all the locations within a year. Thus the analysis of onsite monthly variations makes a fixed seasonal sampling not appropriate for that site. To remove the seasonal bias in the measurement, MeteoPole proposed the following LiDAR wind measurement campaign design strategy:

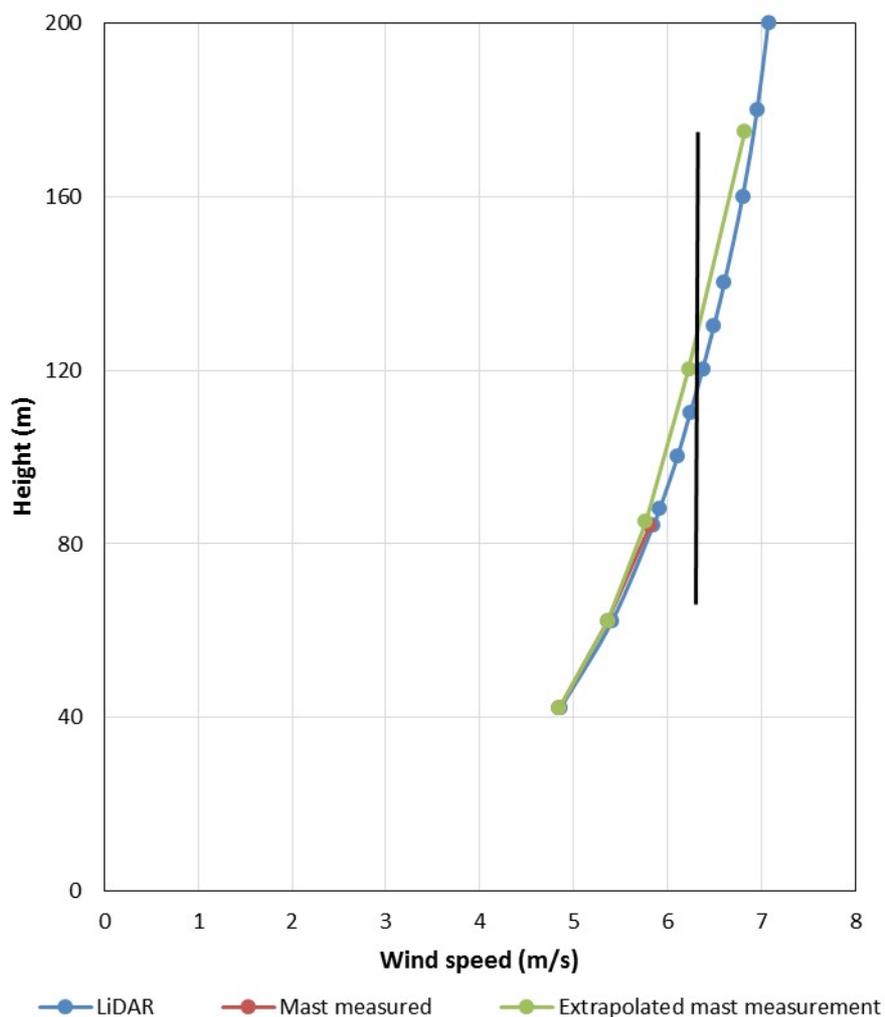
- Wind characteristics will be measured at all the selected four locations during the months of September, October, November, December and January.
- From February to May and from June to August, wind climate is less varying, thus the LiDAR can be placed at all the paces evenly.



The WINDCUBEv2 LiDAR was installed 8 m away from each met mast and the LiDAR moved around the site as per the schedule. In order to minimize the monitoring location shifting times (especially when the shifting frequency is very high), MeteoPole strongly recommended placing the LiDAR device on a moving vehicle. This was done by fixing the LiDAR on a trailer as it can be seen on the picture.

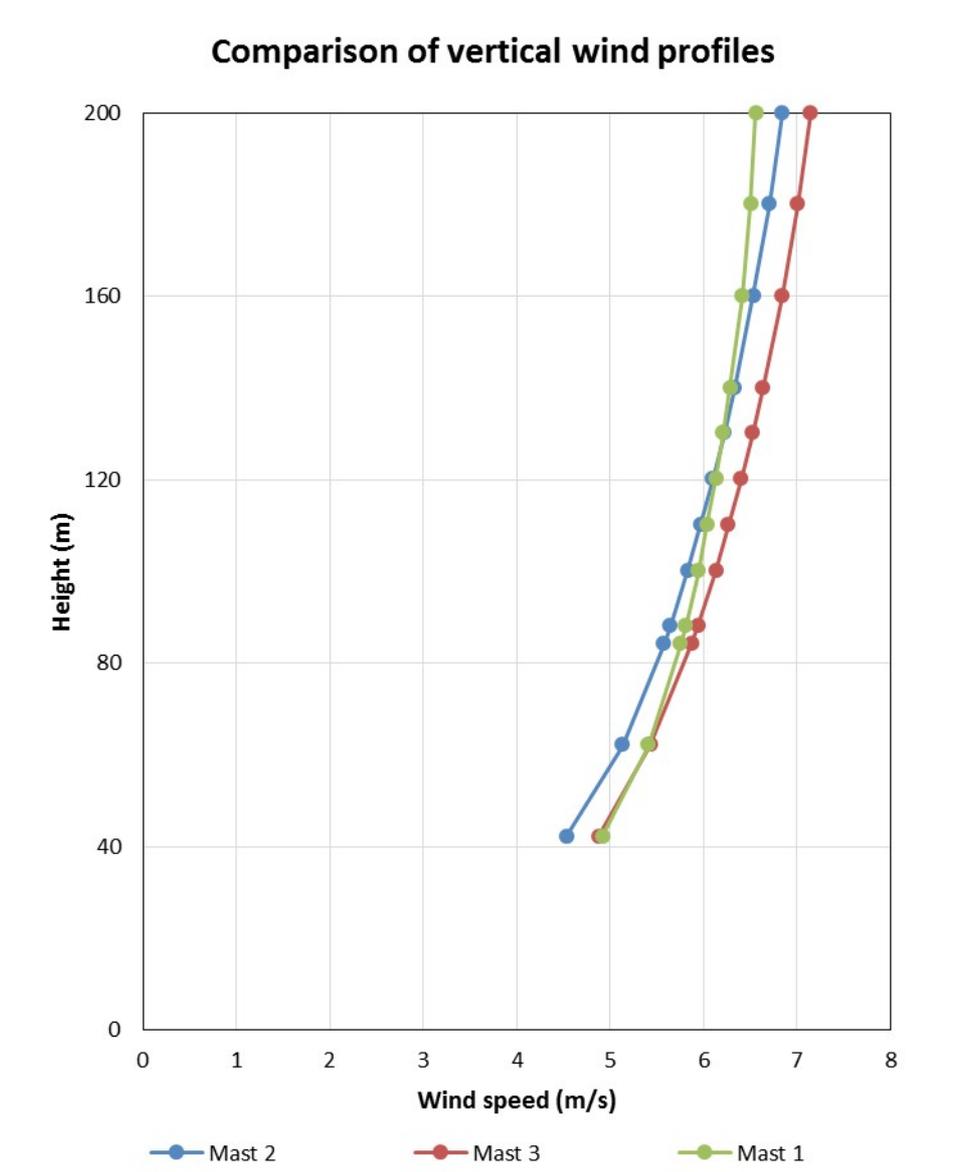
LiDAR and met masts wind measurements were monitored on a daily basis by MeteoPole and reported to the Client at the end of every month. LiDAR wind measurements can be validated by co-located met mast measurements. Comparison of LiDAR data with met mast measured data, extrapolated data to turbine hub height and over the swept area -black line- are shown on the figure below.

### Vertical wind profile



It can be seen from the figure above that the met mast extrapolated vertical profile and LiDAR measured vertical are not matching which shows the importance of using hub height measurements and not relying on vertically extrapolated data, especially for such undulating terrain with complexity in roughness land cover. Due to the observed higher shear in the profile, available kinetic power is lower than the estimated power which is calculated from mast height wind speed extrapolation to hub height.

MeteoPole has made comparison between the LiDAR measured wind speed at hub height with rotor averaged wind speed at hub height which shows a mean wind speed difference of 0.12 m/s. To calculate the wind farm energy yield, it is recommended to use rotor averaged wind speed values rather than the hub height measurement.



It can be concluded from the above figure, all the masts measured vertical wind profile are varying from each other. Though mast 1 and mast 2 measure similar wind speeds at hub height, the shear profile is clearly affected by the atmospheric boundary layer disturbance caused by complex roughness and undulating terrain features. Thus the available kinetic power over the rotor calculated from the hub height and rotor averaged wind speed values are varying significantly. Due to a lack of wind measurements over the rotor swept area, most project owners are not able to capture the variation in shear profile. In order to reduce the shear

uncertainty over the swept area, LiDAR wind measurement is the only feasible solution providing bankable data.

Using seasonal sampling techniques to perform LiDAR measurement at multiple locations can reduce the horizontal extrapolation uncertainty significantly and multiple height wind measurements directly remove the vertical shear uncertainty.

<b>Sources of uncertainty</b>	<b>3 x 85 m masts</b>	<b>3 x 85 m mast + moving LiDAR</b>
Sensor accuracy	2%	2%
Hub height extrapolation	2.4%	0%
Turbine locations extrapolation	3.5%	2%
Long-term representativeness of measurement period	2%	2.70%
Long-term scaling (correlation with reference data)	4%	4%
Total WS uncertainty	6.48%	5.59%
Uncertainty ratio between AEP and WS 1	2.1	2.1
Wind farm efficiency (PC, wake effect, losses...)	6%	6%
<b>Total AEP uncertainty</b>	<b>14.87%</b>	<b>13.19%</b>
<b>P90/P50 ratio</b>	<b>0.809</b>	<b>0.831</b>

With growing turbine hub height and larger rotor diameters, LiDAR wind measurements become necessary to reduce the horizontal and vertical extrapolation uncertainty in order to increase the project bankability and also to assess accurately wind shear and turbulence intensity.