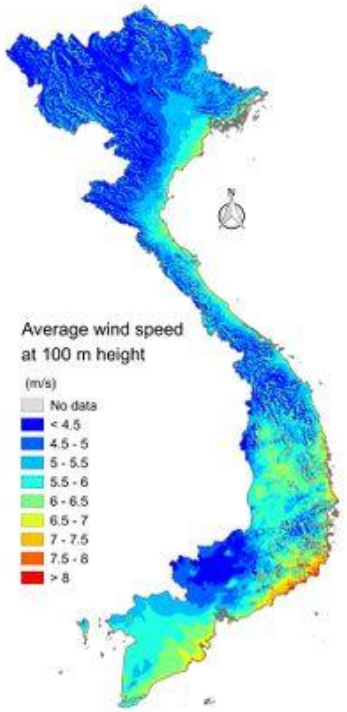
NRG Systems
Technology Advancements of Lidar
For Wind Resource Assessment

VIETNAM
WIND POWER

NRG Systems™

The Advancement of Lidar for Wind Energy

- Introduction to NRG Systems
- Importance of Wind Resource Assessment
- Brief history of Lidar in Wind Energy
- Different technologies and Bankability
- Lidar Applications
- Conclusion



About NRG Systems

- Founded in 1982
- Pioneer in Wind Energy Measurement
- Global HQ: Hinesburg, VT USA
- 100% Green
- Now part of ESCO Technologies (NYSE: ESE)

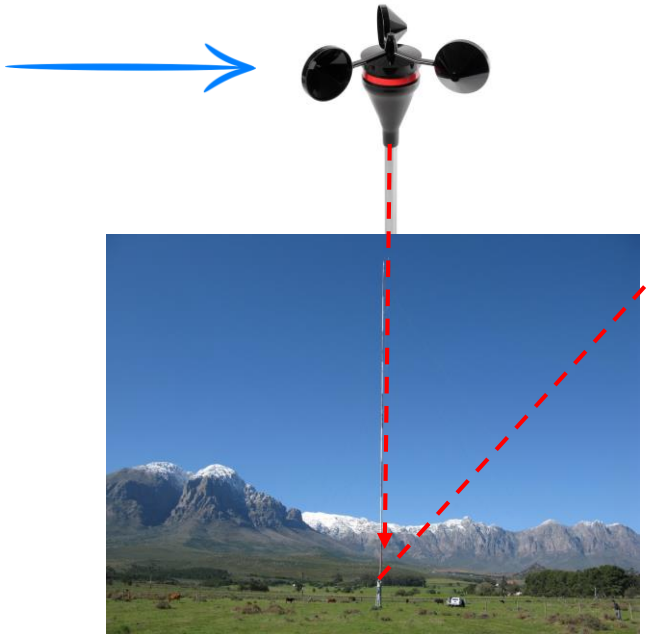
About NRG Systems

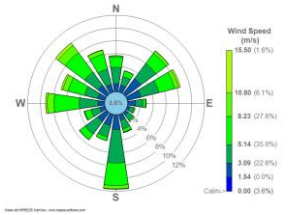
- 160+ Countries
- Over 4000 profitable wind farms globally have been constructed on data collected from NRG products for site assessment

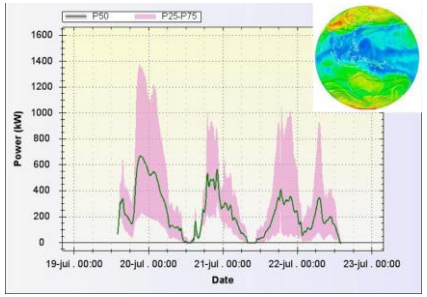
The Importance of Wind Resource Assessment (WRA)

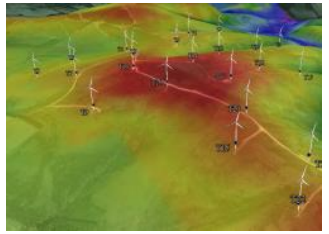
By providing reliable data to investors and owners, a properly executed wind resource assessment campaign can make the difference between a project's failure or success, saving millions in equity investments.

Met Towers are the “Tip of the Spear” in Wind Farm Development









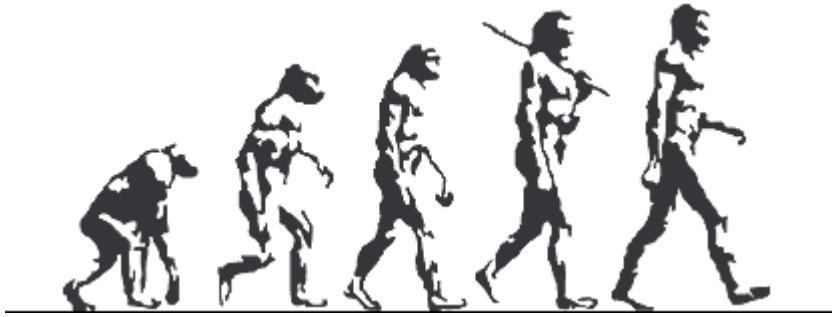
DNV·GL

UL

ARCVERA RENEWABLES

WIND PIONEERS

Short History of Lidar



What is Lidar?

How does it work?

Let me test it for a year.

What do I do with the Data?

Its too expensive!

Its Bankable!

We want to buy

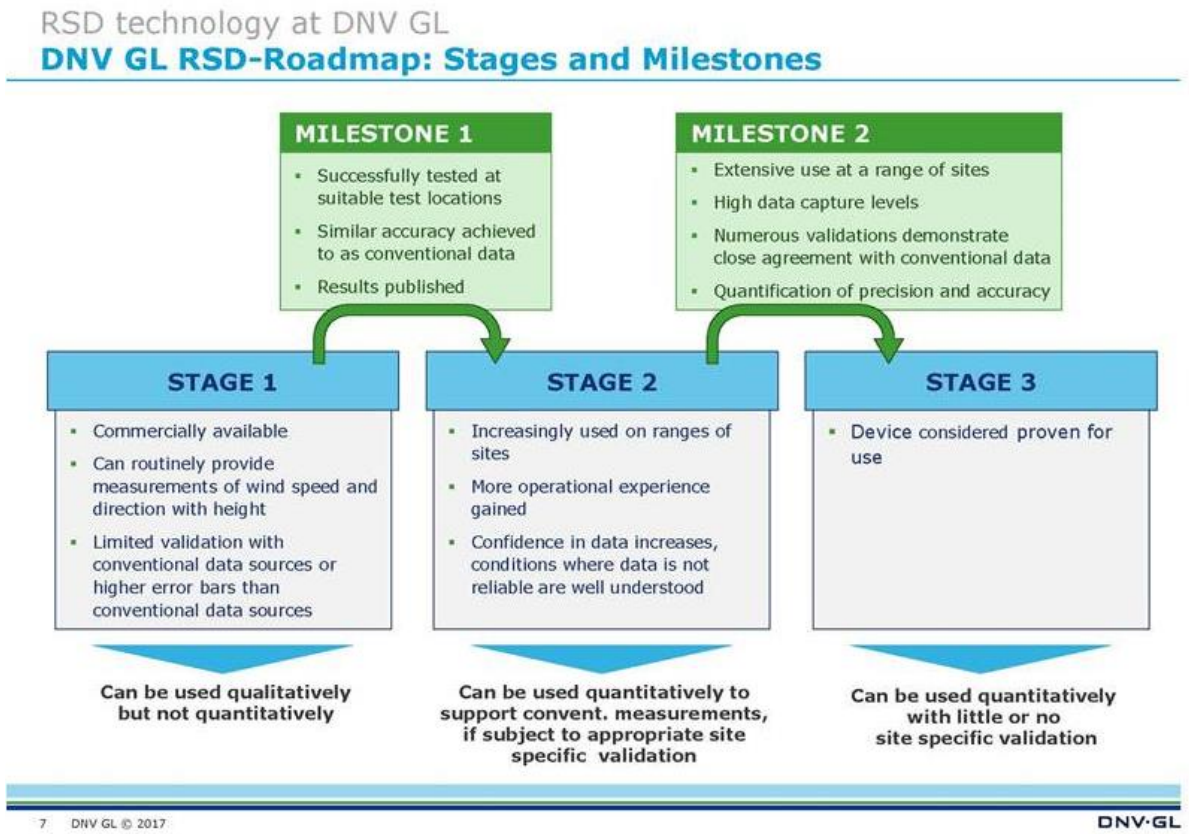
2010

2015

The Technologies

DNV-GL Classification Stages

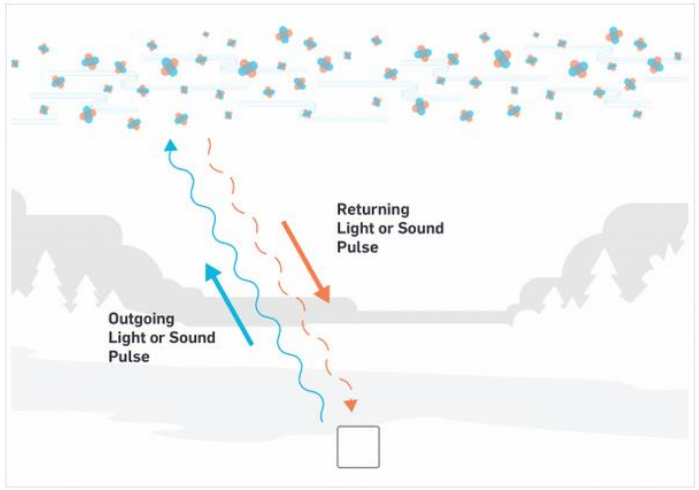
- Stage 1: Not Bankable
- Stage 2: Bankable with site validation (met mast)
- Stage 3: Bankable on its own

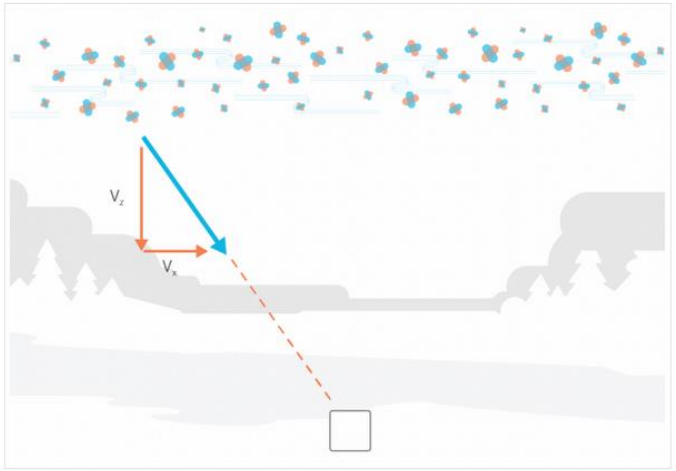


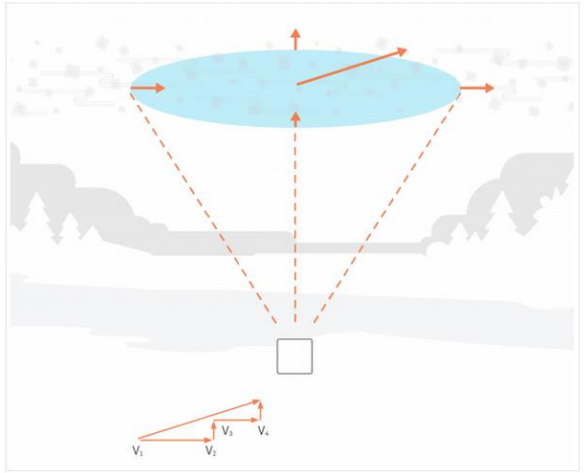
The Technologies: Doppler vs. Direct Detect

Doppler Vertical Profiler:

- Samples the atmosphere with short pulses of infrared light
- Pulses reflect off of atmospheric aerosols and collected back on the ground by the remote sensor
- Frequency of each pulse shifts as it collides with aerosols, due to the Doppler Effect.
- The magnitude of the shift in frequency is proportional to the line of sight velocity of the aerosols and, therefore, the wind at the sampled location





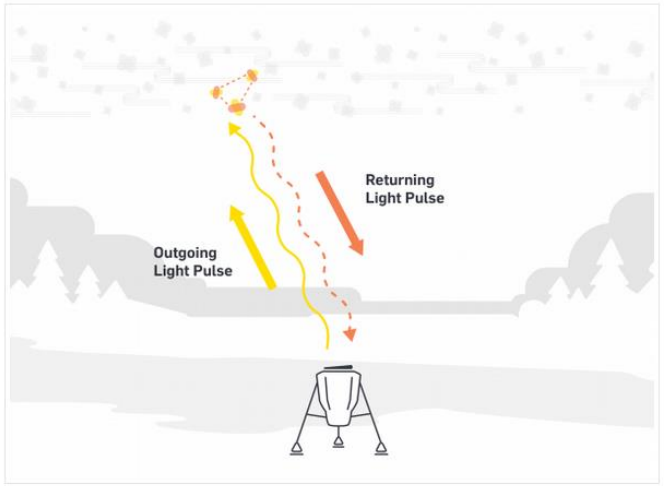


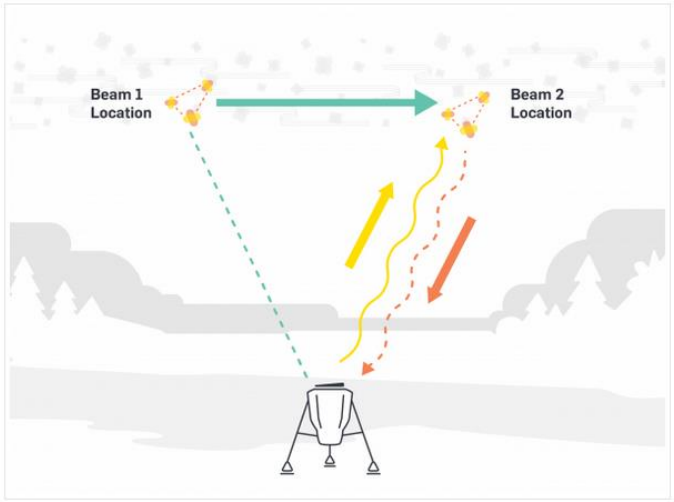
Most widely used, Stage 3 Device, wide cone, most expensive

The Technologies: Doppler vs. Direct Detect

Direct Detect Vertical Profiler:

- Sends outgoing light pulse, which reflects off of airborne aerosols
- The signal pattern of the returning light pulse indicates the density of the aerosols, and varies in time, yielding unique, recognizable signatures (kernels) as different aerosol patterns pass over the system.
- Once a kernel passes an additional beam, time and distance of flight are known, indicating wind speed and direction.

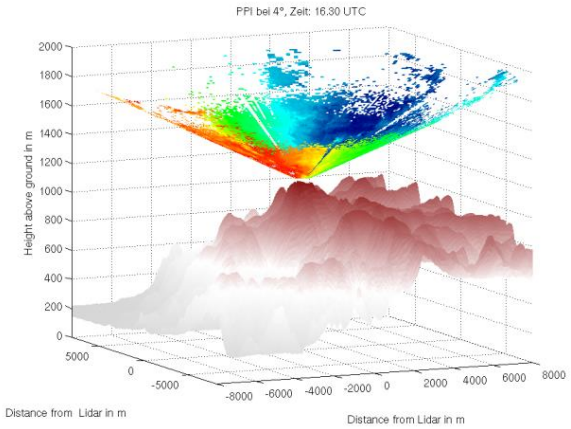


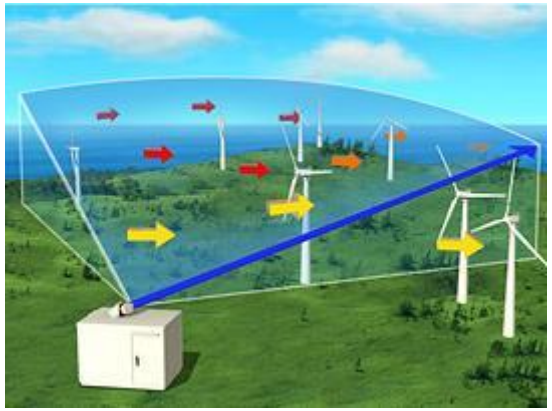


Newer technology, Stage 2 device, narrow cone, lower cost

The Technologies: Doppler vs. Direct Detect

Doppler Scanning Lidar





10km range, 3D Scans, short term campaigns, wake studies, etc. High cost.

The Lidar Technologies:

Doppler Lidar: Pulsed Wave, Vertical Profiler
Leosphere: WindCube

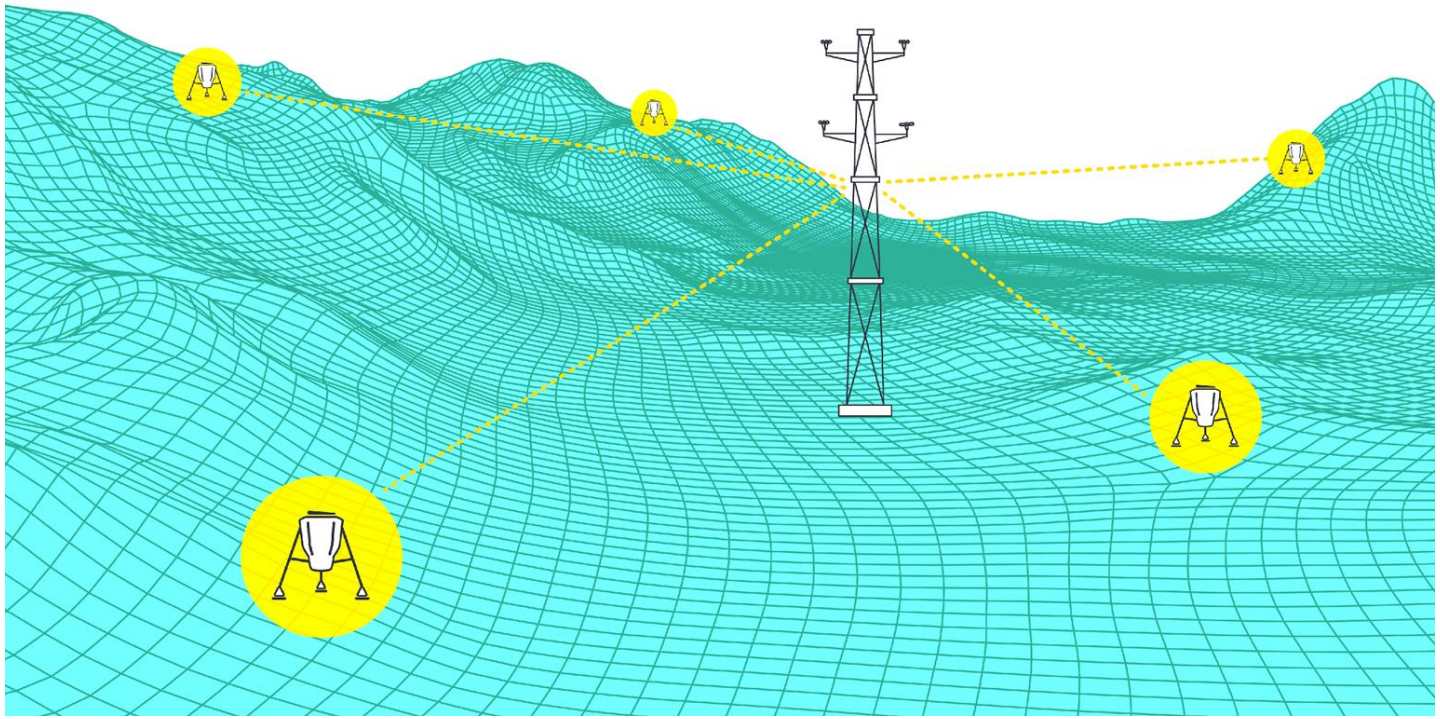
Doppler Lidar: Continuous Wave, Vertical Profiler
ZX Lidar (ZephIR): ZX300

Doppler Lidar: Continuous Wave, 3D Scanning Profiler
Leosphere: WindCube 100S, - 400S

Direct Detect: Pulsed Non-Coherent, Vertical Profiler
NRG (Pentalum): Spidar

Lidar Applications in WRA

Applications for Lidar being used today my major developers.



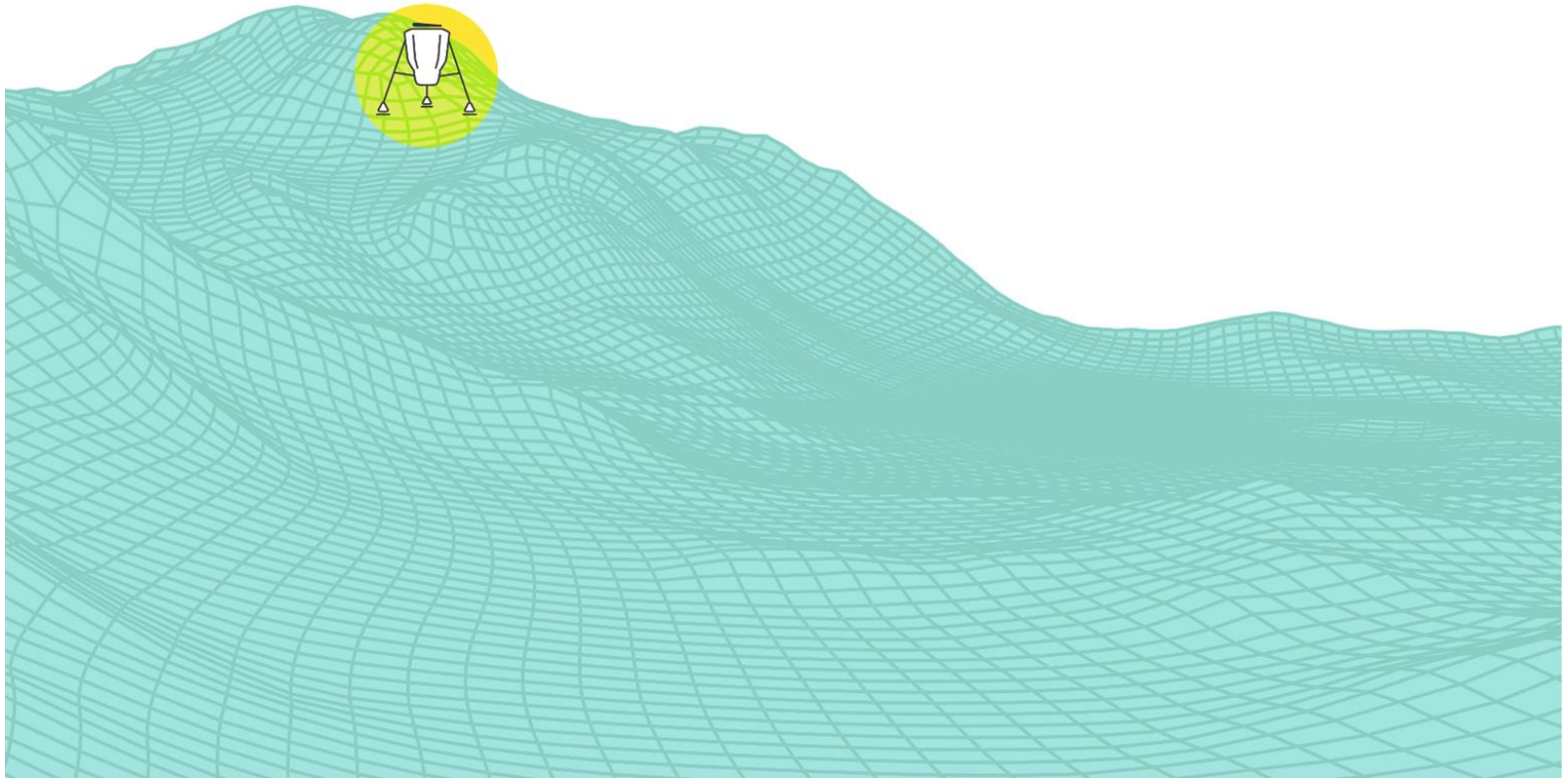
Note: There are regional differences throughout the world!

Prospecting: Stand Alone Solo Measurments

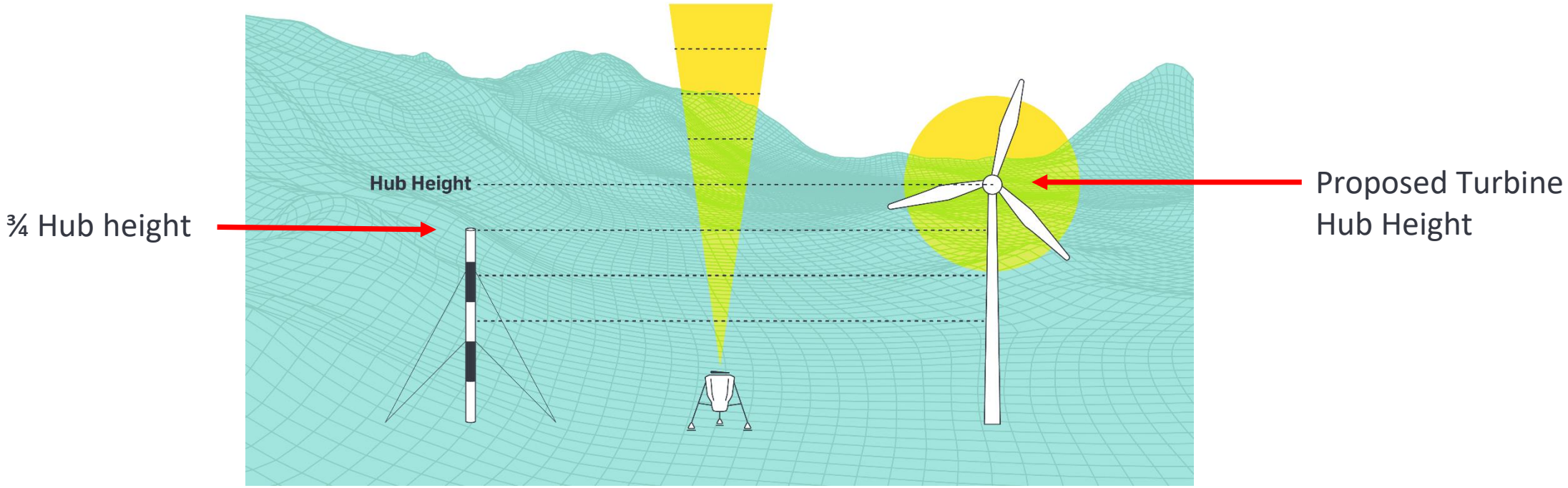
- Pre-development Campaign: Challenging locations with no towers due to terrain and/economics.

- Validation campaign – Lidar deployed immediately upon site screening to confirm findings of Mesoscale maps or earlier collected met data.
  Uncertainty reduction at beginning (i.e. creating an initial turbine layout and preliminary EPE (Energy Production Estimate).

Standalone Measurement



Further Site Prospecting



Stage 2 Lidar used in the initial Mesoscale validation phase with met mast at proposed WTG Hub Height.

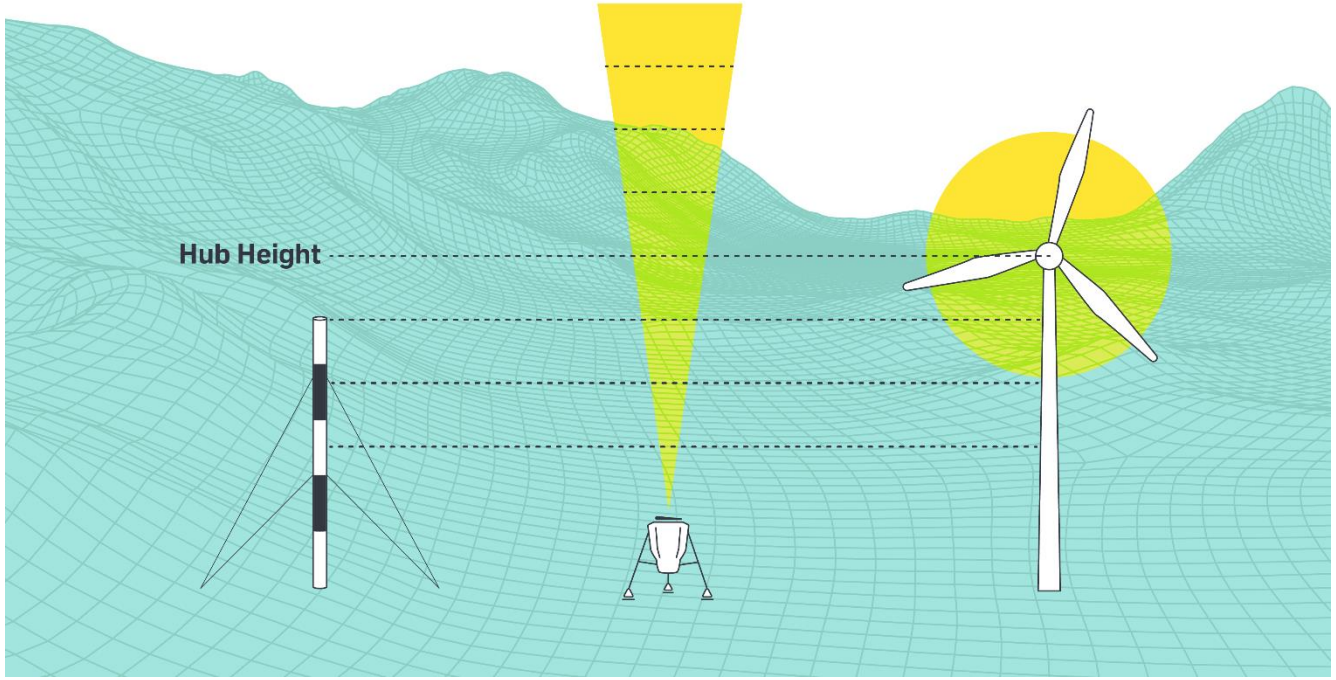
Site Development Stage – WRA Campaign

Vertical Extrapolation:

“Wind Shear Validation” is a process of combining a 60-80m tower with Lidar and extrapolating wind at heights above the tower with Lidar reference.

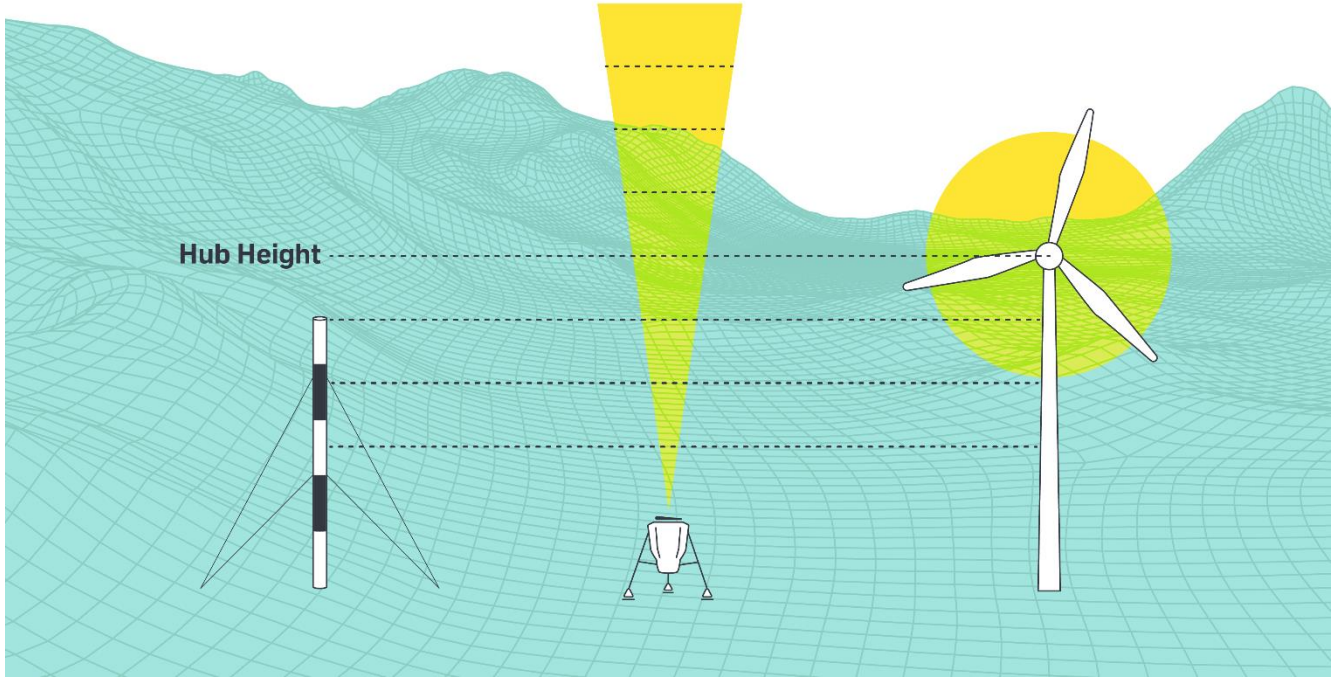
Looking for “Hotspots of Uncertainty”

Vertical Extrapolation: Wind Shear Validation



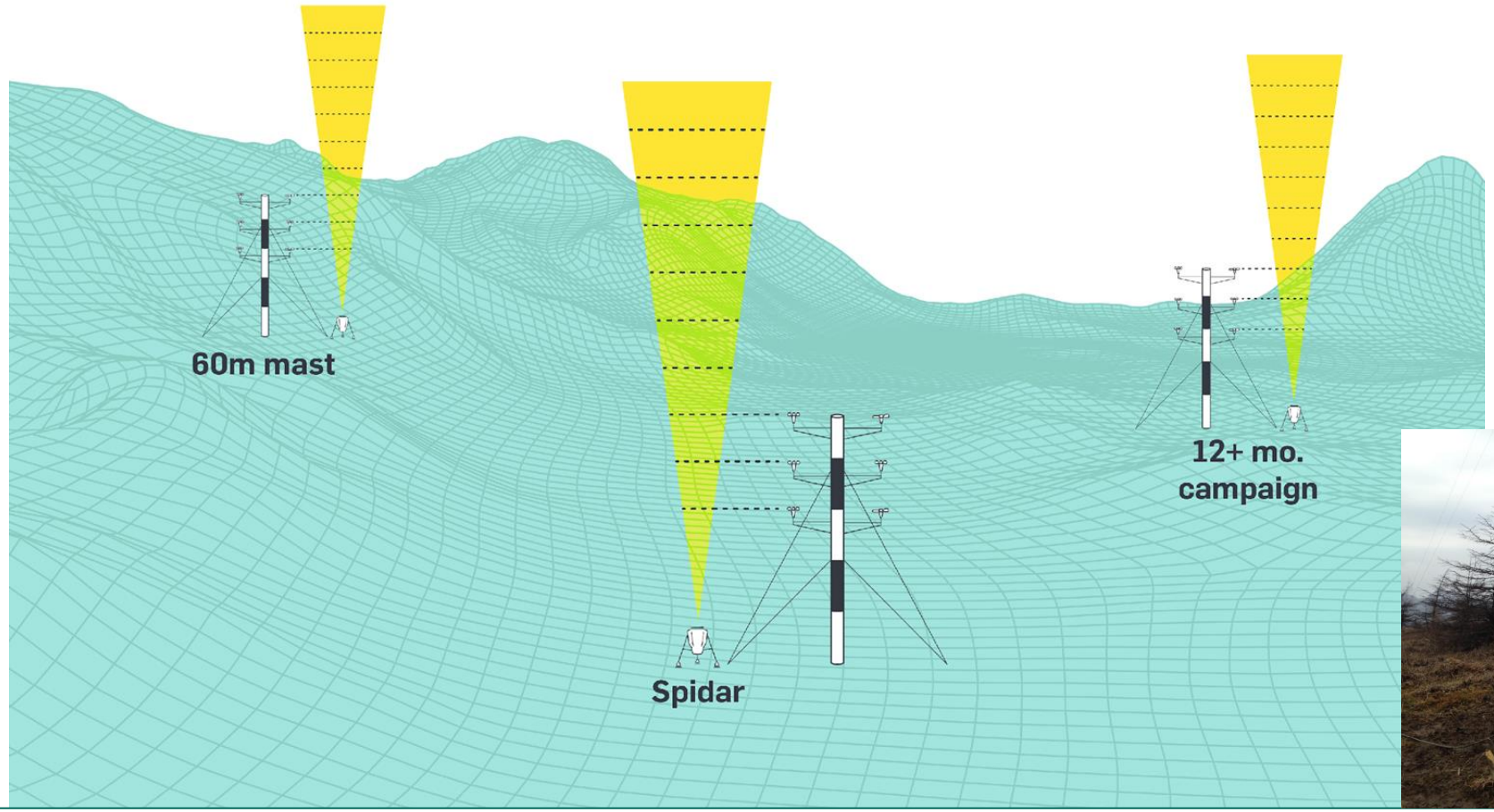
- Expensive lattice towers are required to measure at the hub height of modern turbines using conventional methods.
- Data from shorter, economical met masts must be extrapolated vertically to predict hub height wind speeds.
- These calculated hub height values have high uncertainty, and require validation by other data sources.

Vertical Extrapolation: Wind Shear Validation



- Complementing an economical met mast with a Lidar allows you to measure up to 200m to validate the wind shear profile at your potential turbine location.
- There should be at least 2 common measurement heights, and the top met mast height should be at least 60m.
- Data should be collected for a full year for best results, but shorter 3-6 month campaigns can provide reasonable estimates of annual shear conditions.

Vertical Extrapolation: Wind Shear Validation



- By moving your Lidar every 3-12 months you can validate the calculated shear profiles across a fleet of shorter met towers.
- Following this methodology, multiple expensive, permanent lattice towers can be replaced with more economical, temporary masts paired with a roving Lidar for wind shear validation.

Vertical Extrapolation: Wind Shear Validation

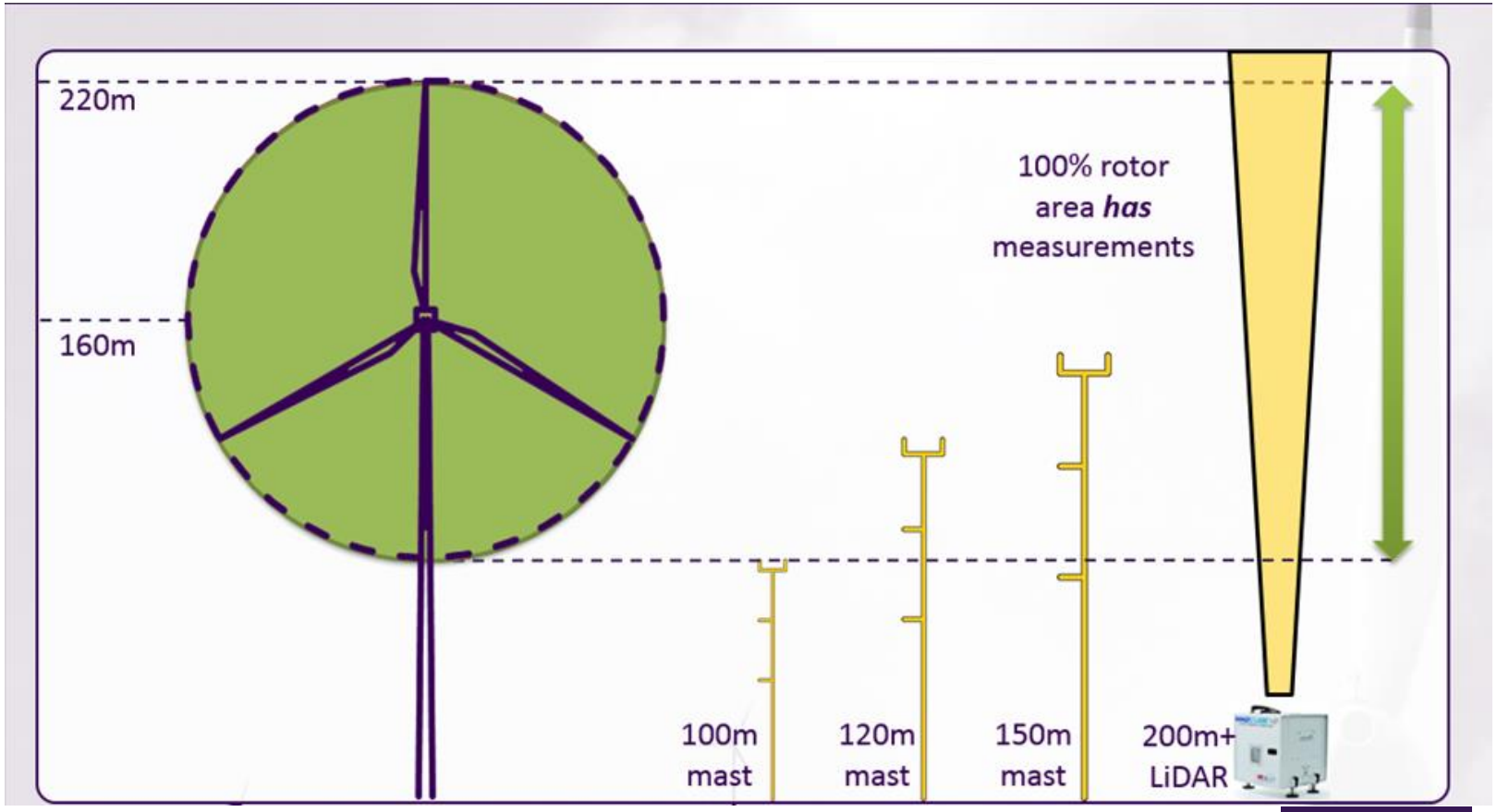
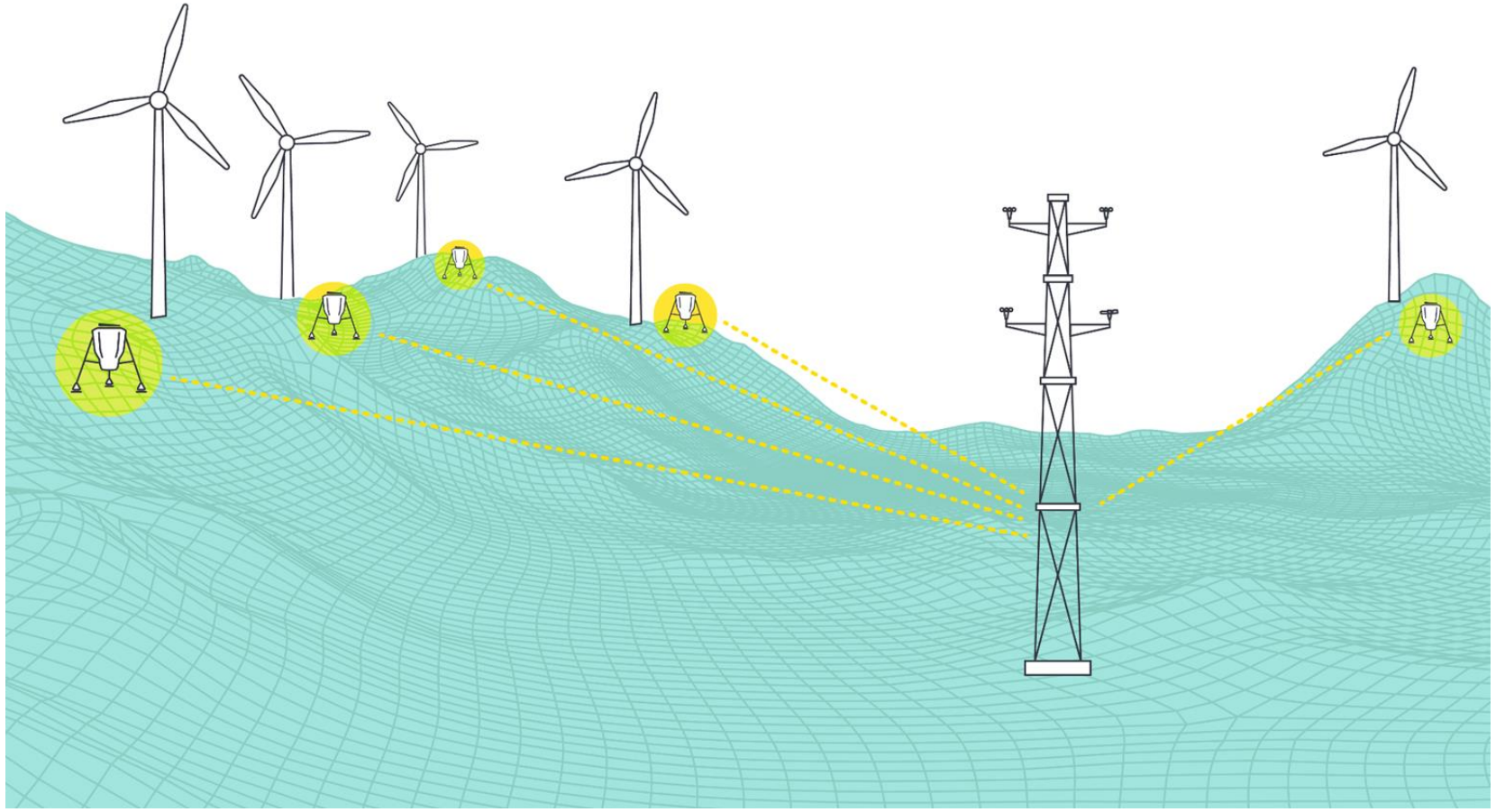


**Image courtesy of Jerry Randall at Wind Pioneers*

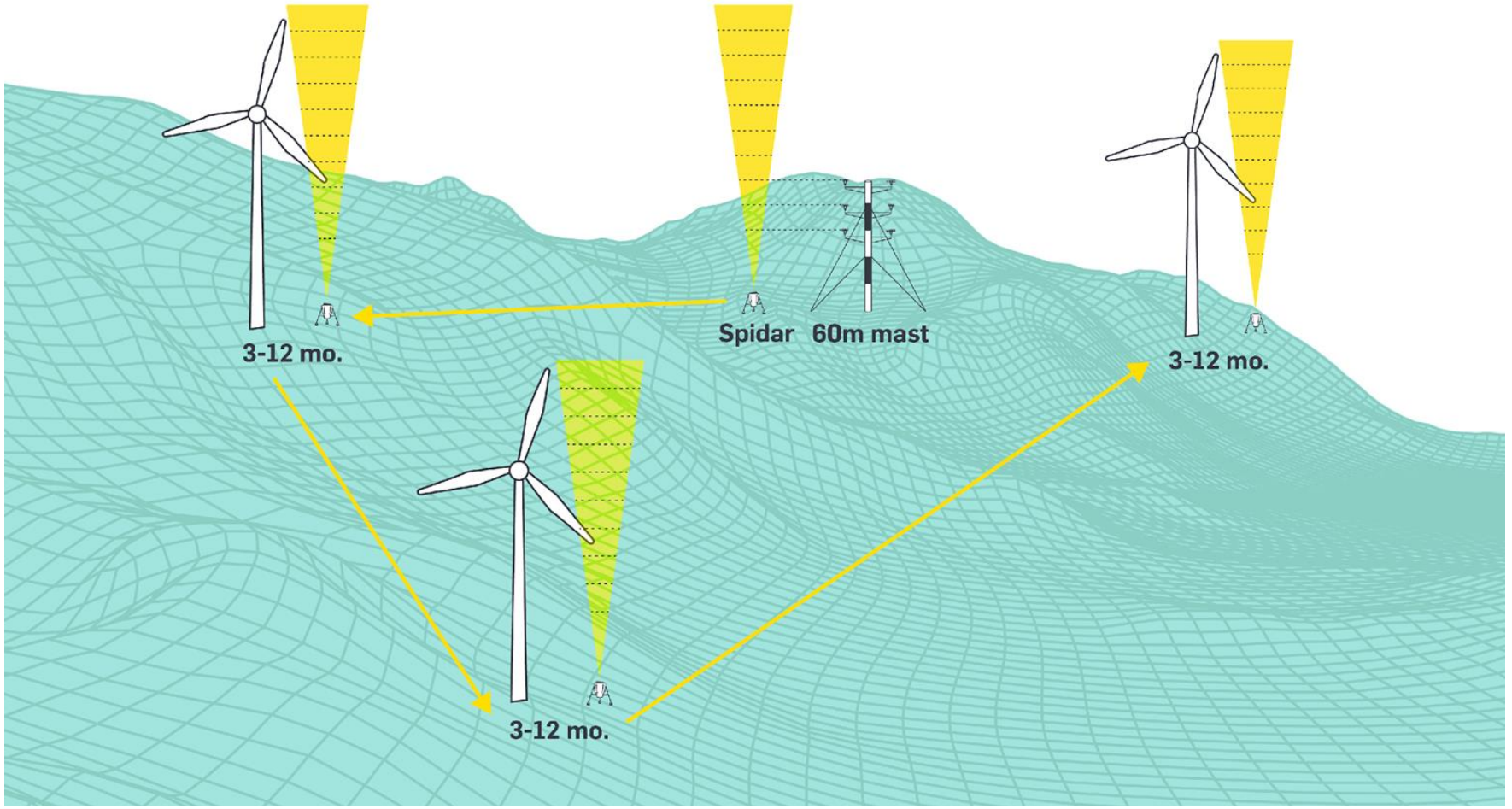
Wind Shear Uncertainty Reduction:

- **Rotor Equivalent Wind Speed (REWS):** Very big driver in WRA: What wind is doing *throughout* rotor swept area not just at hub.

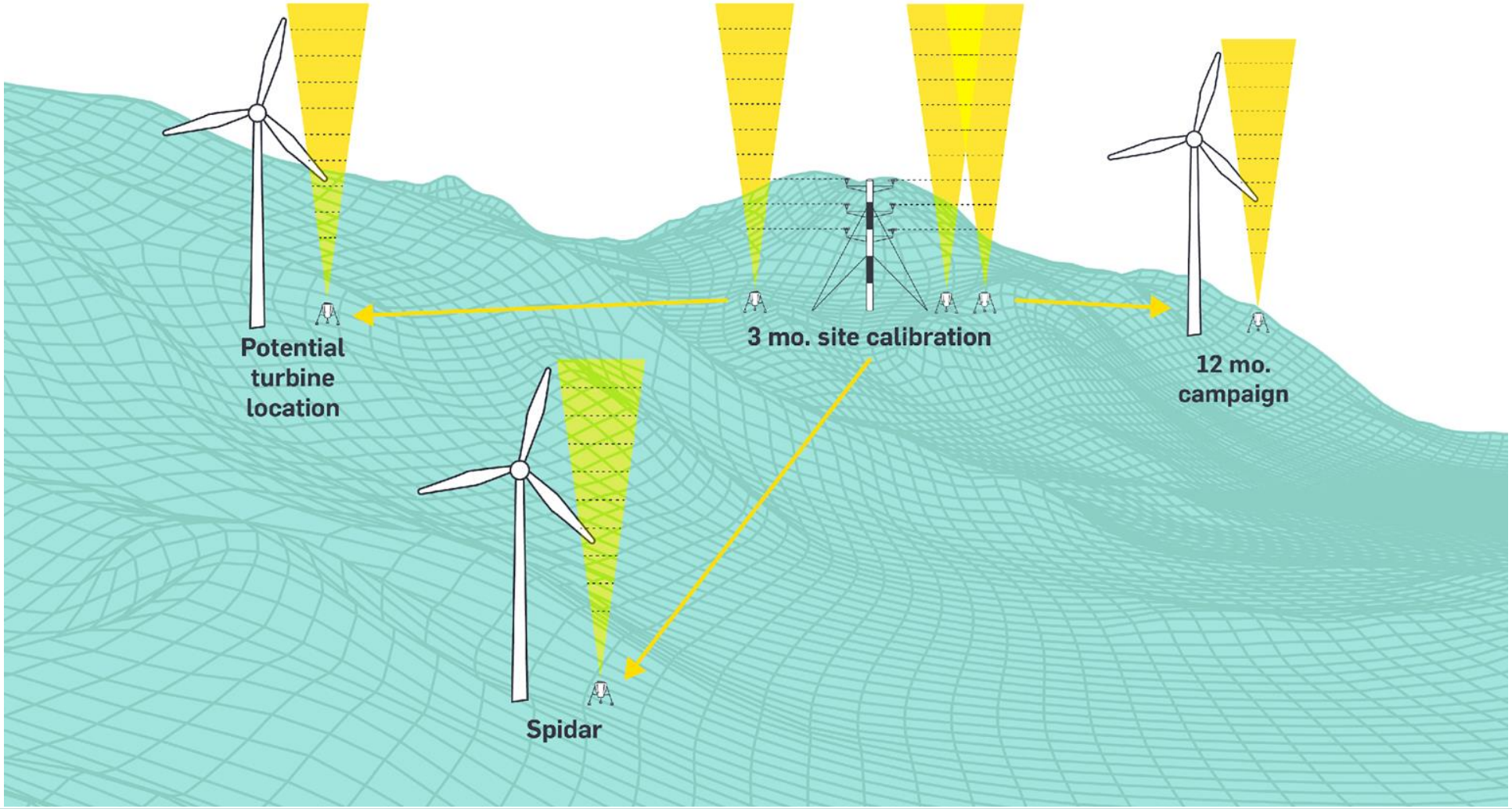
Horizontal Extrapolation



- Not technically or economically feasible to install a tower at every potential turbine location.
- Instead of direct measurements, met tower data are extrapolated horizontally based on the site's terrain.
- These calculated wind speed values at locations without local measurements have high uncertainty, and require validation by other data sources.



- To better understand the horizontal distribution of wind resource across a site, a Lidar can be moved between points of interest while the primary measurement device remains fixed.
- 12 months is best in order to fully capture seasonal differences.



For longer measurement periods at a turbine site, multiple lidar units can undergo site calibration simultaneously before being moved to their final measurement location. This method ensures that you get 12 months of data up to 200m at each potential turbine location that is directly traceable to traditional cup anemometry on your met mast, without having to install a met tower at each potential turbine location.

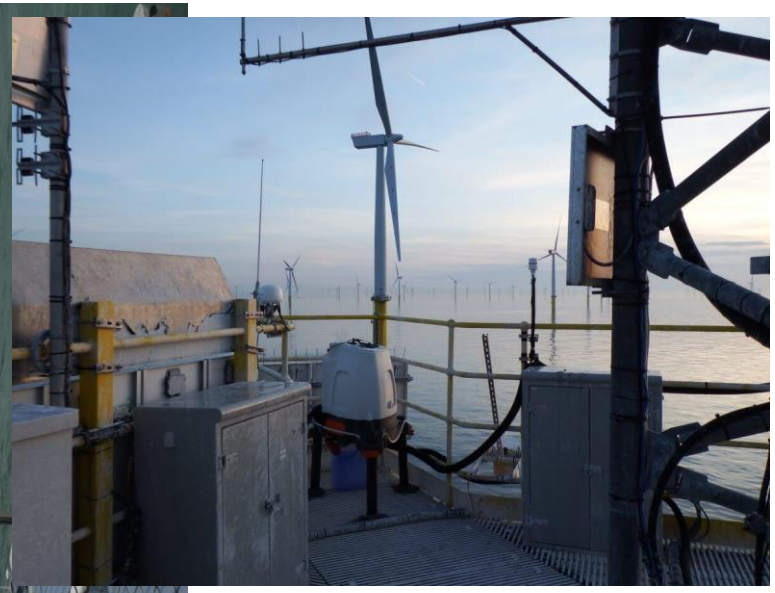
Operations and Maintenance Stage

- Both Contractual (Stage 3) and Non-Contractual Power Performance Testing (Stage 2) of turbines.
  - “Pre-power performance test” concept gaining interest with Stage 2 Lidar to screen individual turbines for potential issues. Suspect turbines can then go through contractual (Stage 3) IEC power curve testing.

Other Lidar Applications:

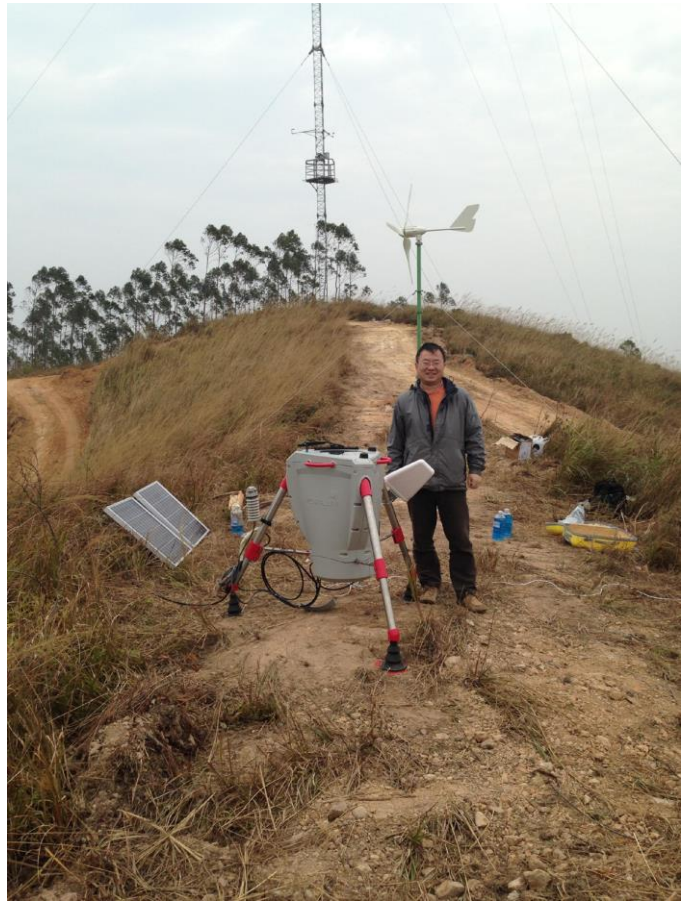
- Permanent on-site met mast
- Power Curve measurements
- Performance optimization
- Apply curtailment strategies
- Mobile measurements for turbine failures or power loss to support insurance claims
- Wake and forecasting
- Feed forward nacelle mounted turbine control
- Validate repowering of turbine
- Craning

Lidar Applications: Offshore



Lidar Applications: Onshore

Remote Site Installation for Wind Resource Assessment



Lidar Applications: Onshore

Remote Site Installation for Wind Resource Assessment

Lidar Applications: Security

Remote Site Installation for Wind Resource Assessment

Remote Power Supply

Fujian Province

Guangxi Province

Conclusion

- Lidar technology provides bankable data, when used properly
- Profitable and successful wind farms have been constructed with lidars only
- Lidars are in use worldwide by developers
- Lidars will not replace met towers. They will compliment towers in campaigns