Cost effective offshore wind measurement

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REACHING FOR THE WIND

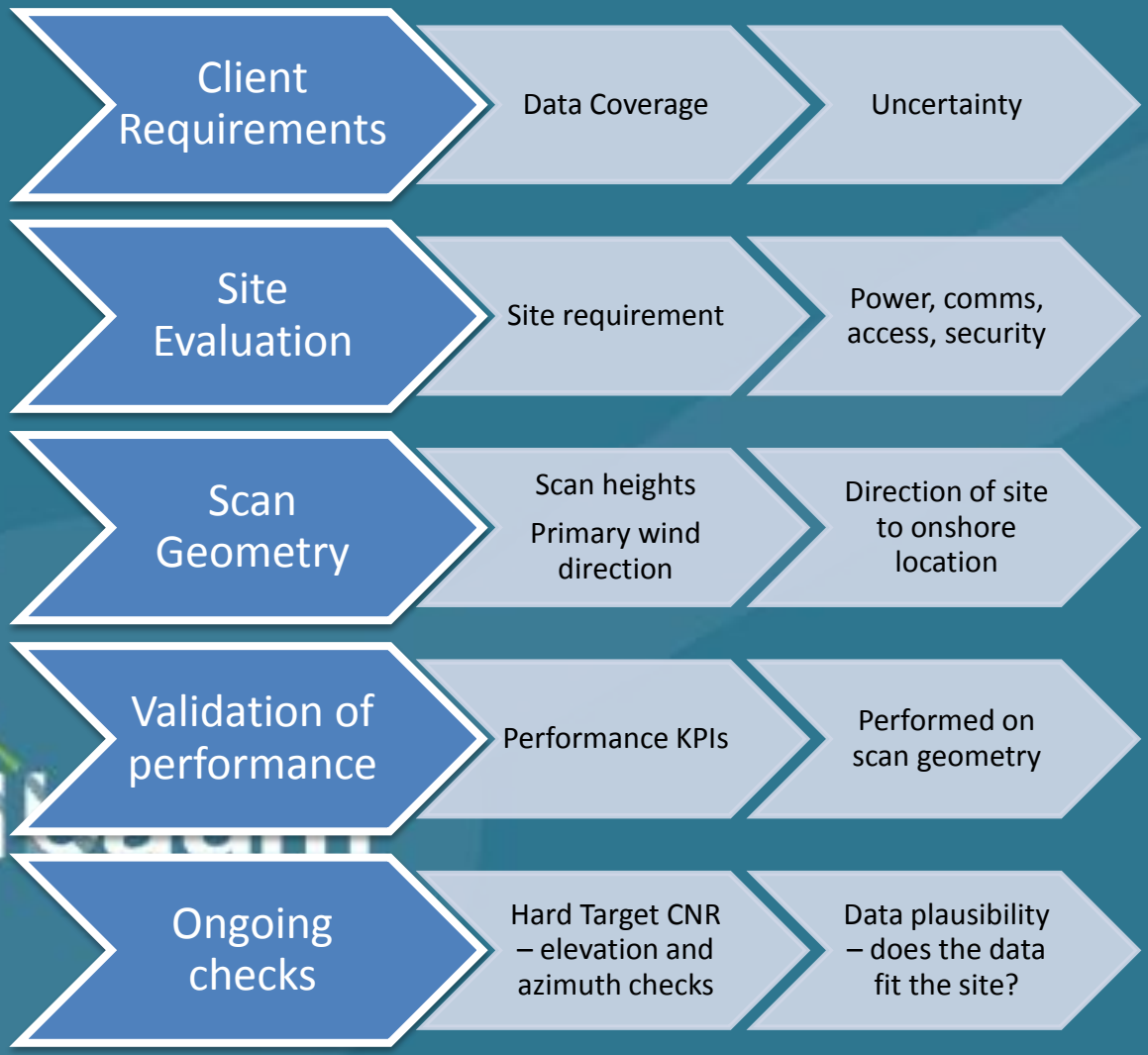
Traditional Measurement Offshore

- Gold Standard in measurement – but increasingly costly
- Can command prices in order of 15 million Euros
- 98% of cost in structure & engineering, 2% on platform use
- Permitting required and not guaranteed
- Large capital outlay well before any income stream is realised
- Health and safety issues for platform access and instrument maintenance
- Is the data requirement being met by the instrument? Or is cost leading to an increase in uncertainty?
- Is there an alternative? Scanning LiDAR campaign is investigated

Measuring from onshore Deliver offshore

- Reduce costs – 15 x less
- Reduce risk
- Deliver physical data to 10km
- Use as part of integrated campaign
- Easy permitting
- Easy access for instrument maintenance
- Scanning LiDAR for greater spatial resolution

What is required for acceptance?



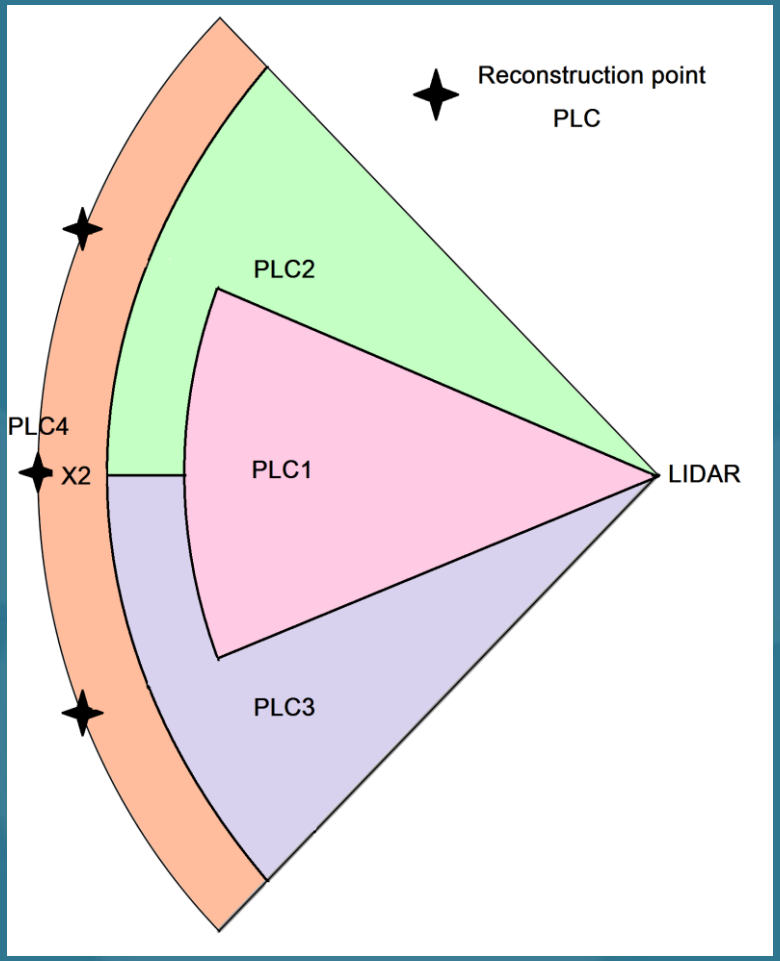
Scanning LiDAR – LEOSPHERE 400S

- Range of 10km
- 0.5s to 10 s accumulation time
- 75/100/150&200m physical range options
- 320 gates
- Up to 30deg/s scan head speed
- Positional accuracy to within 0.01 degrees
- Class 1M
- IP65 case
- Suitable for offshore use

Validation - Setup

- Units on hangar 8 m above ground
- Dist. to reference 100m mast “WMM_N100” : 1770 m
- Laser beam elevation angle 3° to hit mast top

Validation - Scan Pattern Setup



- Single scan at 2 elevations
- Scan arc of 90 degrees used at 3 degrees per second
- Acronym Warning (PLC – Primary Laser Cup!)
- Analysis sectors split into 4 reconstruction cases:
  - PLC1 45° West
  - PLC2 45° Northwest
  - PLC3 45° Southwest
  - PLC4 90° West
- Illustration shows the 4 reconstruction arcs used (note length does not denote range of LiDAR)

Validation – Key Performance Indicators Criteria

Wind Speed Acceptance Criteria	Mean Abs error (m/s)	STD error (m/s)	Slope	R^2
(i) Along	0.3	0.5	0.98-1.02	0.98
(ii) Orthogonal	0.5	1	0.97-1.03	0.96
(iii) All Directions	0.5	1	0.97-1.03	0.96

Wind Dir Acceptance Criteria	Slope	R^2	Max Abs Mean WD Difference
(i) Along	0.97-1.03	0.97	<5°
(ii) Orthogonal	0.97-1.03	0.97	<5°
(iii) All Directions	0.97-1.03	0.97	<5°

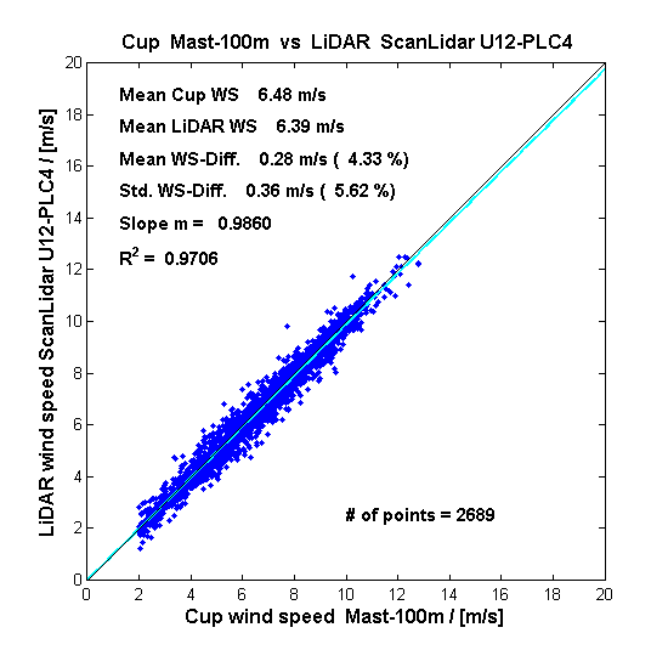
(i) Along wind direction – data from 45° sector around dominant wind direction - E-W in test case
(ii) Orthogonal to wind direction – data from 45° sector around orthogonal wind direction - N-S in test case

Validation – Key Performance Indicators Results 1

PLC4 – Wind Speed > 2 m/s	Mean Abs Error (m/s)	STD Error (m/s)	Slope	R^2
(i) Along	0.24	0.32	0.991	0.976
(ii) Orthogonal	0.32	0.40	0.982	0.966
(iii) All Directions	0.28	0.36	0.986	0.971

Failed Criteria

Passed Criteria



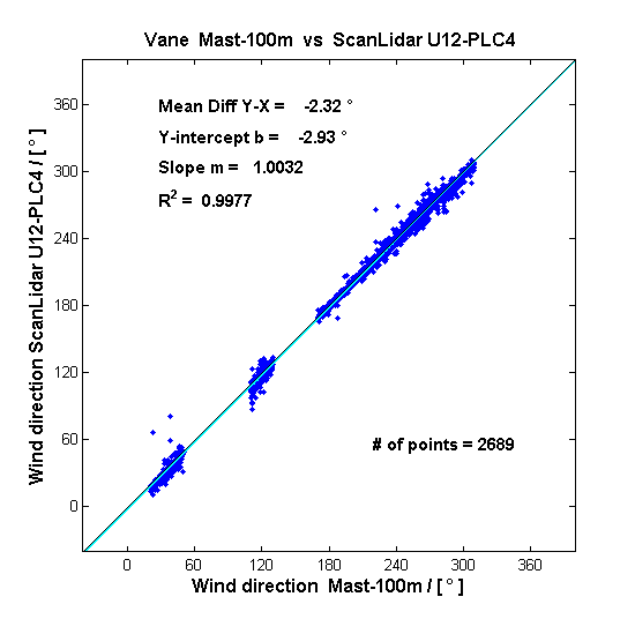
- System availability – 100%
- Available Radial Wind speeds – 94%
- Available Reconstructed 10-minute average wind speeds prior to filtering – 87%-89%

Validation – Key Performance Indicators Results 2

PLC4 – Wind Direction > 2 m/s	Slope	R^2	Mean Wind Direction Difference
(i) Along	0.999	0.995	-2.742
(ii) Orthogonal	1.014	0.998	-1.924
(iii) All Directions	1.003	0.998	-2.325

Failed Criteria

Passed Criteria



Although only showing Results for 1 system here, results are consistent between systems.

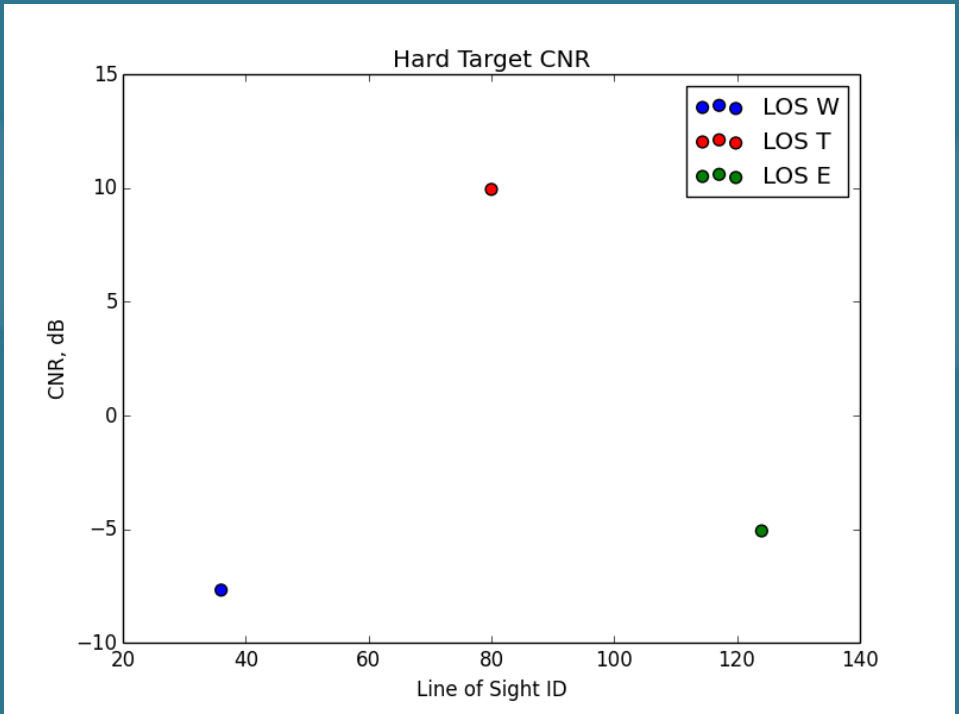
Case Study - Deployment

- Onsite checks to ensure location and height of LiDAR (GPS)
- Check levelling of scan head (Digital Spirit Level)
- Obtain accurate location and height of Hard target (GPS & Theodolite)

- Scan hard target to obtain hard target location in LiDAR frame of Reference
- Use LiDAR measured hard target location with true location to obtain LiDAR azimuthal and elevation offsets
- Now able to accurately programme desired scan scenario

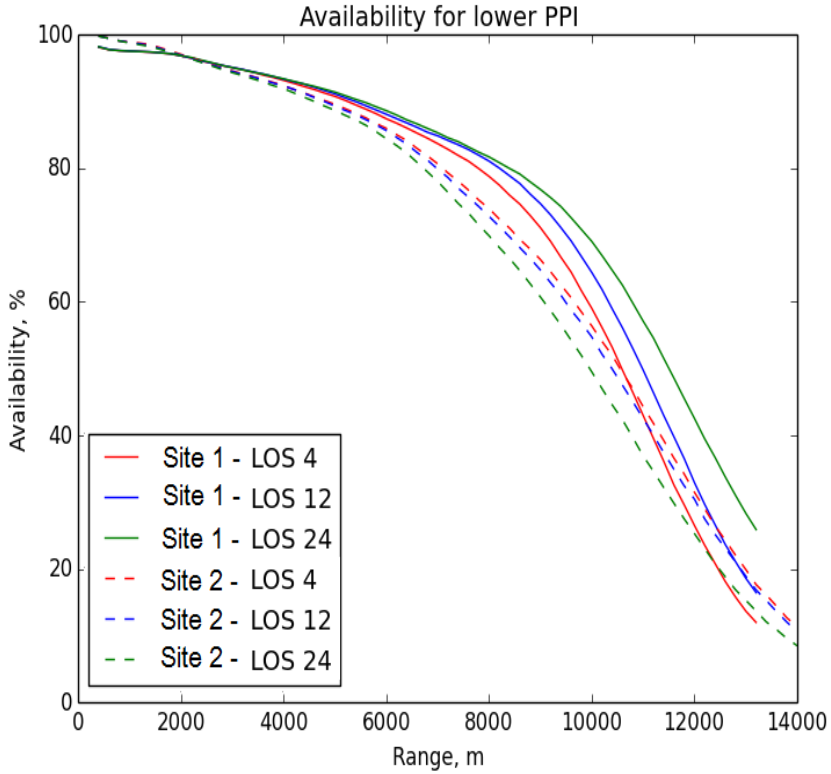
Case study – Performance - CNR Checks

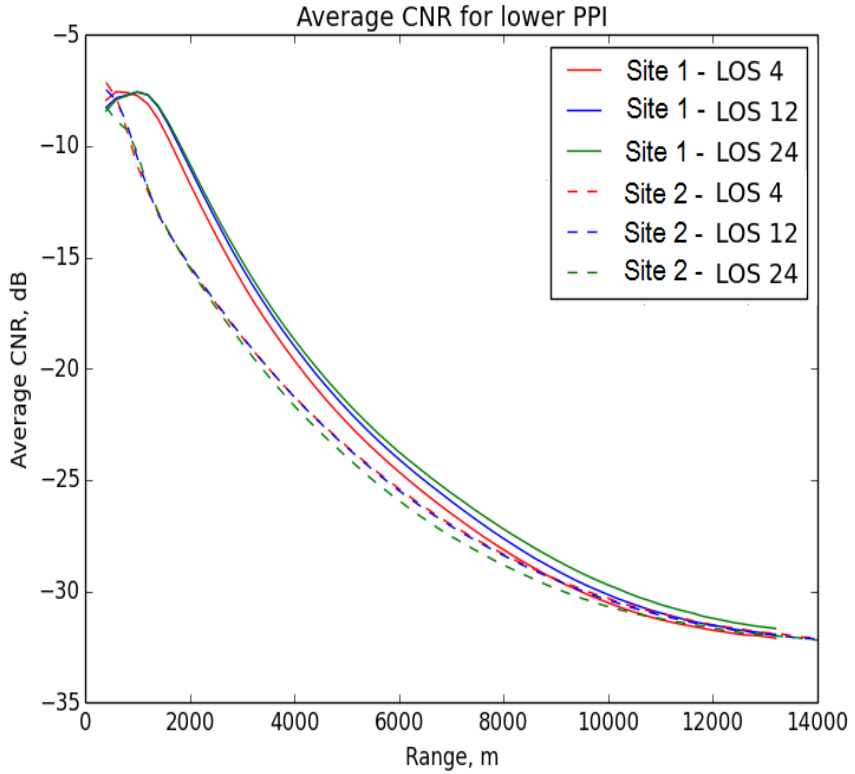
- Daily CNR hard target checks to ensure stability and accuracy of LiDAR
- Check known position of hard target to get CNR (below)
- Blind check of CNR values to get position of hard target



Case Study - Radial Data Availability

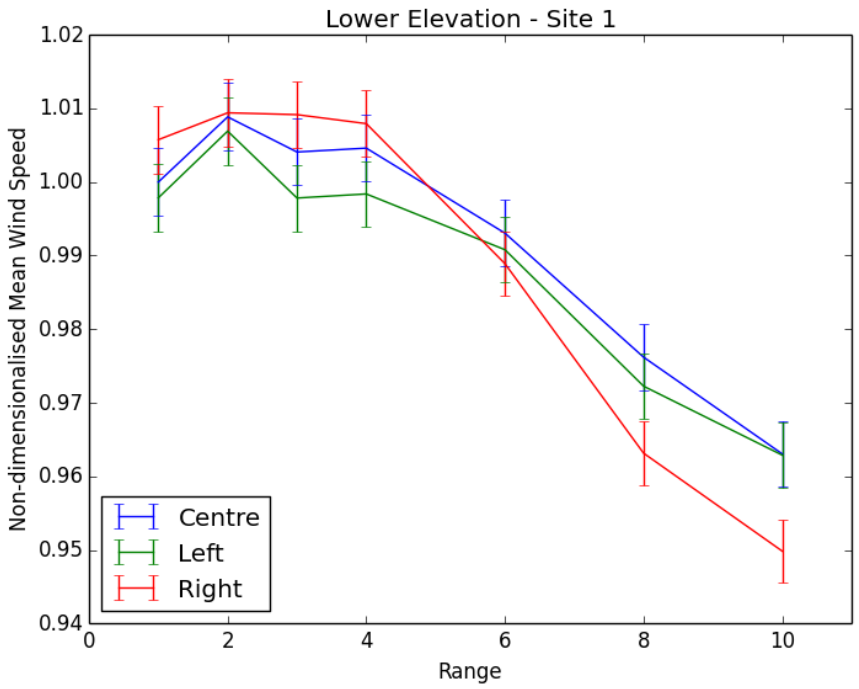
- Both sites share overall trend with small quantitative differences
- 1km availability >90%
- 6km availability >80%
- 10km availability >50%

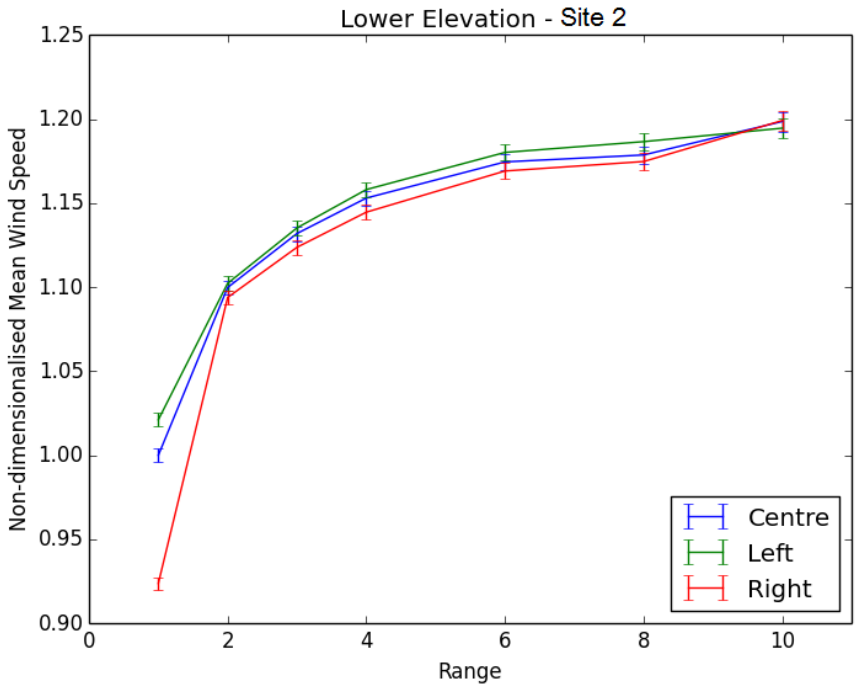




Case Study - Reconstructed Wind Speed

- Example of average 10-minute reconstructed wind speed as a function of range at 3 different azimuthal angles
- Different behaviour at the two sites
- Difference in wind speed across the scan sector





Summary

- Offshore measurements are key to establishing the IRR and cost competitiveness of a project
- Met mast measurements gold standard, but compromised by spatial resolution in current Large scale developments (>300MW)
- Modern Scanning LiDAR can be used to increase spatial measurement coverage
- Project proves that the system can be used and deliver data suitable for wind resource assessment.
- Cost benefits are clear, but investment in time to analyse should not be underestimated.