Wind Monitoring
Using 2nd Generation Wind Lidars

Peter Clive

Technical Development Consultant

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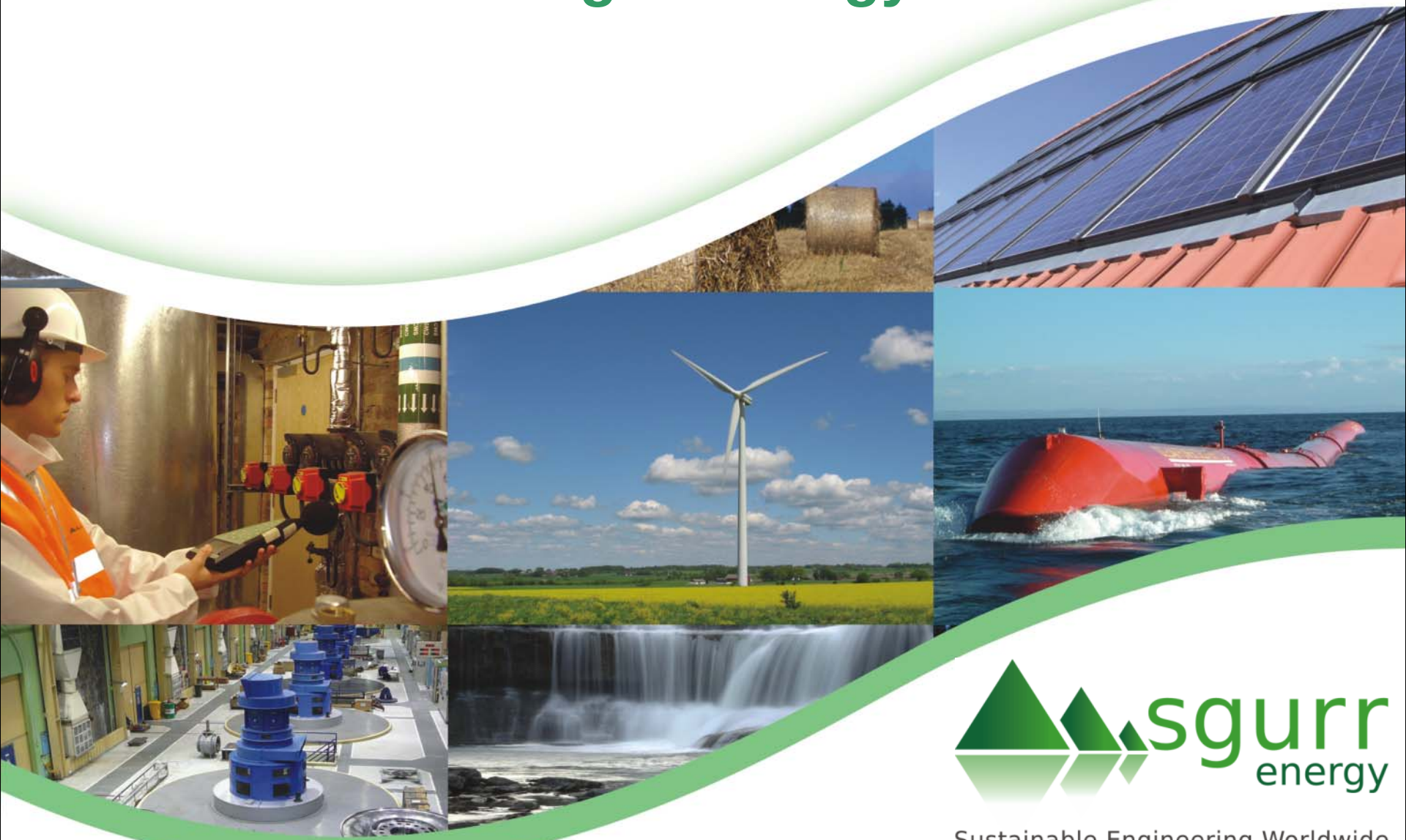
Introduction to SgurrEnergy



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SgurrEnergy today

- Leading independent engineering consultancy

- International
  - Glasgow (Head Office)
  - Beijing
  - Pune
  - Wexford
  - Vancouver
  - Scottish Highlands
  - Paris
  - Boston

- Experienced
  - Over 100 responsive engineers and consultants

Triple certification

FS 85385 EMS 85386 OHS 538996

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Leading position by experience

We have consulted on over 40,000 MW of renewable energy in over 30 countries covering both project development and due diligence

Europe

- Belgium
- Estonia
- France
- Germany
- Greece
- Republic of Ireland
- Italy
- Malta
- The Netherlands
- Poland
- Portugal
- Spain
- Sweden
- UK

Asia

- China
- India
- Korea
- Pakistan
- Philippines
- Russia
- Saudi Arabia
- Sri Lanka
- Turkey
- Vietnam

Africa

- Angola
- Kenya
- South Africa

Oceania

- New Zealand

North America

- Canada
- USA

South America

- Chile
- Galapagos Islands

What we do

SgurrEnergy personnel hold unparalleled knowledge to ensure successful project delivery.

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Overview of capability

Wind

Wave & tidal

Hydro

Solar

Bio-energy

Micro-generation

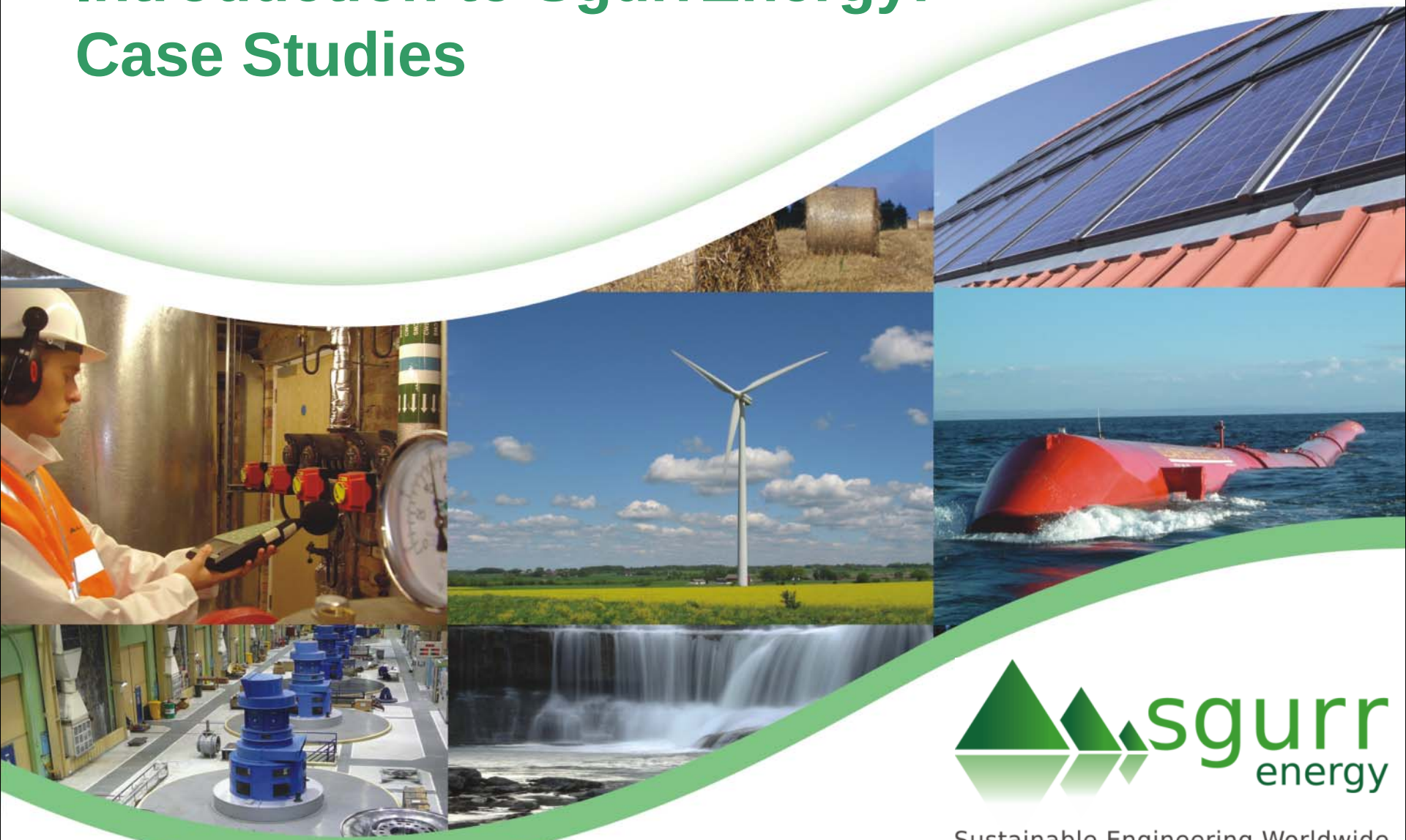
- Due diligence
- Lenders engineer
- Energy yields
- Technology audits & reviews
- Hybrid systems

Project management

Noise & vibration

- Technical advisor

Introduction to SgurrEnergy: Case Studies



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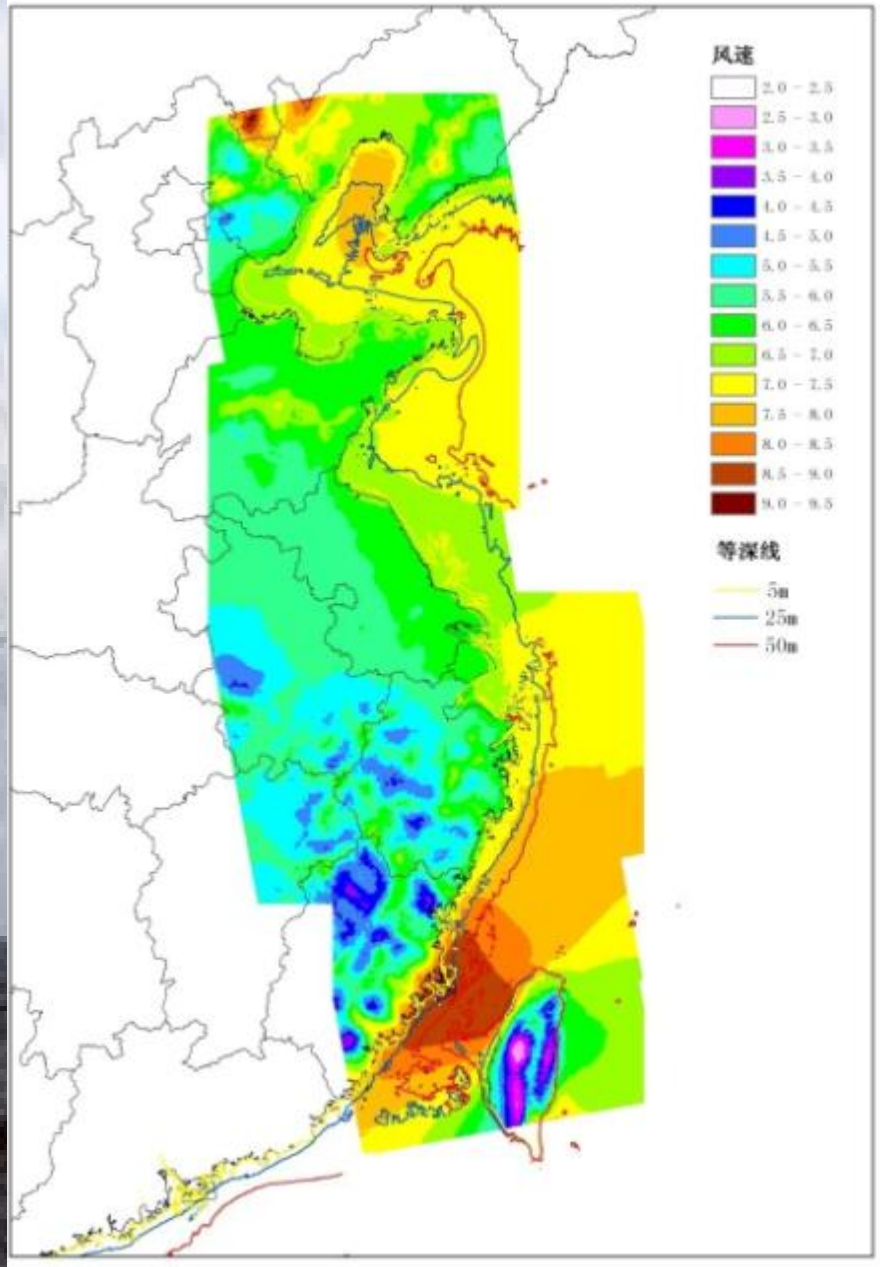
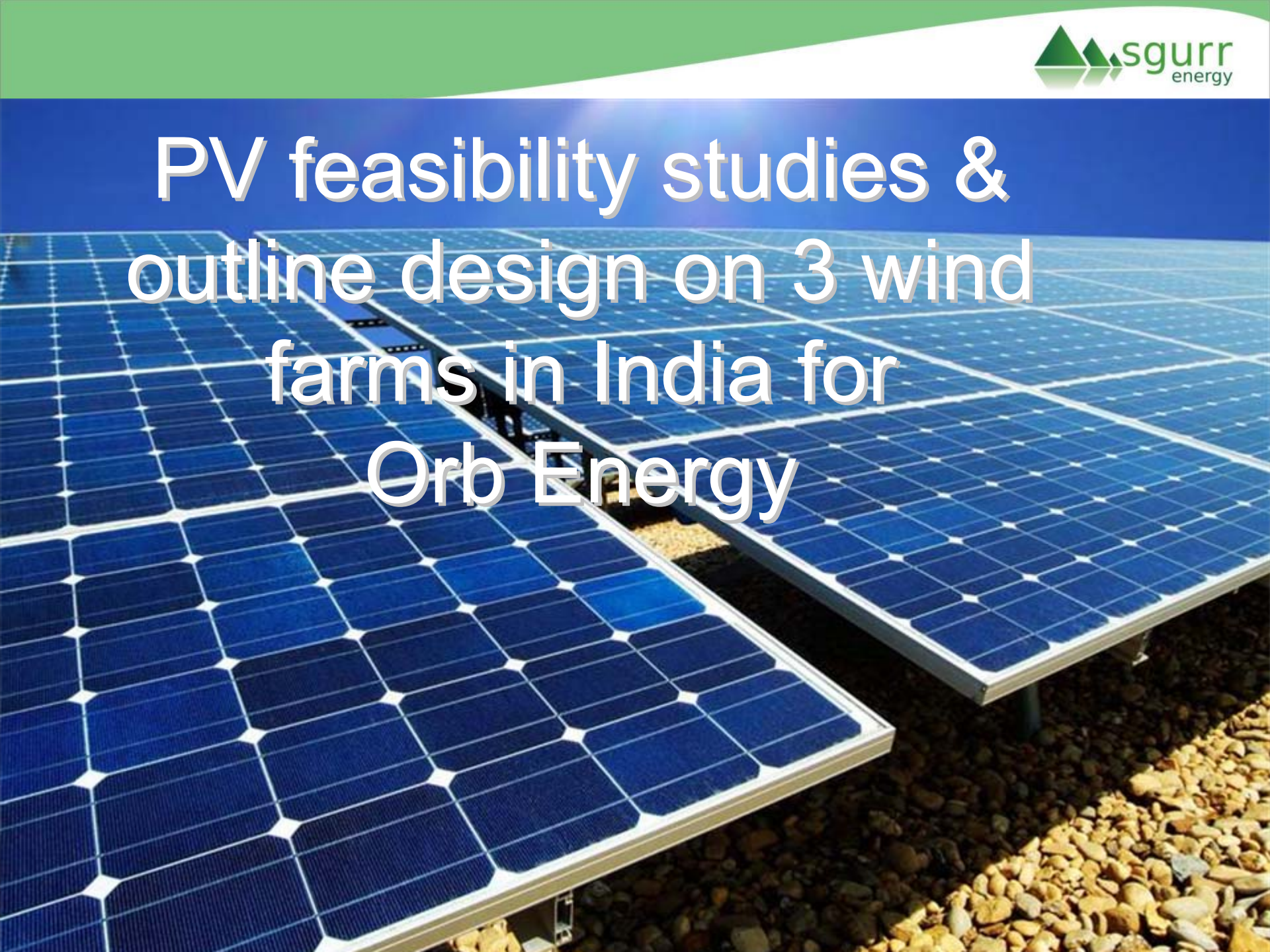
First Western designed wind farm in China

supporting Honiton Energy

Advising the Chinese government on offshore wind strategy



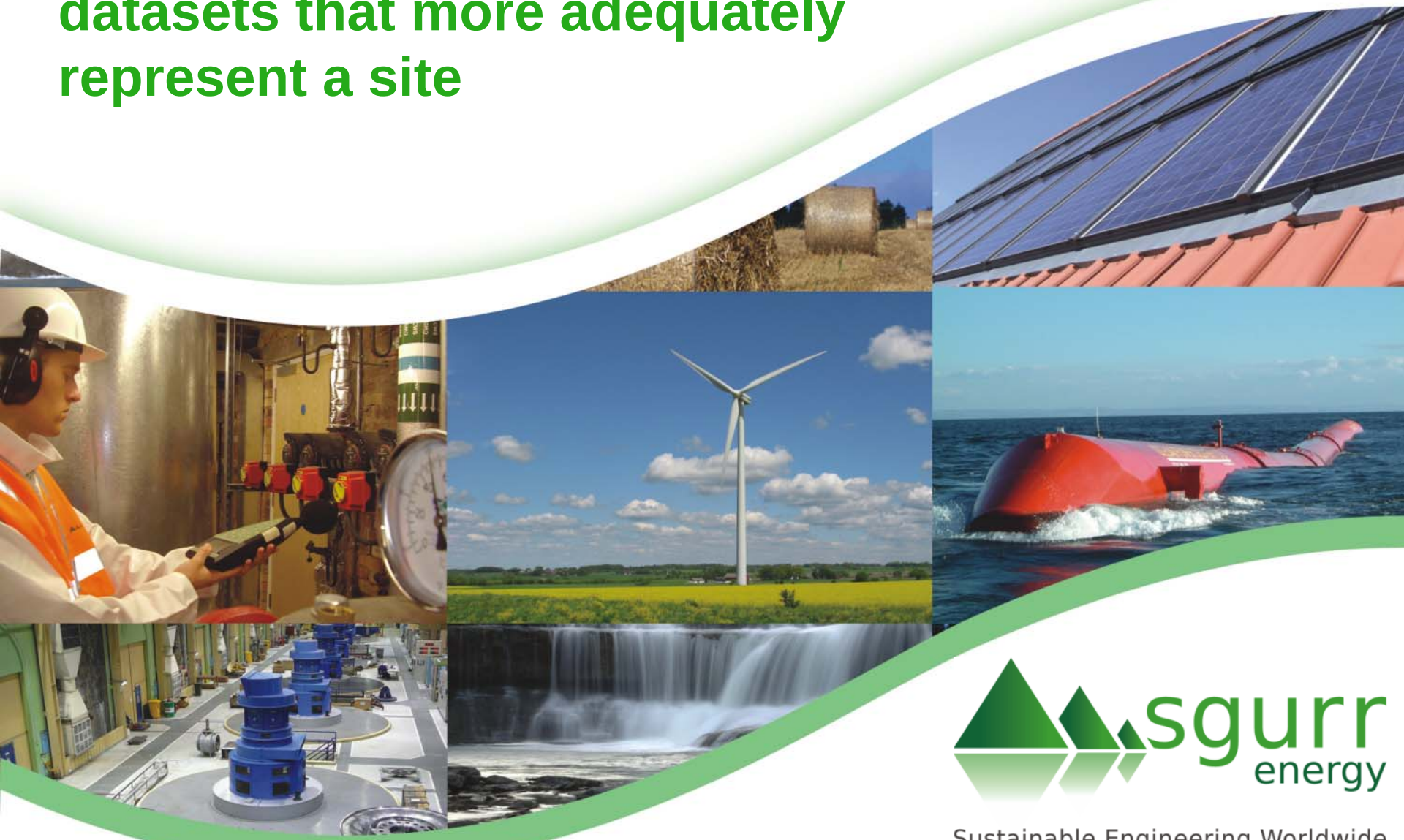
PV feasibility studies & outline design on 3 wind farms in India for Orb Energy




Advised SSE on £1.1bn acquisition of Airtricity's global portfolio across China and Europe


Global review of wave and tidal devices for a leading utility

Why remote sensing? acquiring rich datasets that more adequately represent a site



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THE Sun 30p

Thursday, January 8, 2009 30p thesun.co.uk

MISSING BLADE RIDDLE

UFO HITS WIND TURBINE

4am prang at 300ft

A WIND turbine stood wrecked yesterday with one of its giant 65ft blades torn off — after it was hit by a UFO.

Locals were woken by the 4am smash after strange lights were spotted streaking towards the

EXCLUSIVE by VIRGINIA WHEELER

200ft-tall generator on a wind farm.

Baffled power chiefs said of the smash in Conisholme, Lincs: "We have a team investigating." There was no trace of the missing blade. A UFO expert said: "We are very excited."

Full Story – Page Five

Clobbered . . turbine yesterday

EXCLUSIVE

BEATRICE £15k CAR NICKED SEE PAGE 7


AUG 25 2007

Design life

- Wind characteristics influence not just productivity but also longevity

- Wind characteristics that can actually damage your asset include
  - Excessive turbulence arising from complex terrain and adjacent turbines
  - Shear and veer stressing blades and causing unbalanced loads
  - Flow inclination
  - Extreme wind speeds

Lidar

Mature technology, new application

Compact and portable for rapid and easy deployment

Acquires wind speed, direction, shear, veer, TI, and inclination data

Measures at proposed turbine locations and operational assets

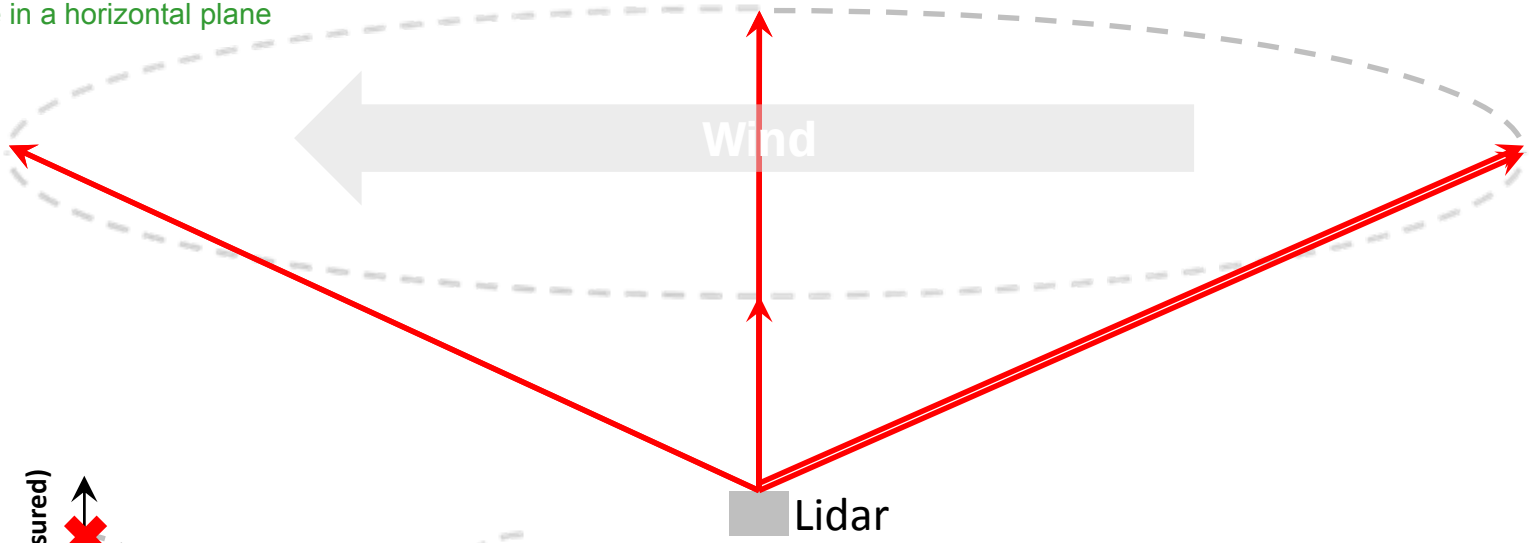
Wind resource assessment and model validation

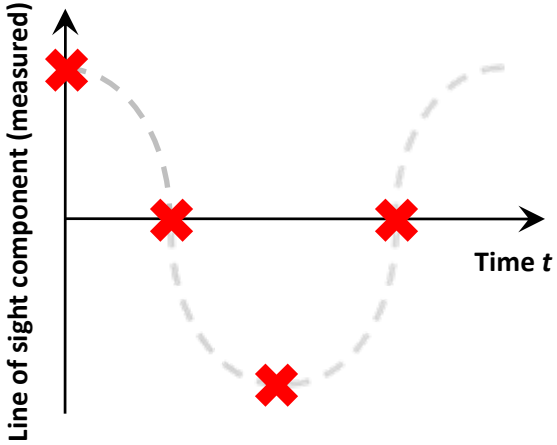
Performance monitoring and assessment of operational turbines

Conventional scan geometry

VAD scan geometry

Locus of measurement sites is a circle in a horizontal plane





$x = A \sin(\omega t + B) + C$

A gives horizontal wind speed
B gives wind direction
C gives vertical wind speed

VAD - wind veer profiling

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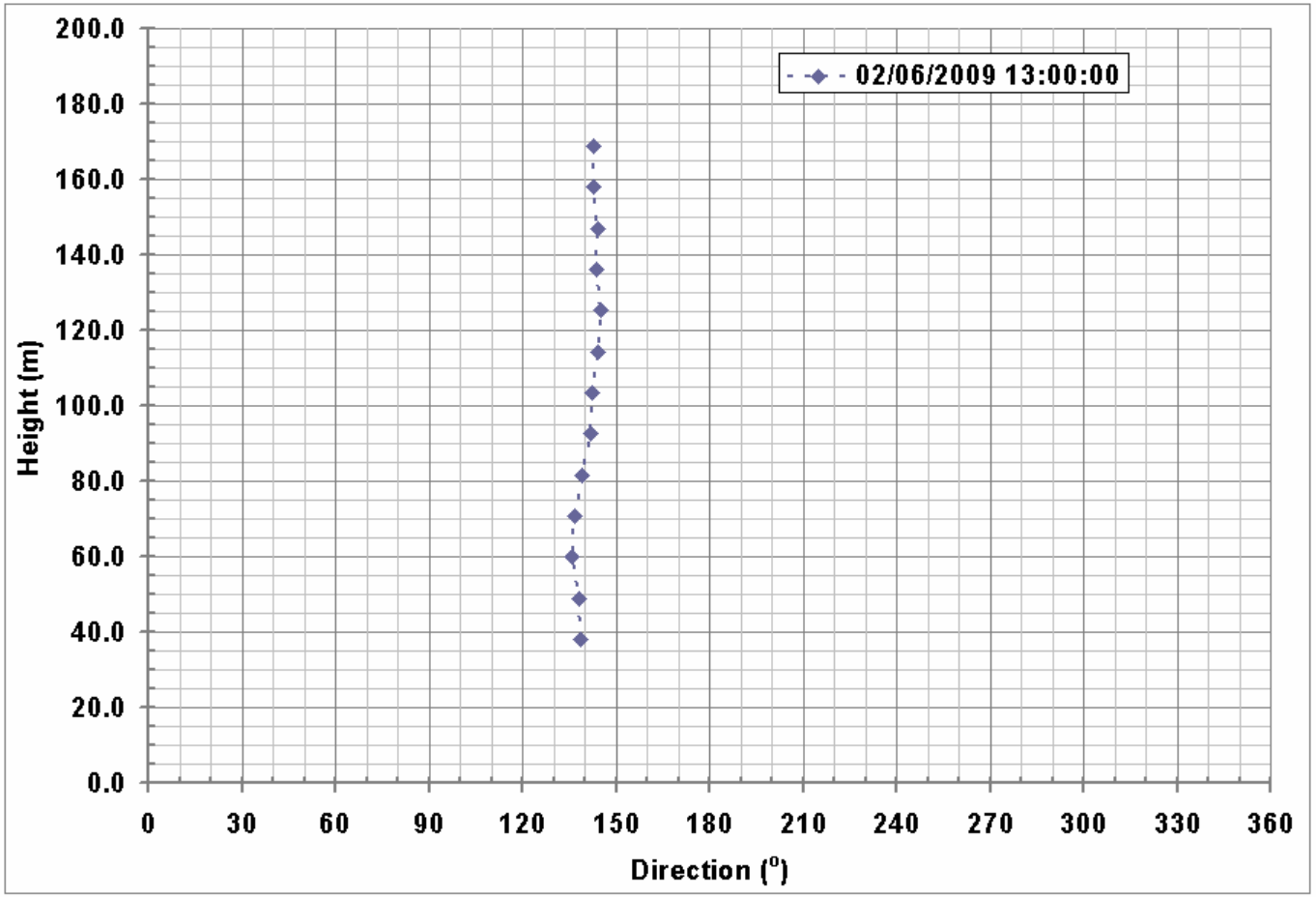

Wind Profiling

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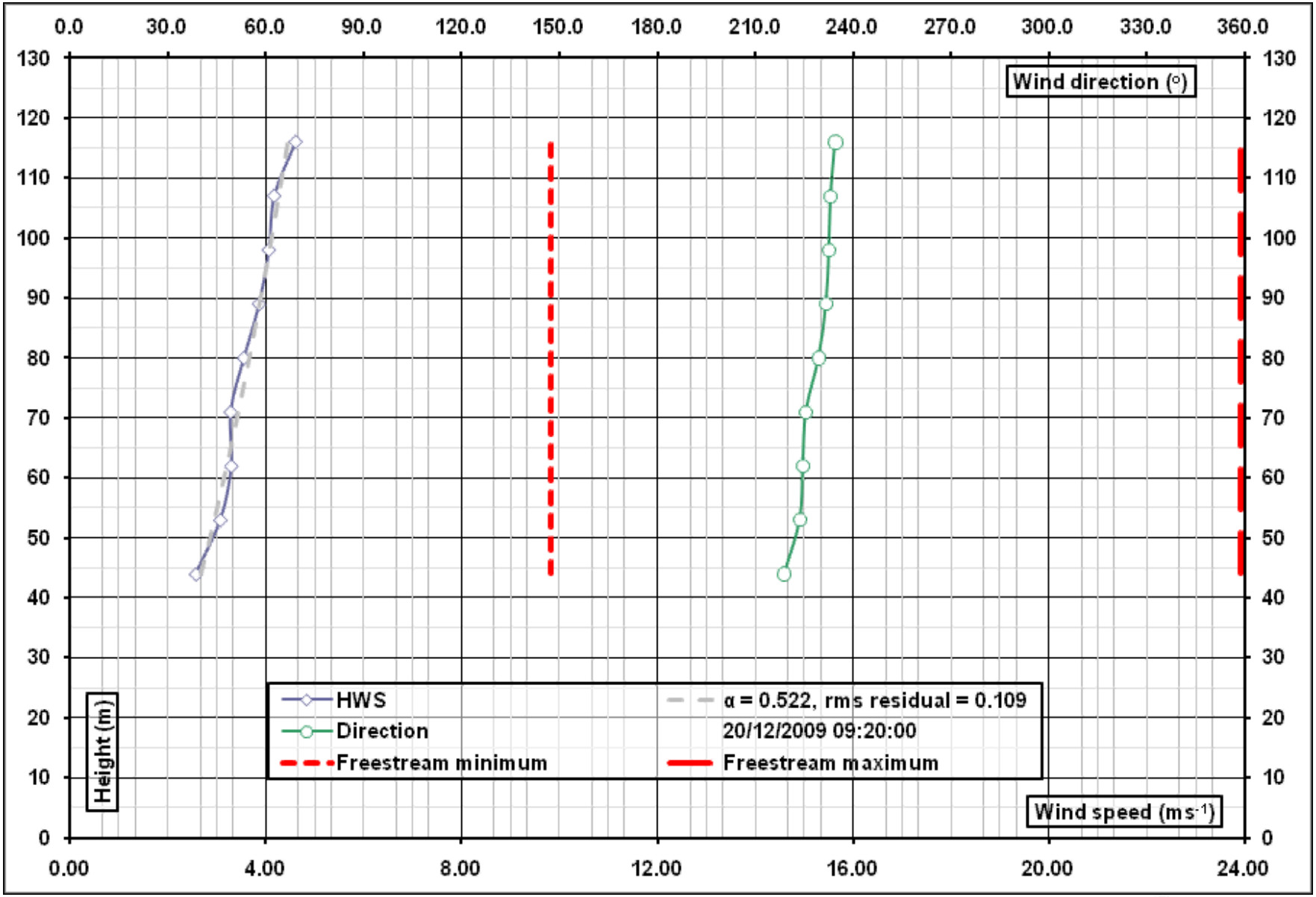
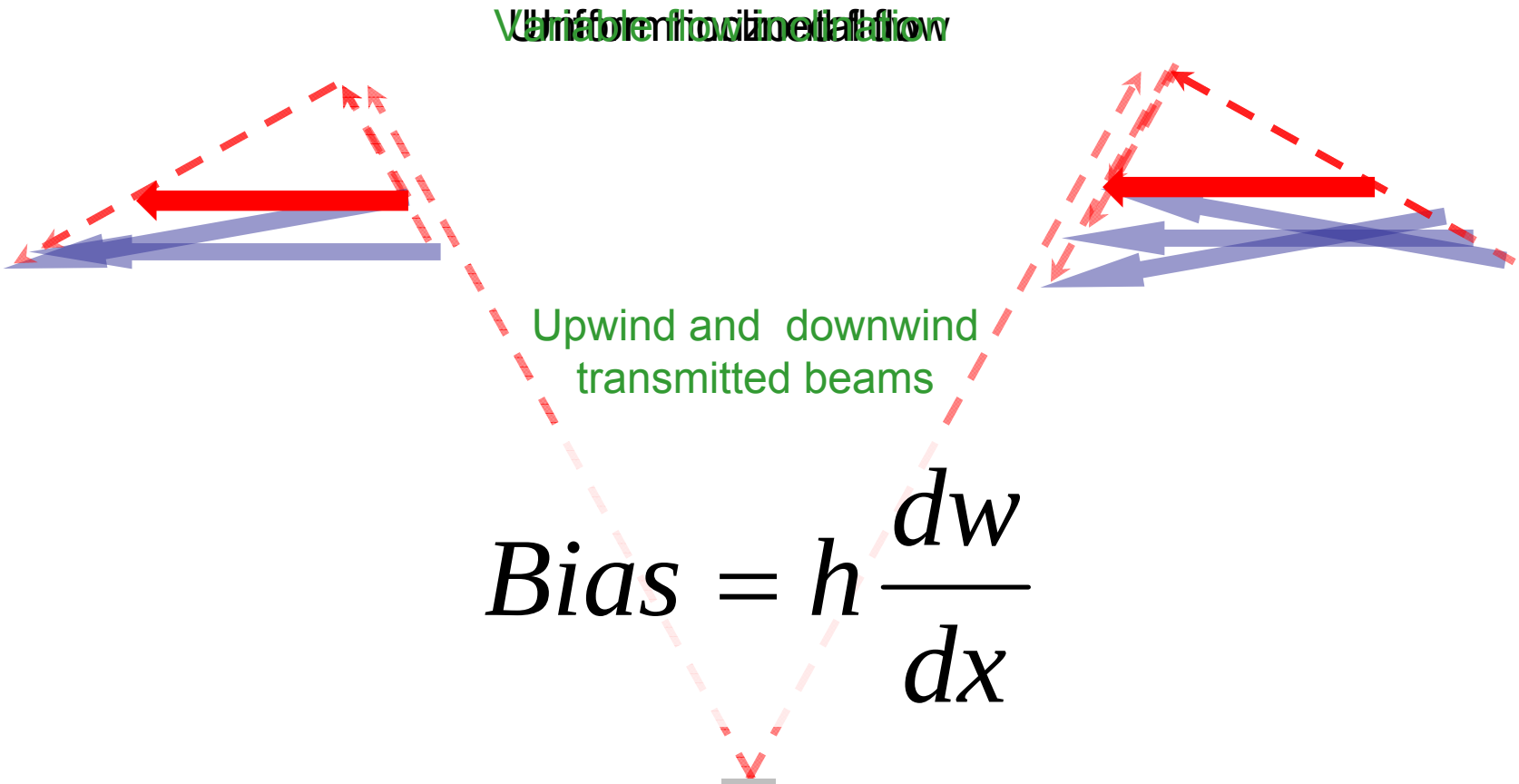


Complex terrain



$$Bias = h\frac{dw}{dx}$$

Complex terrain induces flow inhomogeneity

Flow inhomogeneity causes bias in VAD results

2nd Generation Lidars

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- **Must implement scan geometries that mitigate issues that arise in complex terrain;**

- **2 degrees of scan freedom:**
  - **Arbitrary scan geometry;**
  - **Measurement volume not necessarily above the device;**
  - **Long range applications possible;**
  - **Pulsed beam necessary.**

Galion

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Galion

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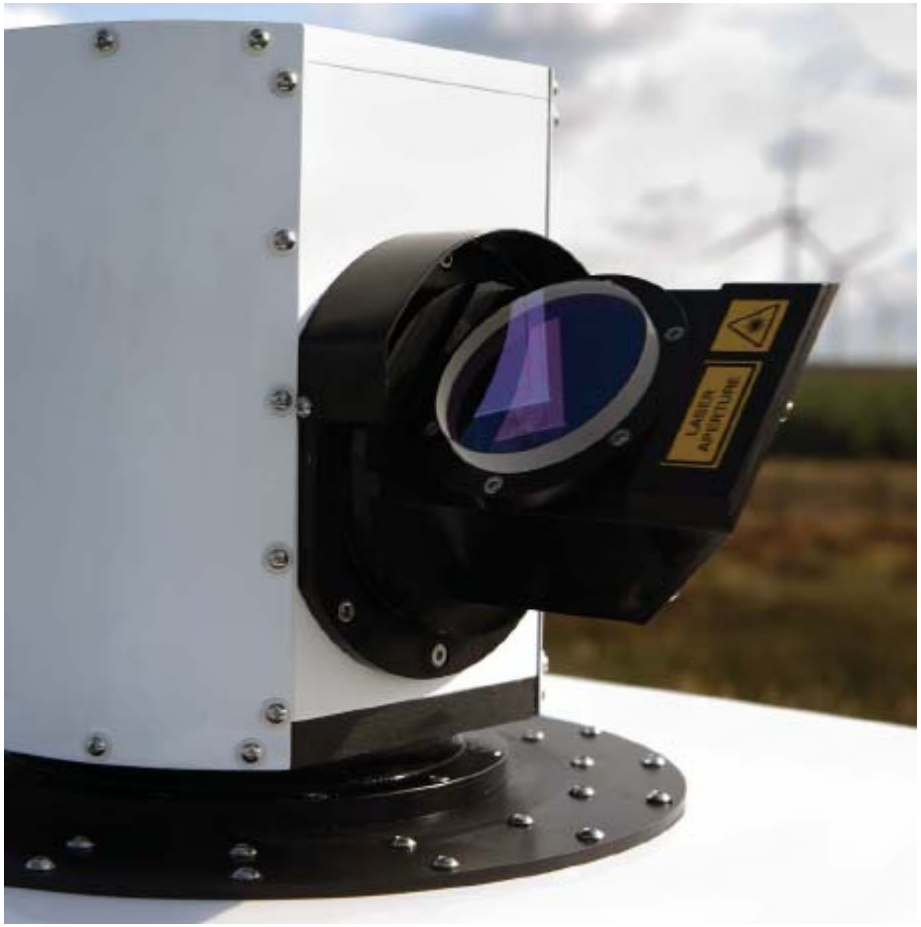
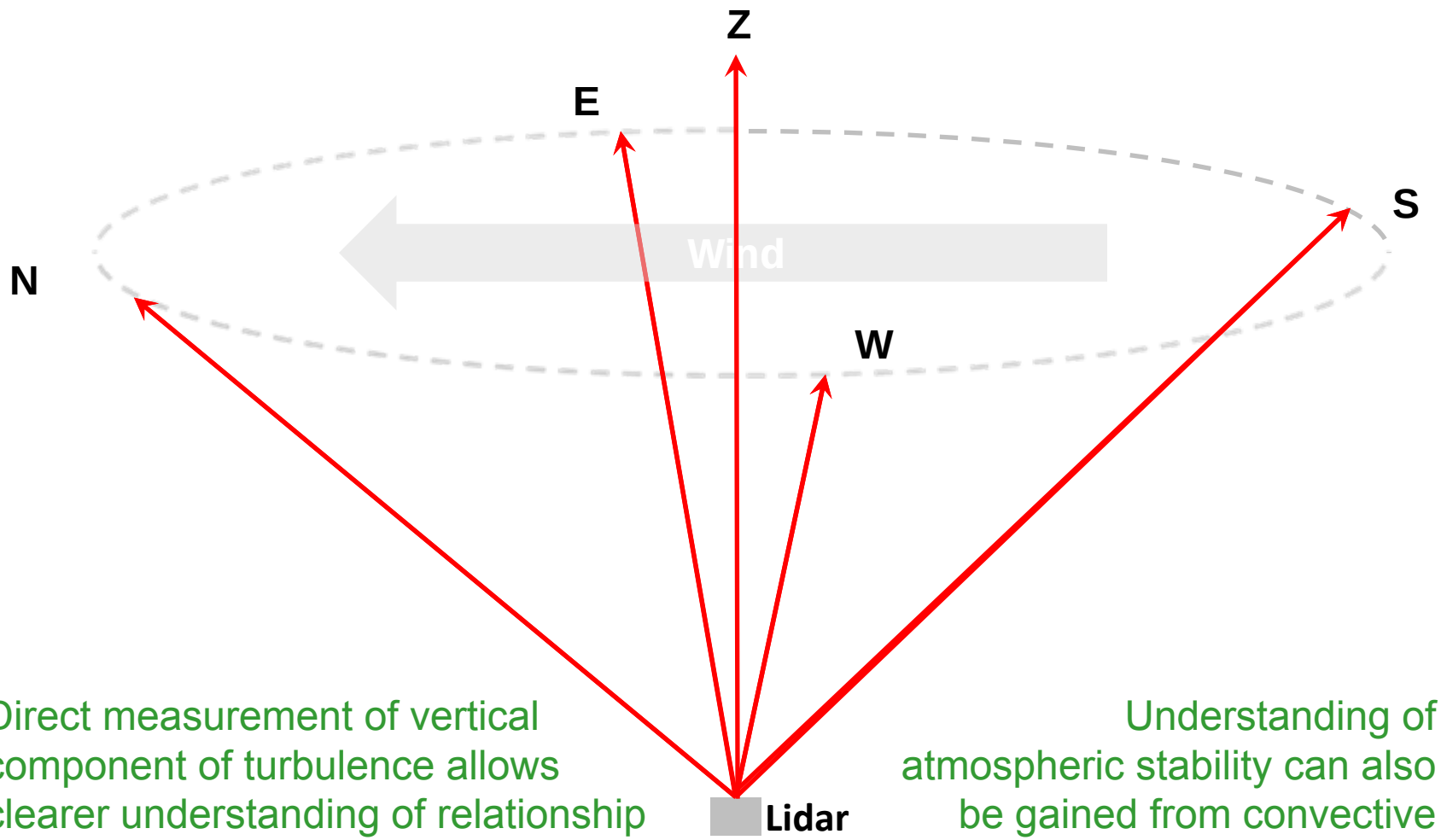
Galion™




Galion

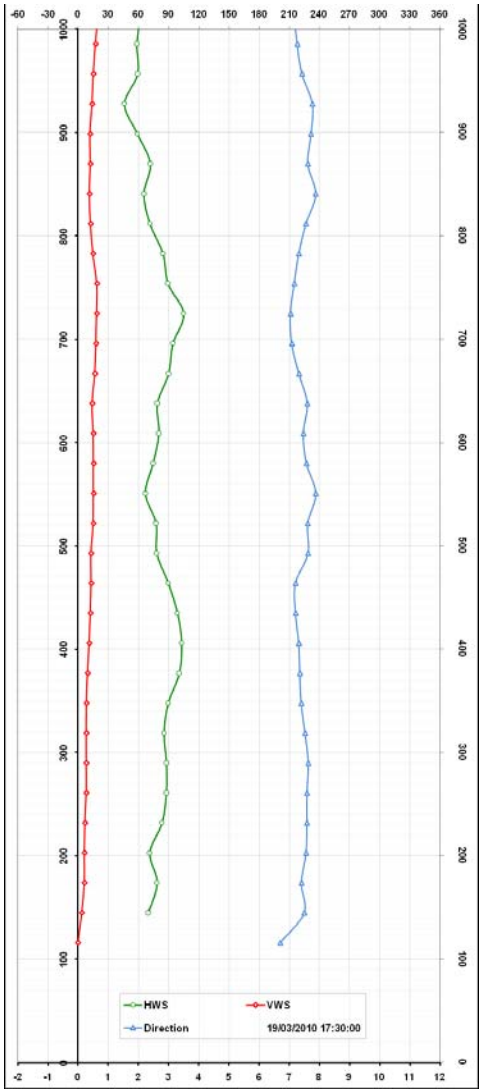
5-Beam scan



Direct measurement of vertical component of turbulence allows clearer understanding of relationship between cup and Lidar TI measurements

Understanding of atmospheric stability can also be gained from convective structures and variance in w at multiple heights

Compound scan



Narrow cone to obtain measurements at higher elevations

Probe length restricts low height resolution with narrow cone

Wide cone to obtain measurements at low elevations

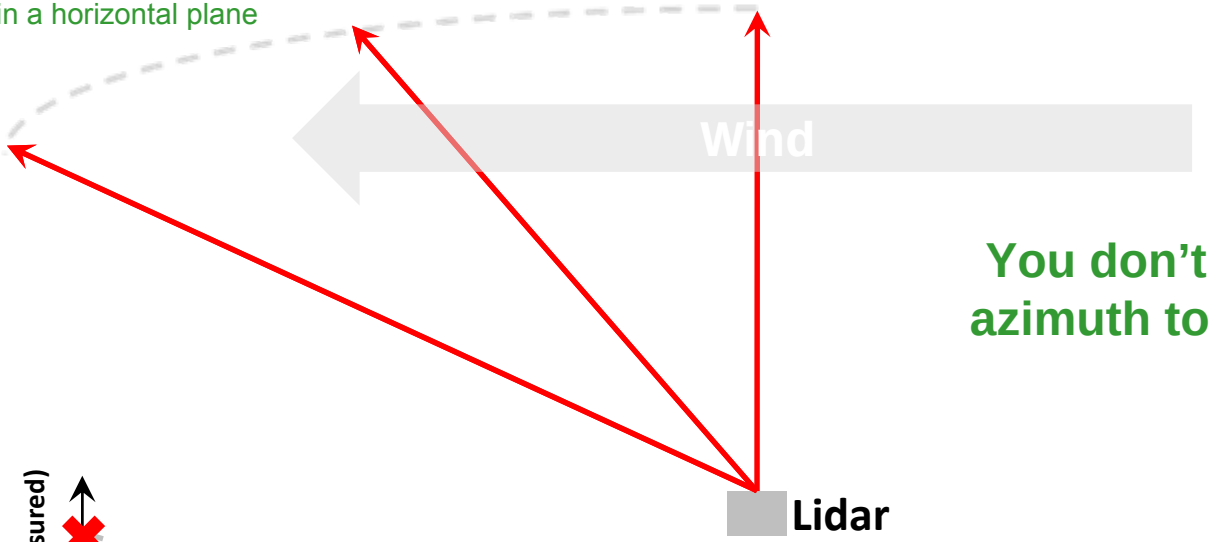
φ_2

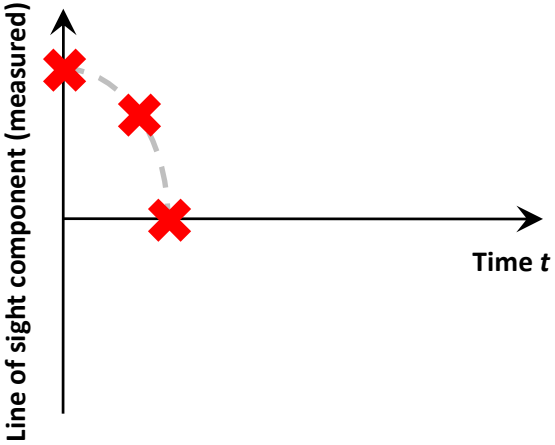
φ_1

Arc scanning

Arc scan geometry

Locus of measurement sites is an arc in a horizontal plane



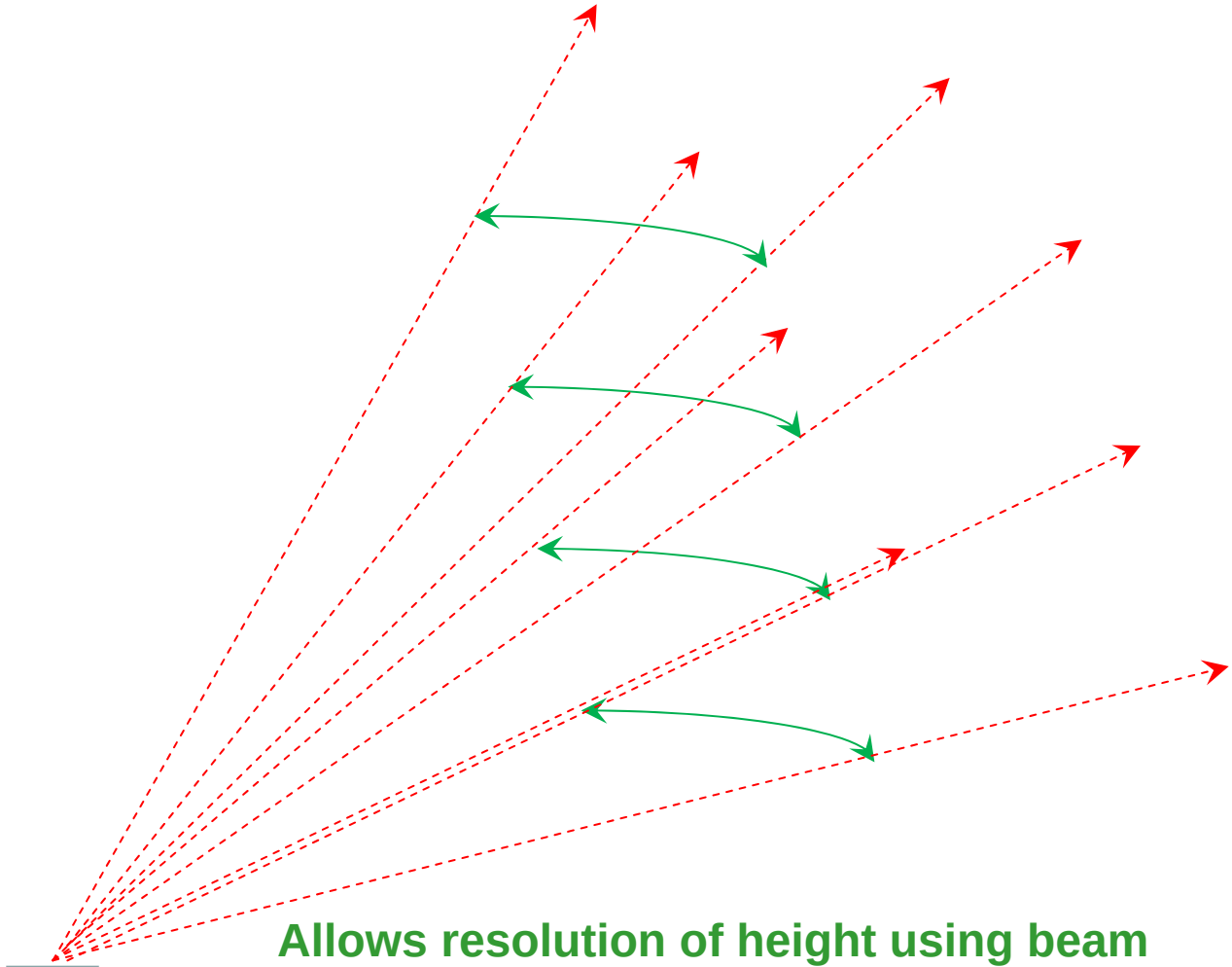


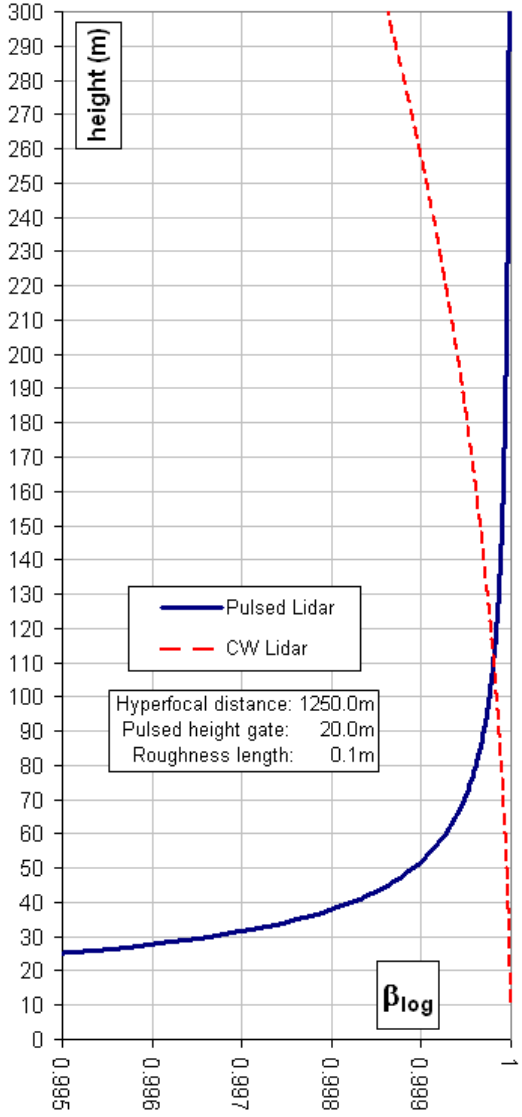
You don't need 360° of azimuth to fit a sinusoid

$$x = A \sin(\omega t + B) + C$$

A gives horizontal wind speed
B gives wind direction
C gives vertical wind speed

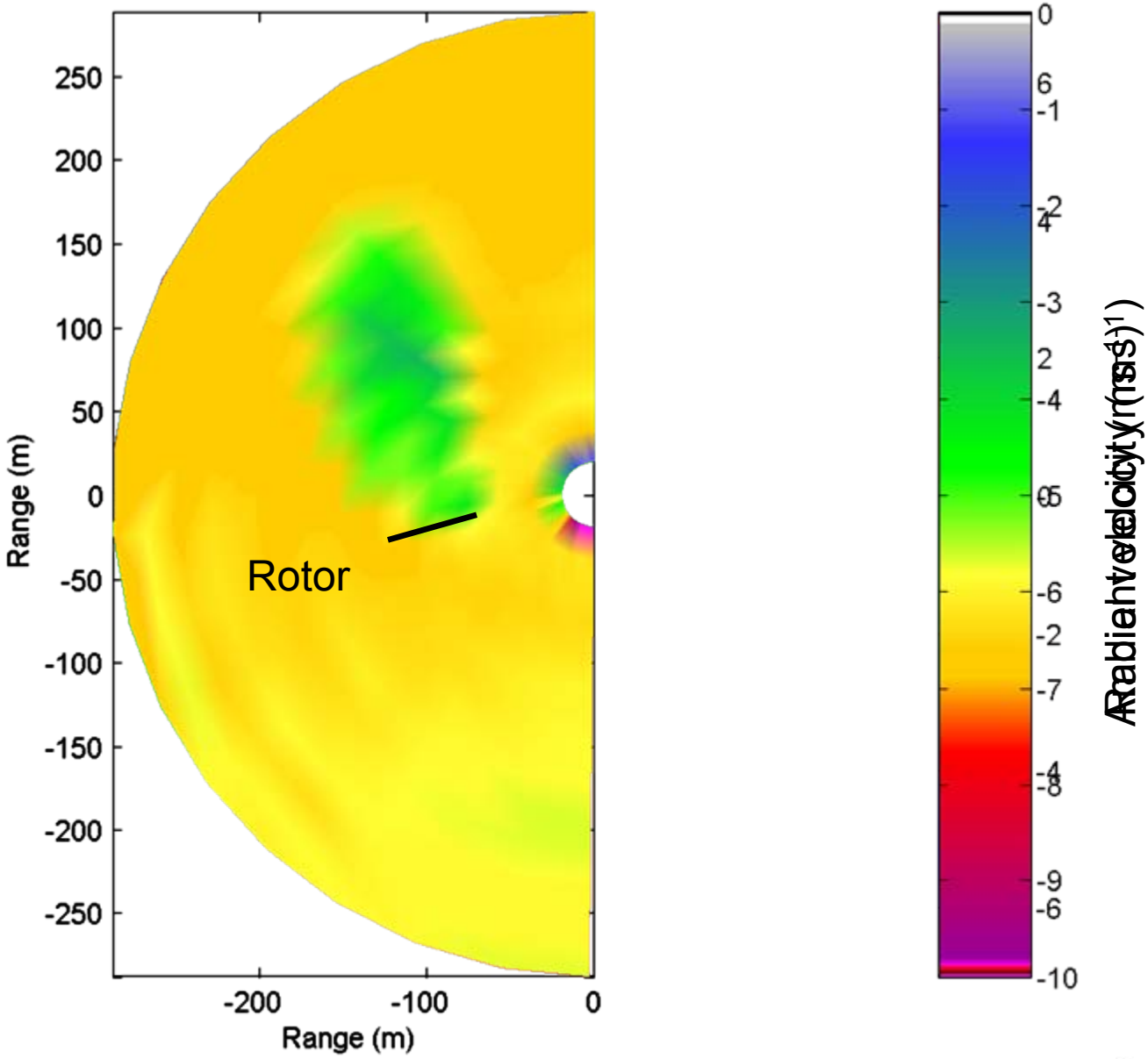
Arc scanning



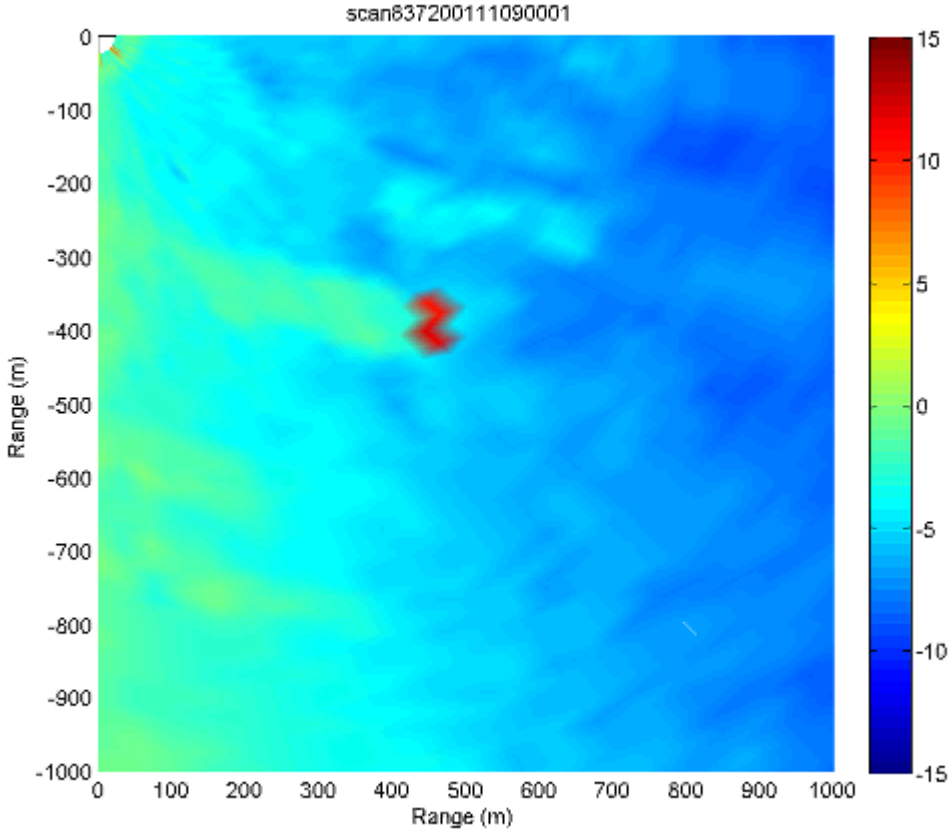


Allows resolution of height using beam orientation rather than distance along line of sight

PPI

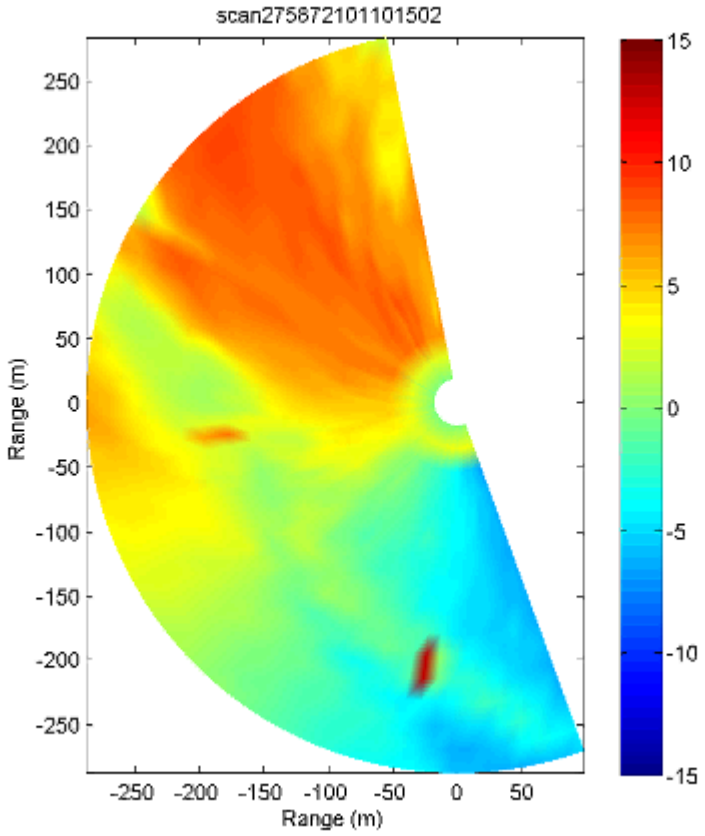


PPI



Galion installed at (0,0)
Radial velocities/line-of-sight data
Velocity deficits seen where turbine wakes intersect PPI

PPI



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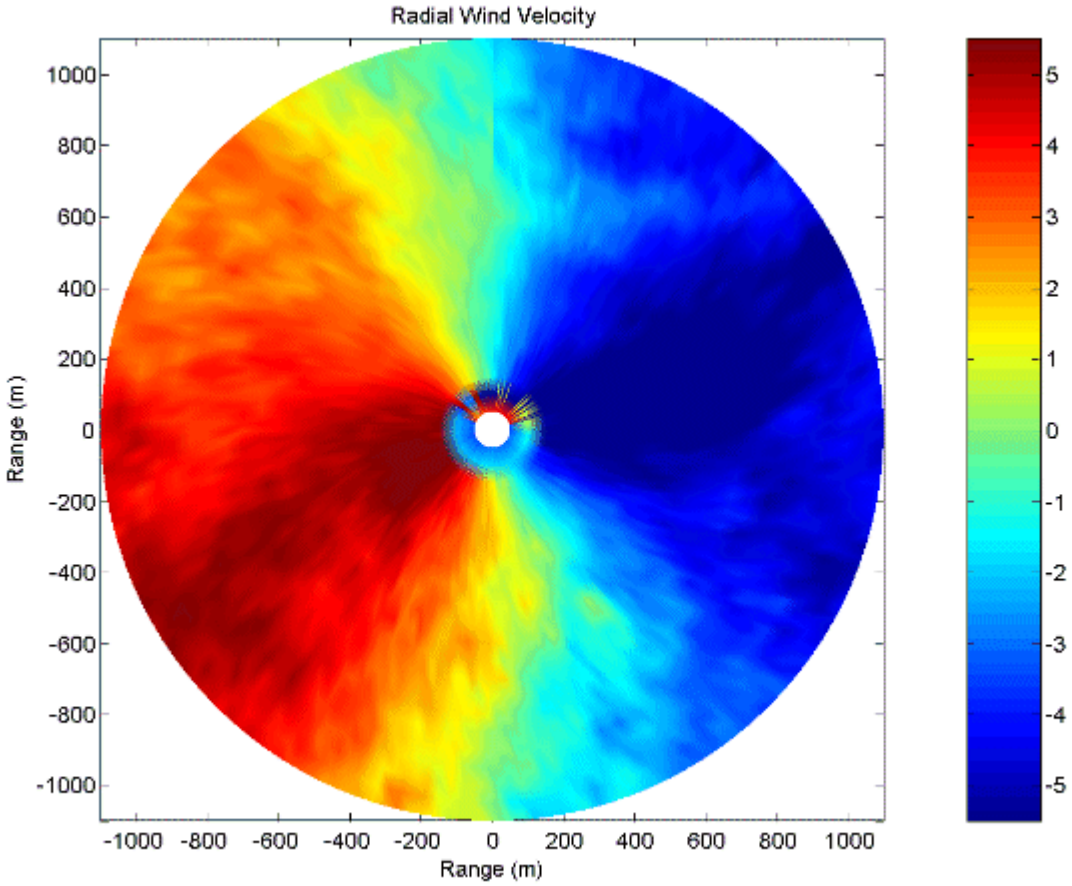
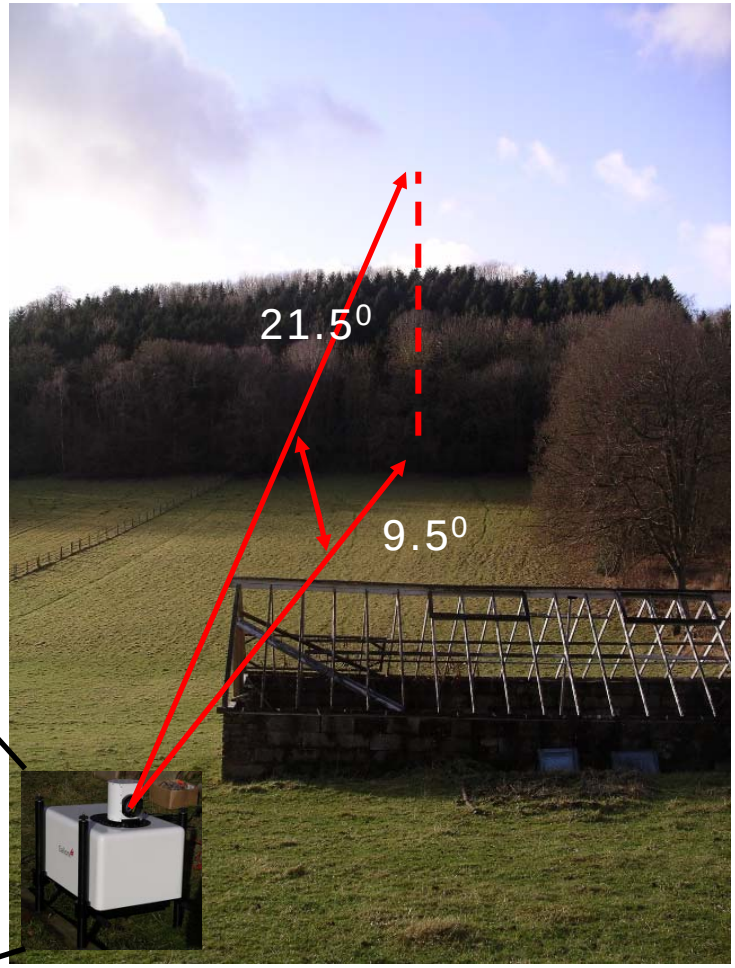


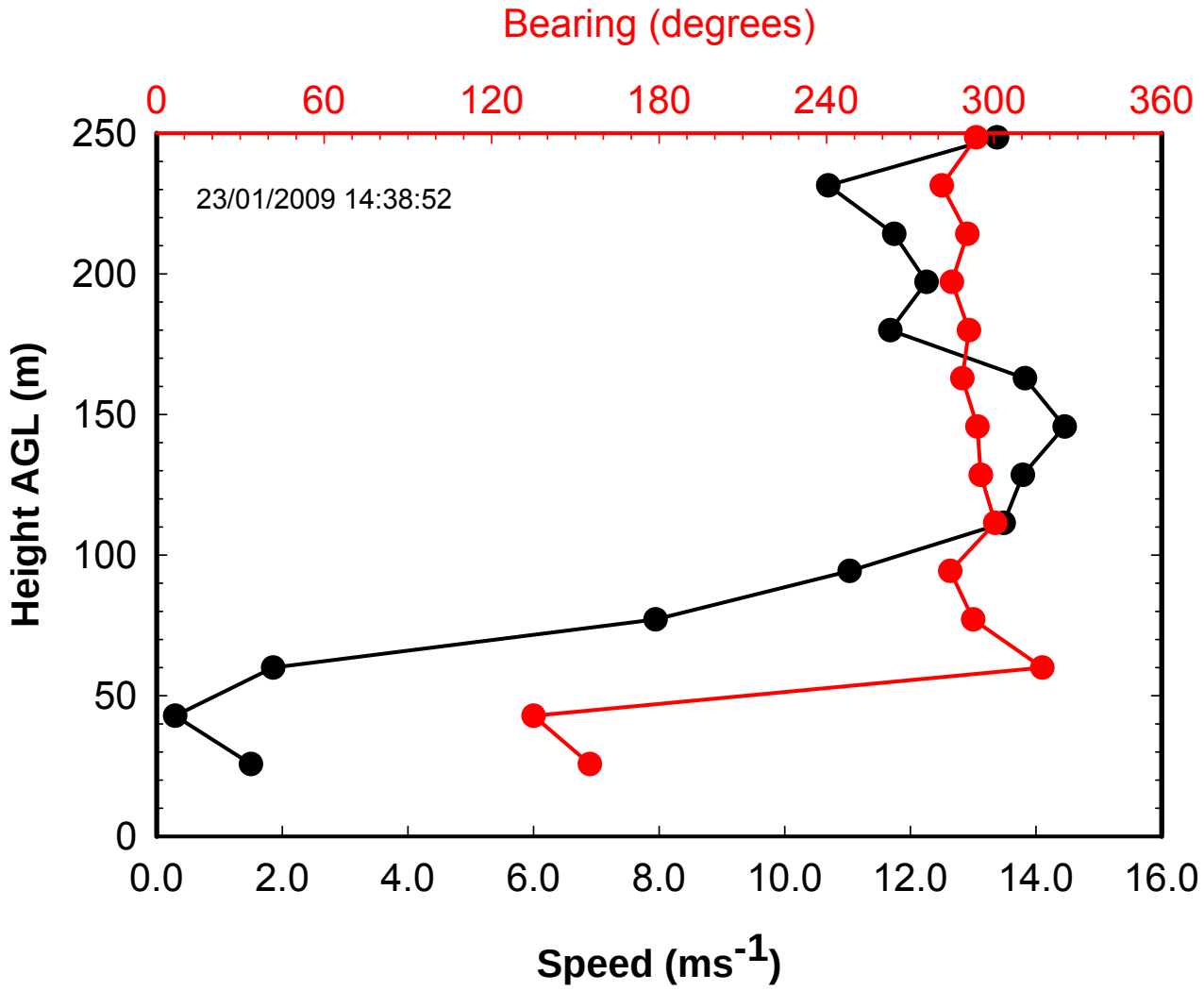
RHI

- Fixed azimuth (260^0), elevation scanned
- Each frame: 13 rays, 1 degree step, 30 sec per scan
- 16 frames
- Wind coming towards lidar over trees
- Clouds were scudding along but
  it was relatively calm down at the lidar

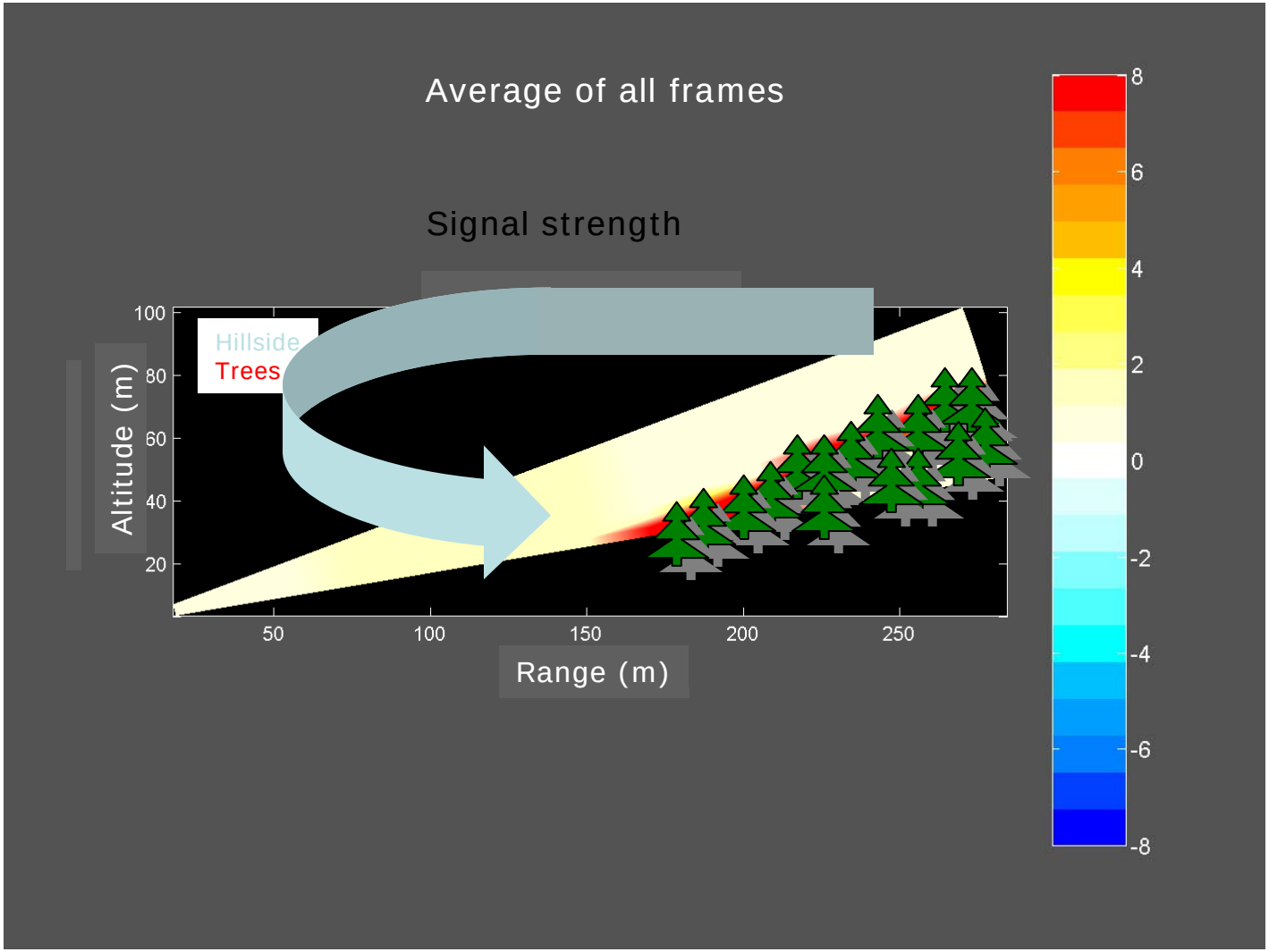


RHI

Wind profile taken at the end of the scan sequence



RHI



Is remote sensing bankable?

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Bankability depends on being able to quantify uncertainty, not on the specific instruments used.

- **Compliance with the articles of the Boulder Protocol* should ensure that the contribution of remote sensing to project uncertainty is understood and can be represented in the project P90.**

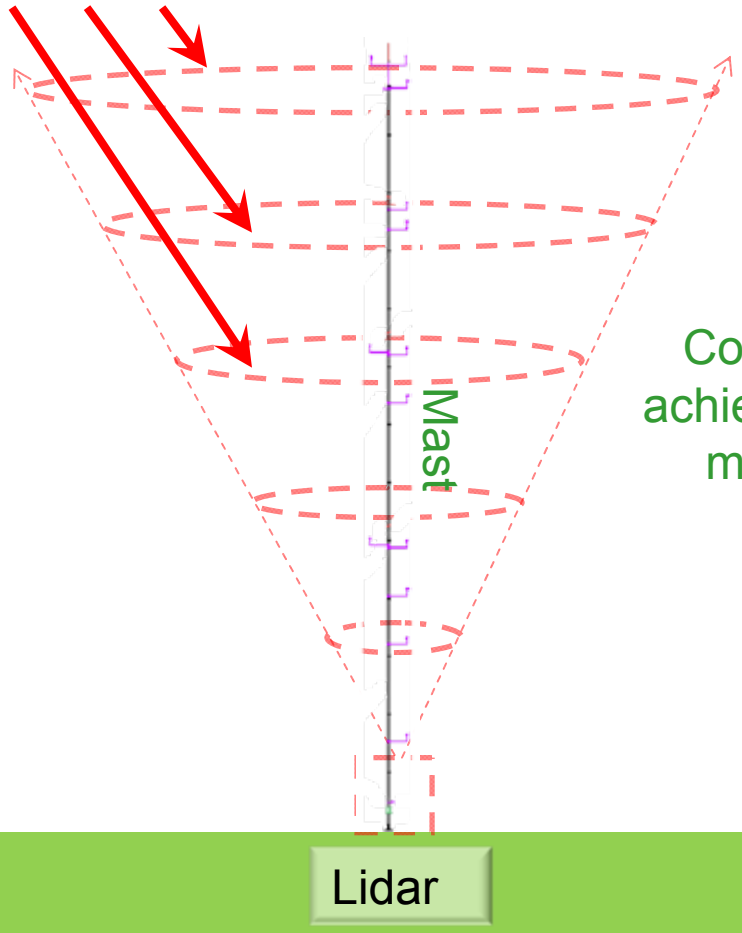
- **Every instrument :**
  - **Introduces uncertainty as a result of measurement errors;**
  - **Removes uncertainty by virtue of the data acquired.**

  This includes conventional cup anemometry.

*Proposed at the IEA Wind Energy Task 11 Topical Expert Meeting on Remote Sensing of the Wind held in Boulder, Colorado in October 2009

NorseWind Criteria

Lidar measurements acquired at heights where mast is instrumented



Compliance with article 1 achieved by comparing Lidar measurements to mast measurements

NorseWind Criteria

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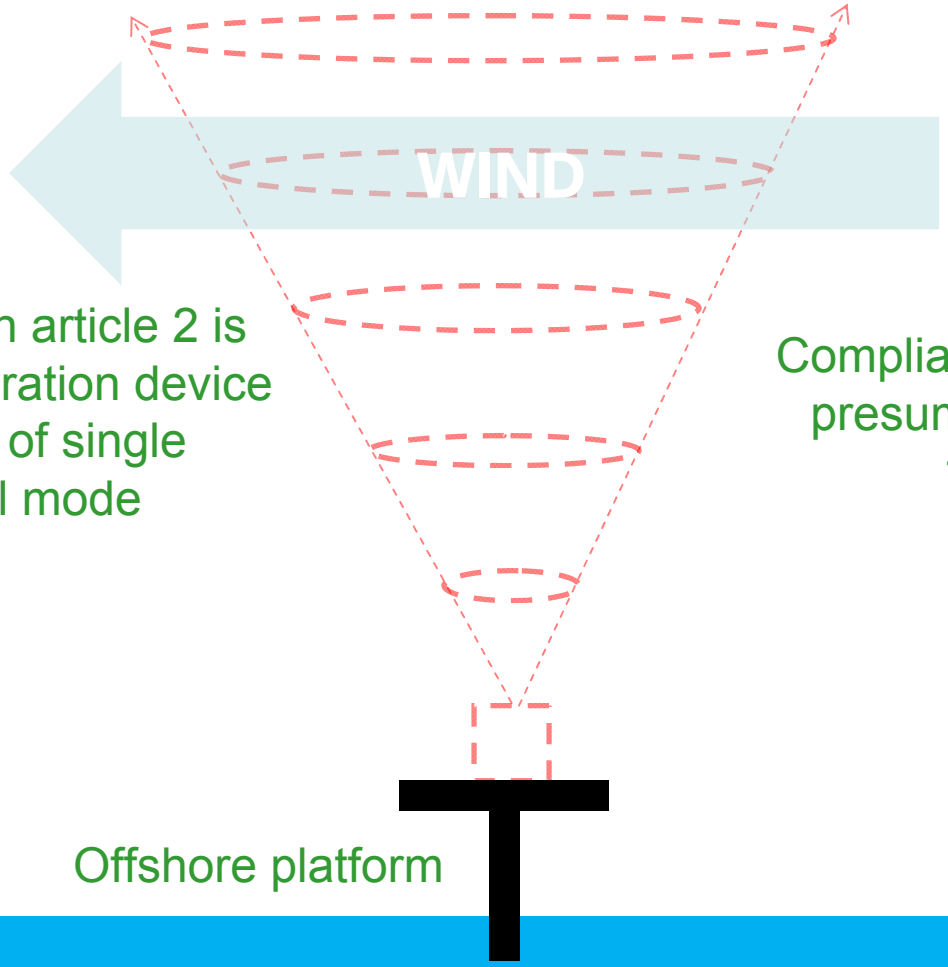

Compliance with article 2 is trivial as 1st generation device only capable of single operational mode

Compliance with article 3 is presumed due to lack of topography

Arc scan

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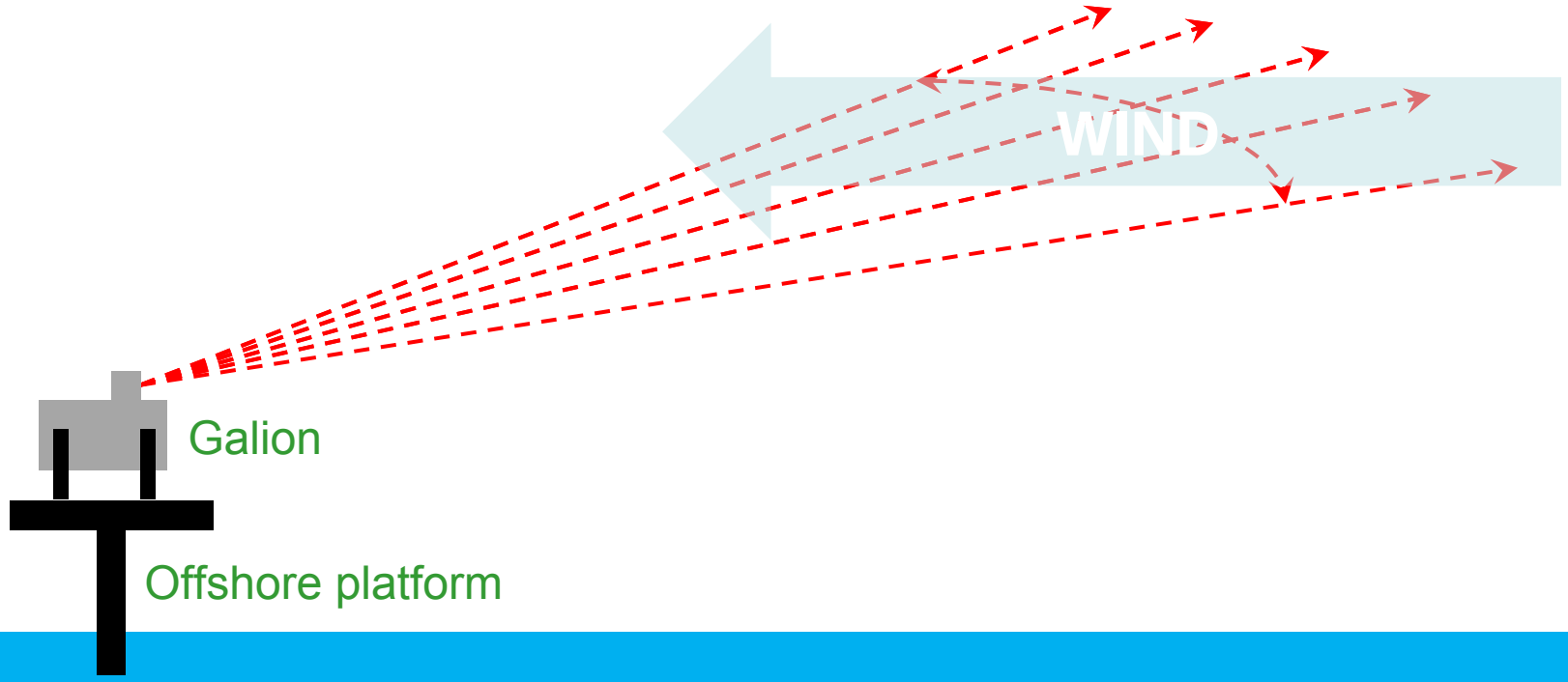
2nd generation scan geometry employed to survey wind directly at proposed wind turbine locations and in regions where the wind flow is unaffected by the influence of the platform to ensure compliance with article 3



Arc scan

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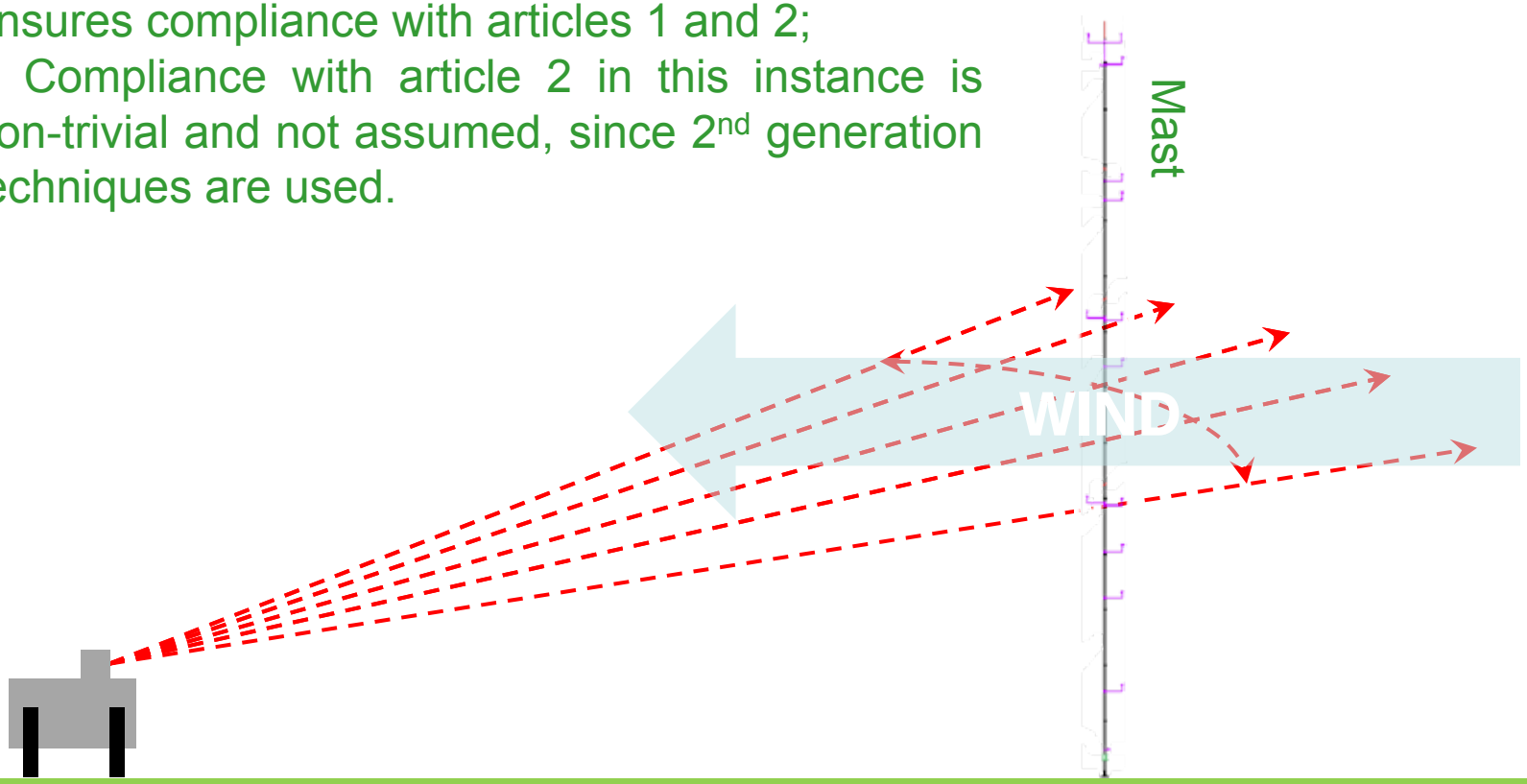
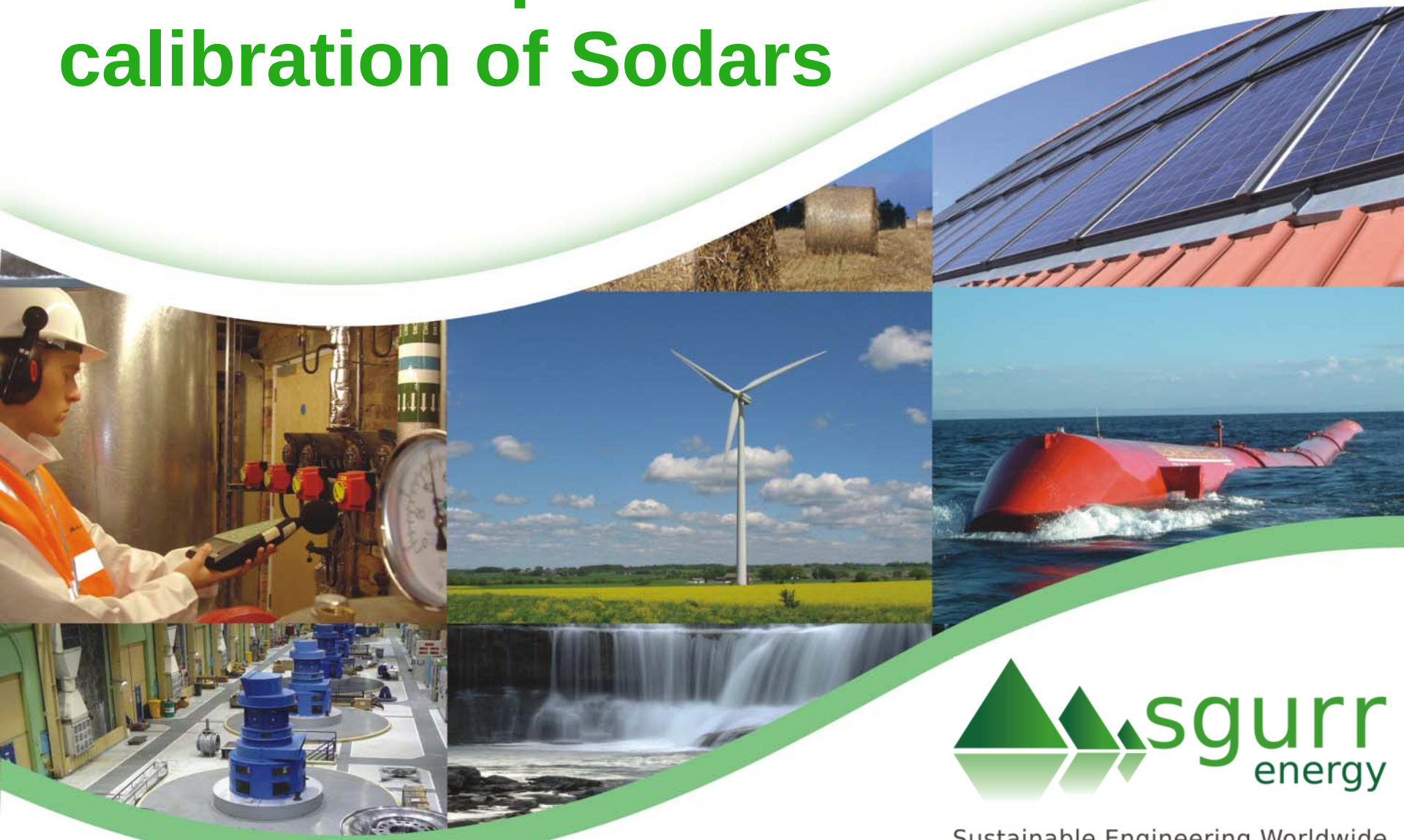
- Comparison with reference instrumentation before and/or after the measurement campaign ensures compliance with articles 1 and 2;
- Compliance with article 2 in this instance is non-trivial and not assumed, since 2nd generation techniques are used.



in situ site specific calibration of Sodars



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Why?

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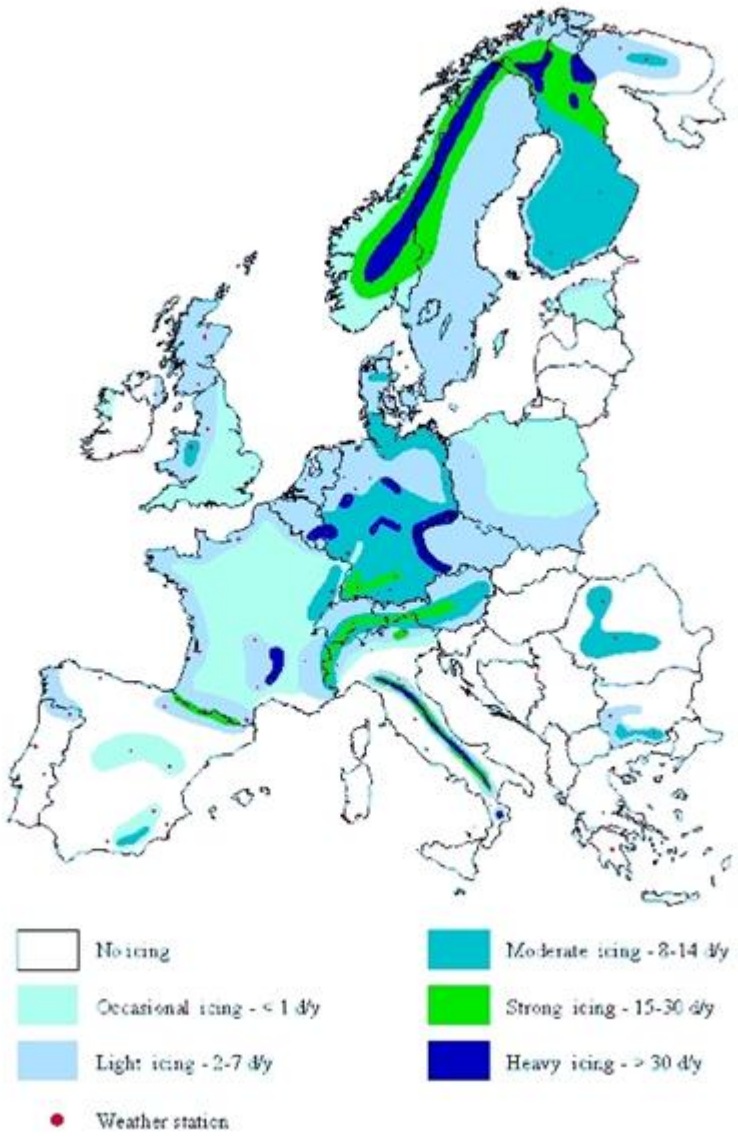

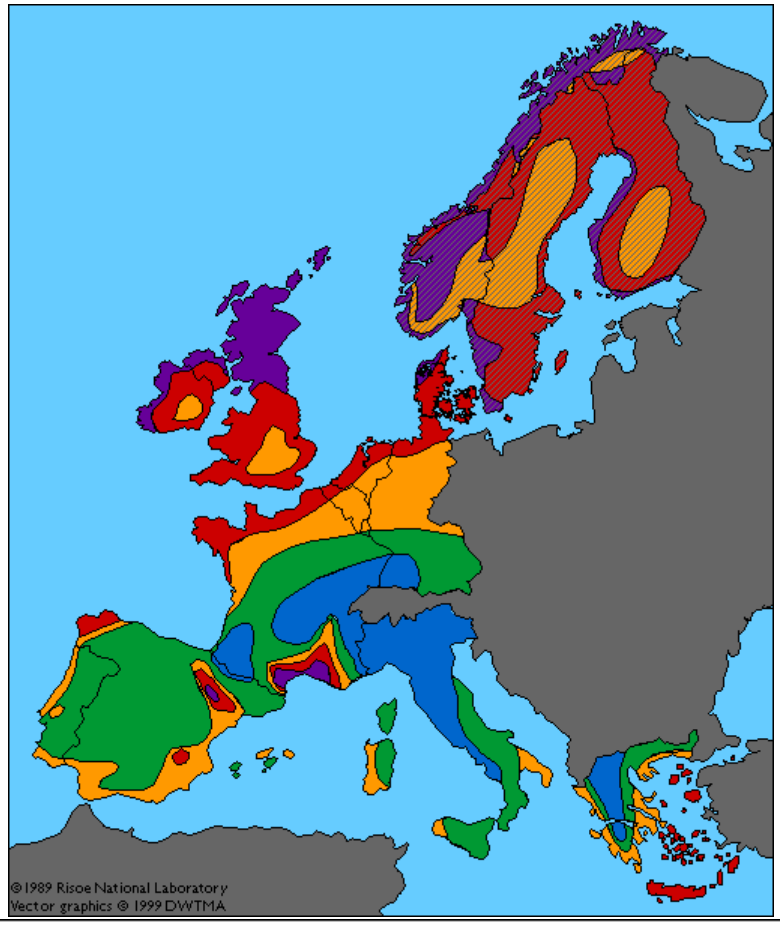

m/s	W/m²	m/s	W/m²	m/s	W/m²	m/s	W/m²	m/s	W/m²
>6.0	>250	>7.5	>500	>8.5	>700	>9.0	>800	>11.5	>1800
5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0-8.5	400-700
<3.5	<50	<4.5	<100	<5.0	<150	<5.5	<200	<7.0	<400
		>7.5							
		5.5-7.5							
		<5.5							

What we would like

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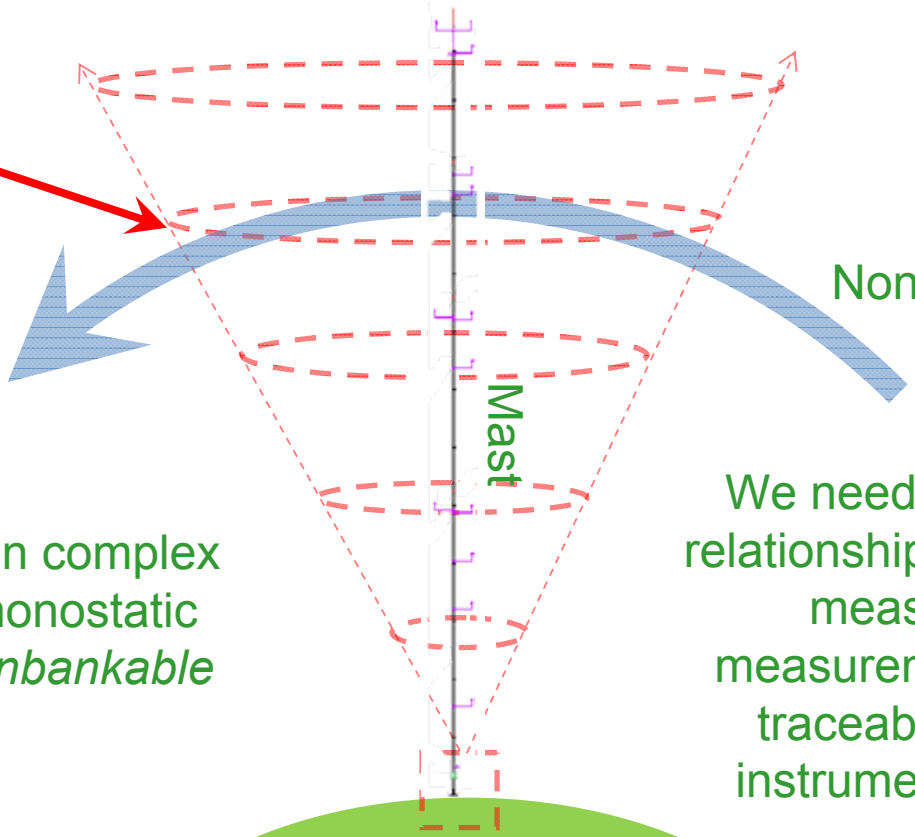

Non uniform flow in complex terrain renders monostatic remote sensing *unbankable*

We need to understand the relationship between the Sodar measurements and measurements conventional traceable mast mounted instruments *would* acquire

Complex terrain (hill) induces non-uniform flow in the measurement volume

What we can have

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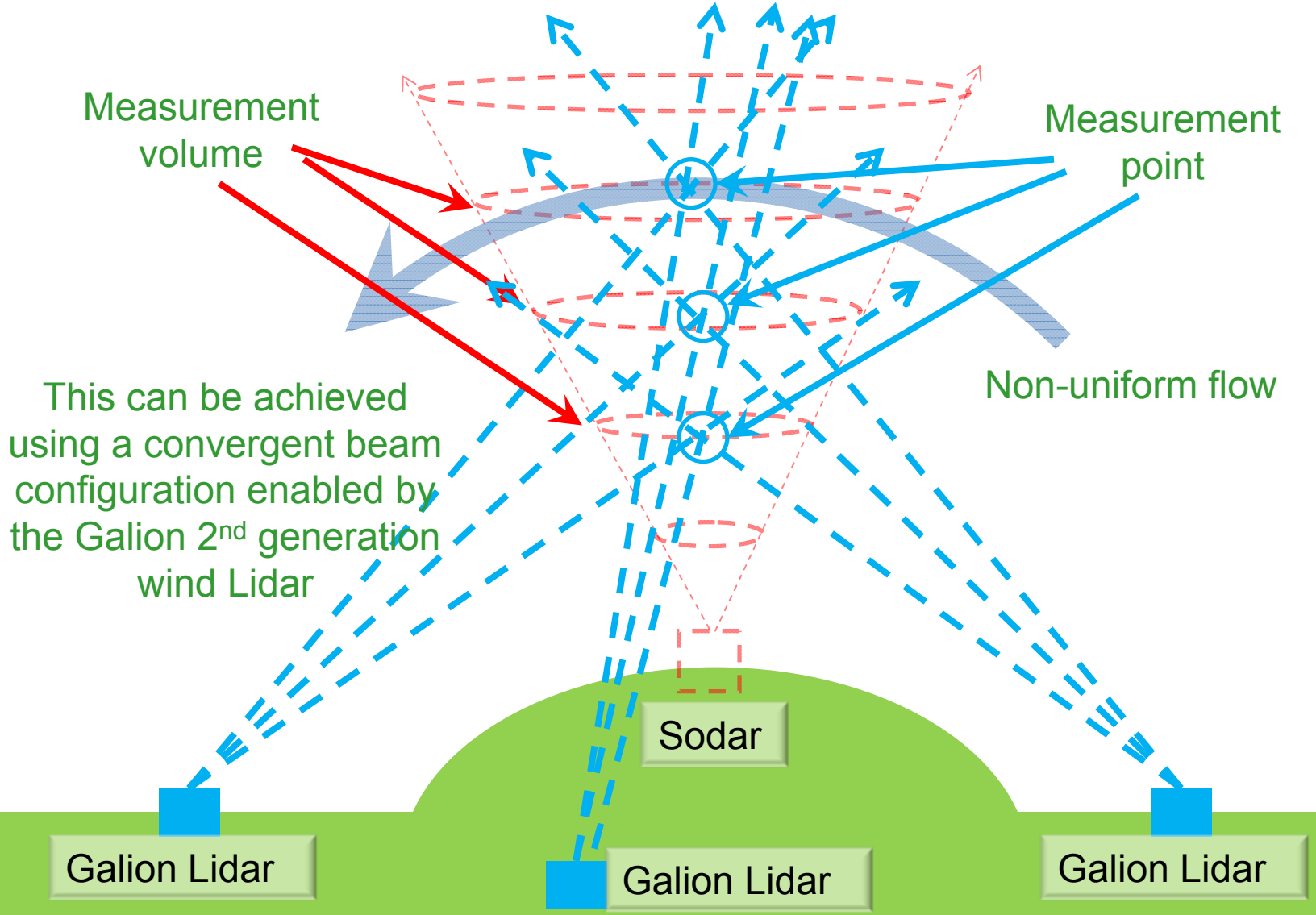

Demonstrating article 3 compliance

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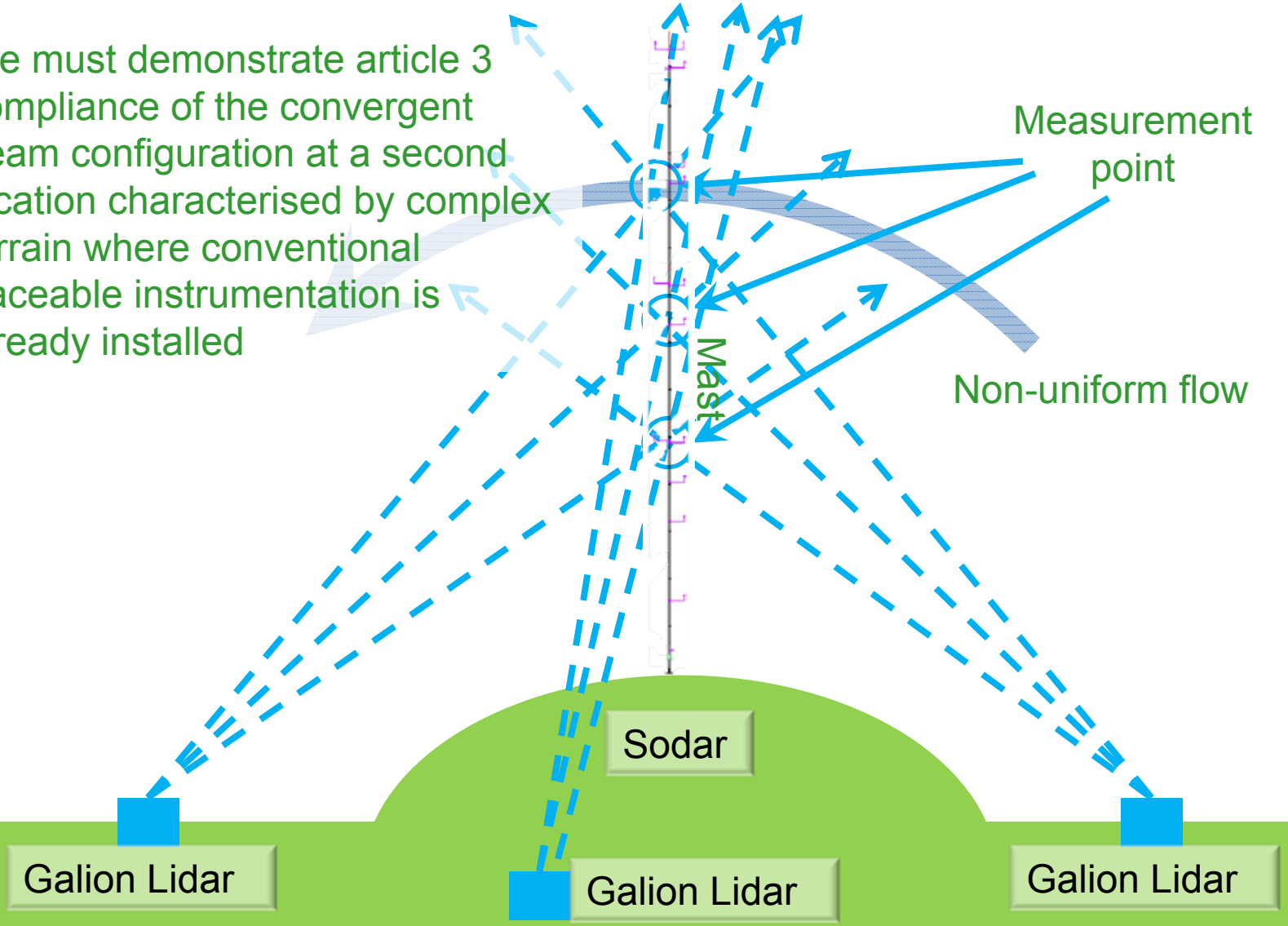
We must demonstrate article 3 compliance of the convergent beam configuration at a second location characterised by complex terrain where conventional traceable instrumentation is already installed



Convergent beams

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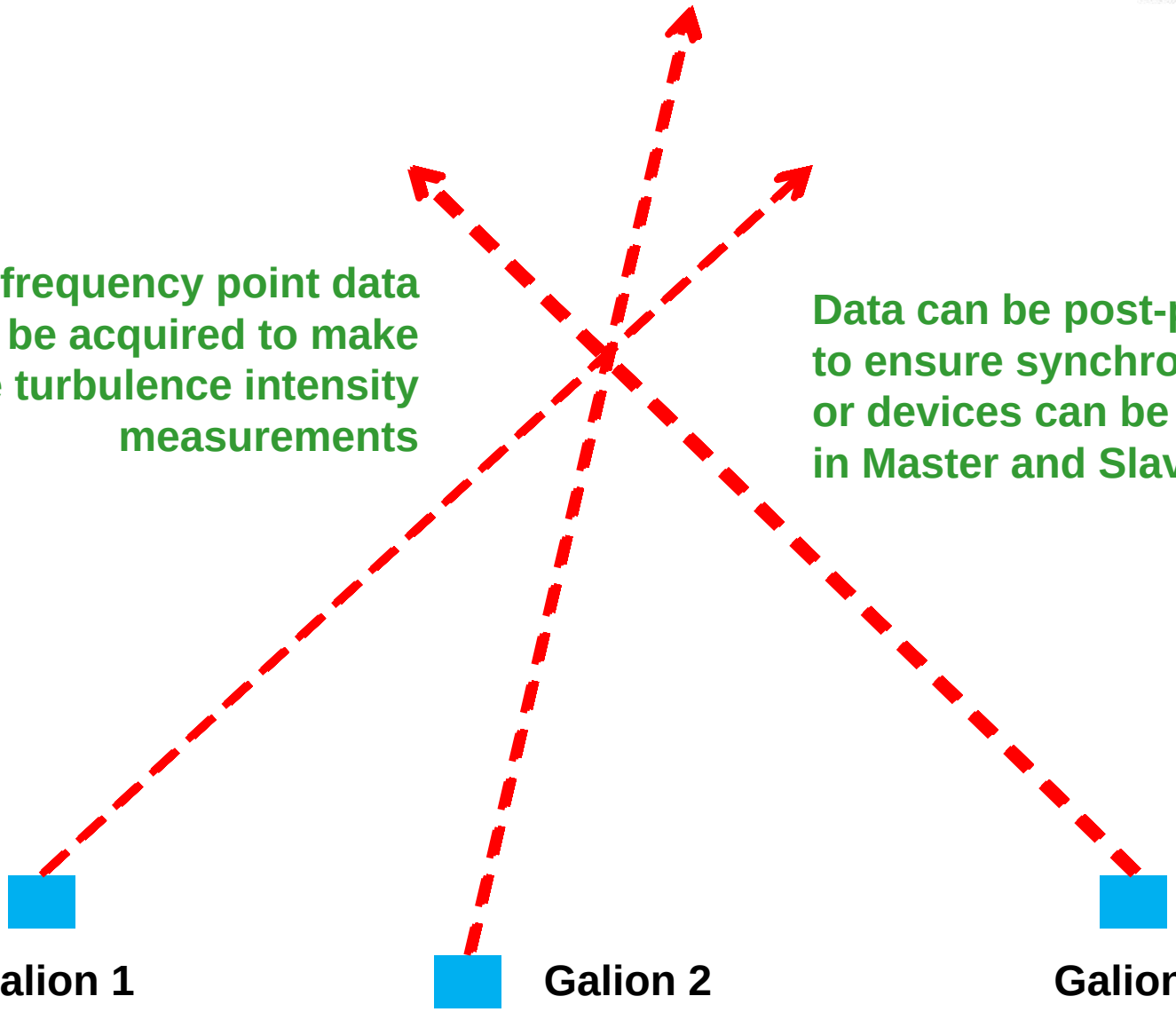
High frequency point data can be acquired to make precise turbulence intensity measurements



Data can be post-processed to ensure synchronisation, or devices can be operated in Master and Slave mode

Conclusions

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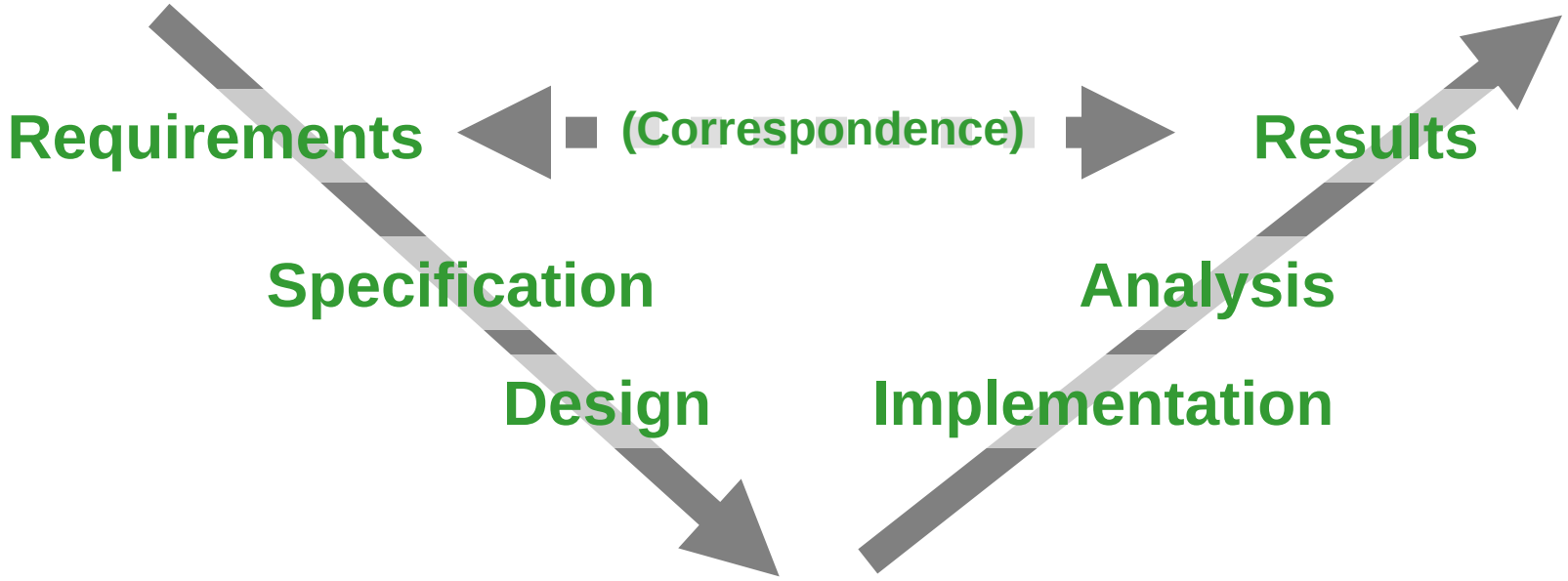
Campaigns were previously designed around what measurements were possible

The capabilities of the Galion mean campaigns are designed around what is required



Conclusions

- **Wind Power applications demand high precision, low cost, robust, and compact remote sensing solutions for projects with narrow margins in challenging locations;**

- **1st generation remote sensing solutions encounter difficulties in complex terrain;**

- **These challenges have driven developments that have produced devices that are now suitable for airport applications, and wind Lidars are now entering the airport space.**