Floating lidar standards and guidance, an update centred around the upcoming technical specification IEC 61400-50-4

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BLACK & VEATCH

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  - Offshore wind measurements
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  - Use cases
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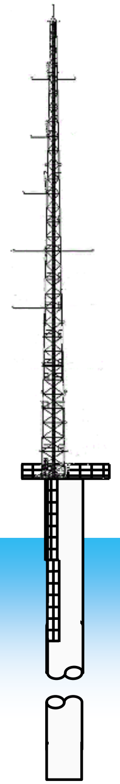
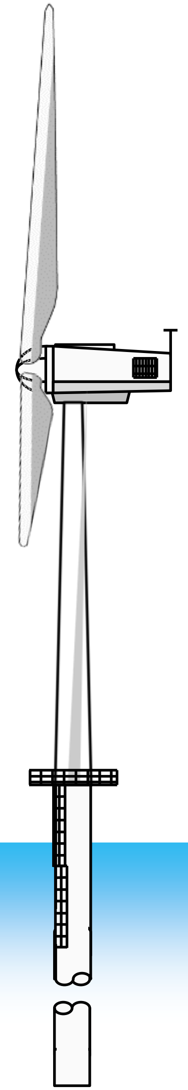
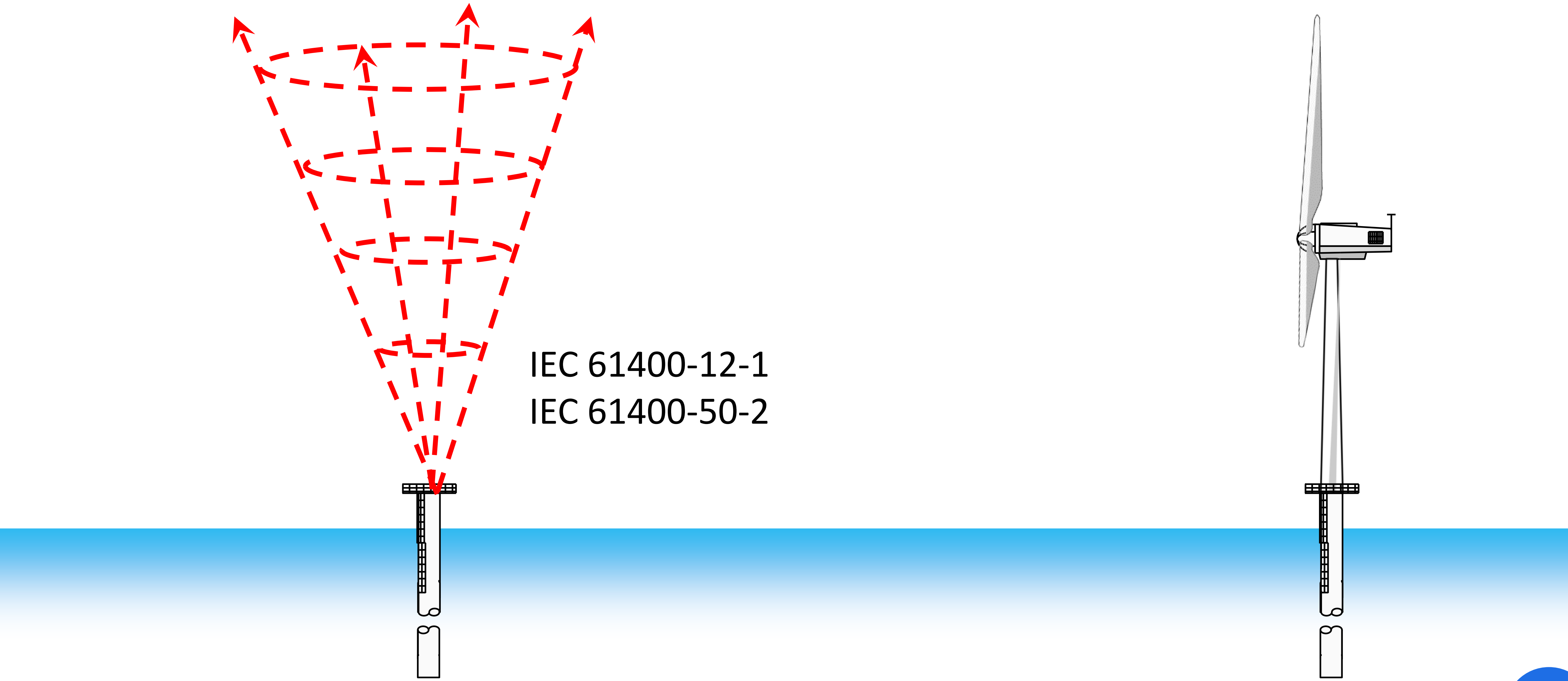
Measurements: met mast



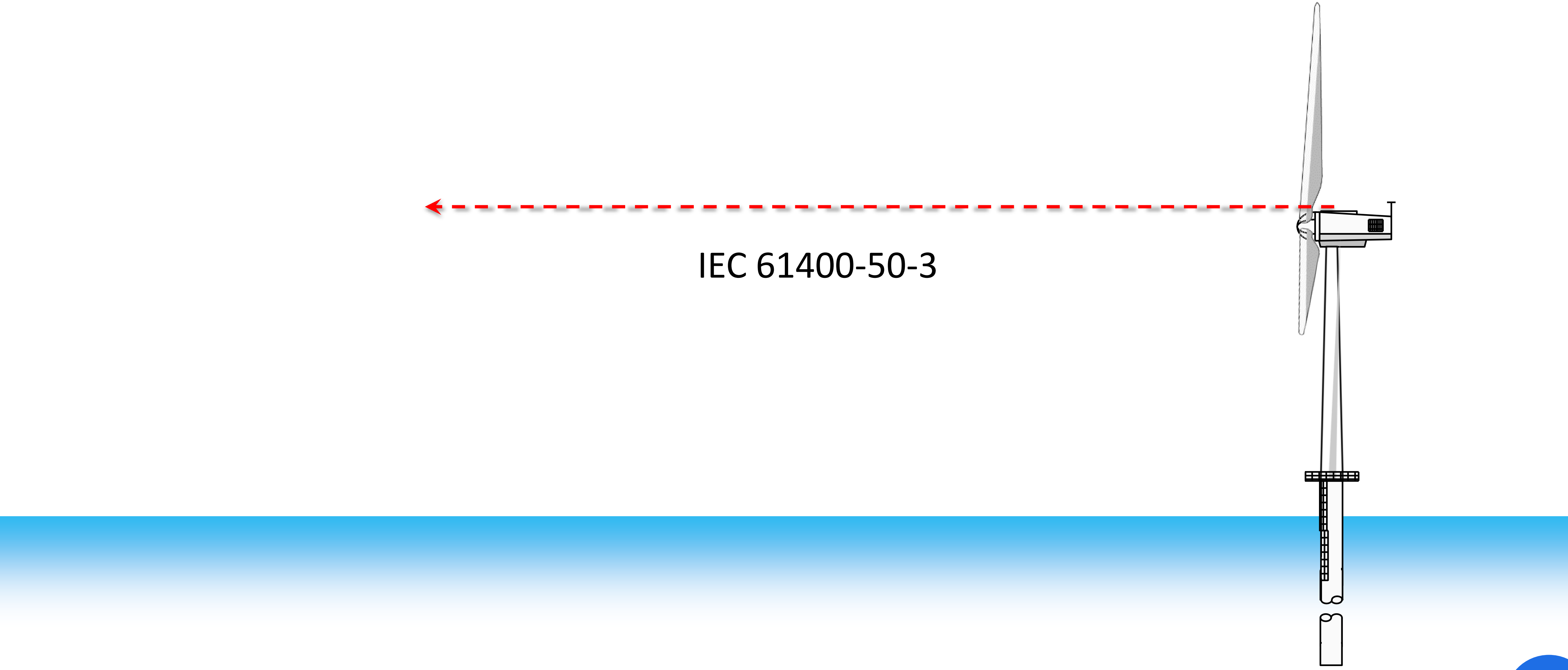
IEC 61400-12-1
IEC 61400-50-1



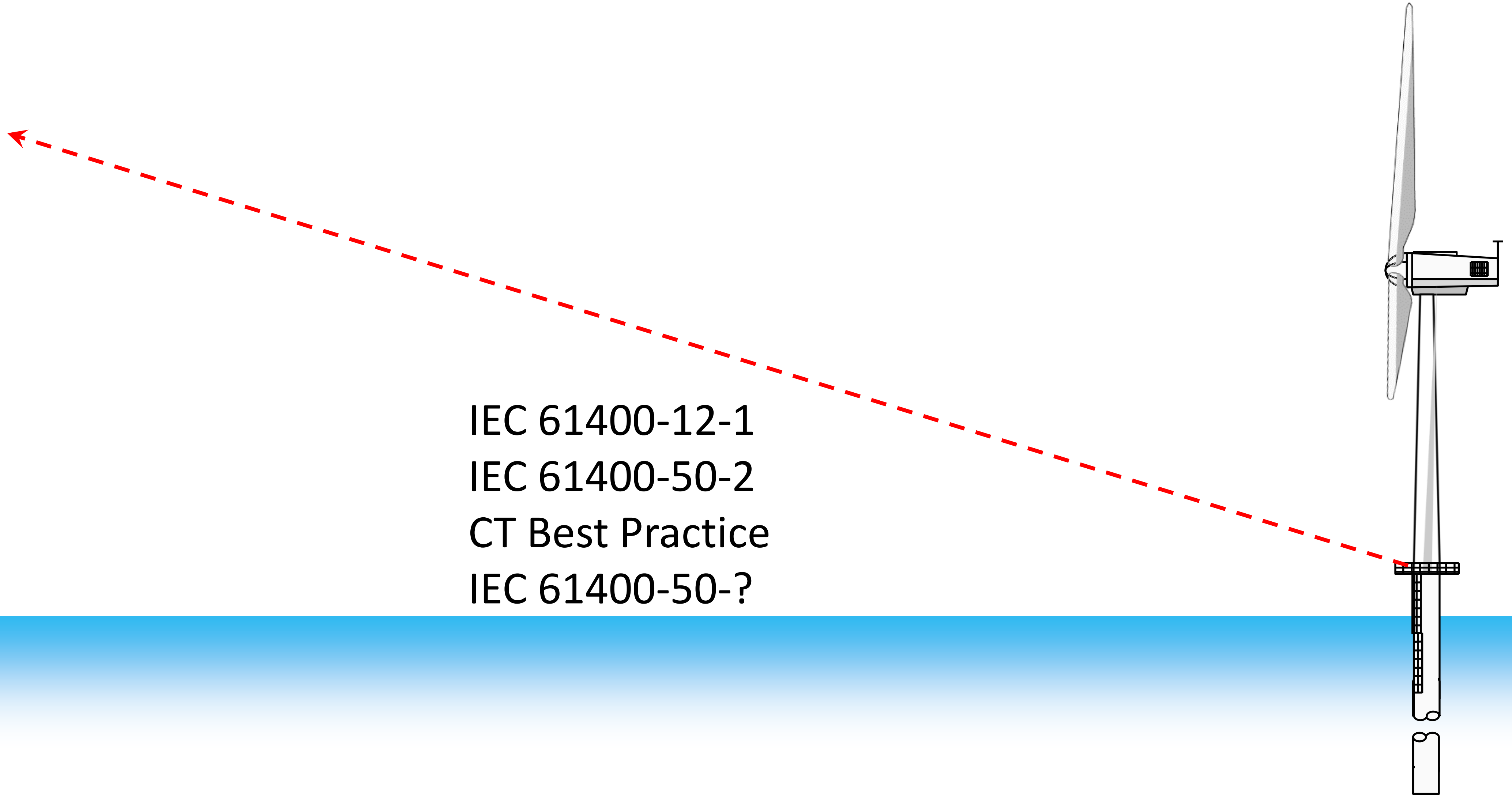
Measurements: vertically profiling lidar



Measurements: nacelle mounted lidar

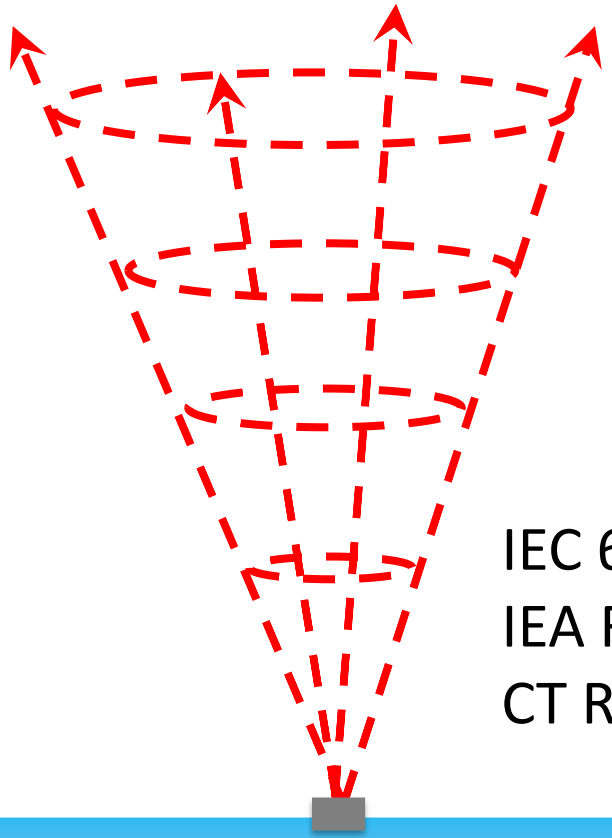


Measurements: t-piece mounted lidar

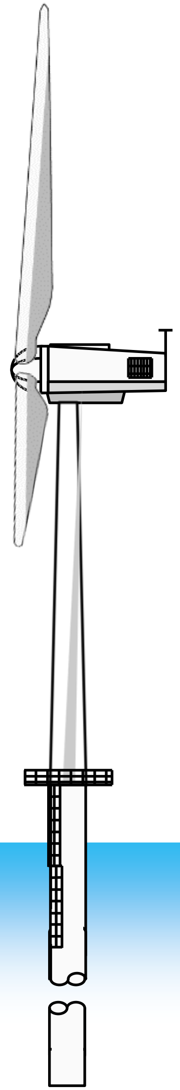


IEC 61400-12-1
IEC 61400-50-2
CT Best Practice
IEC 61400-50-?

Measurements and data requirements: floating lidar

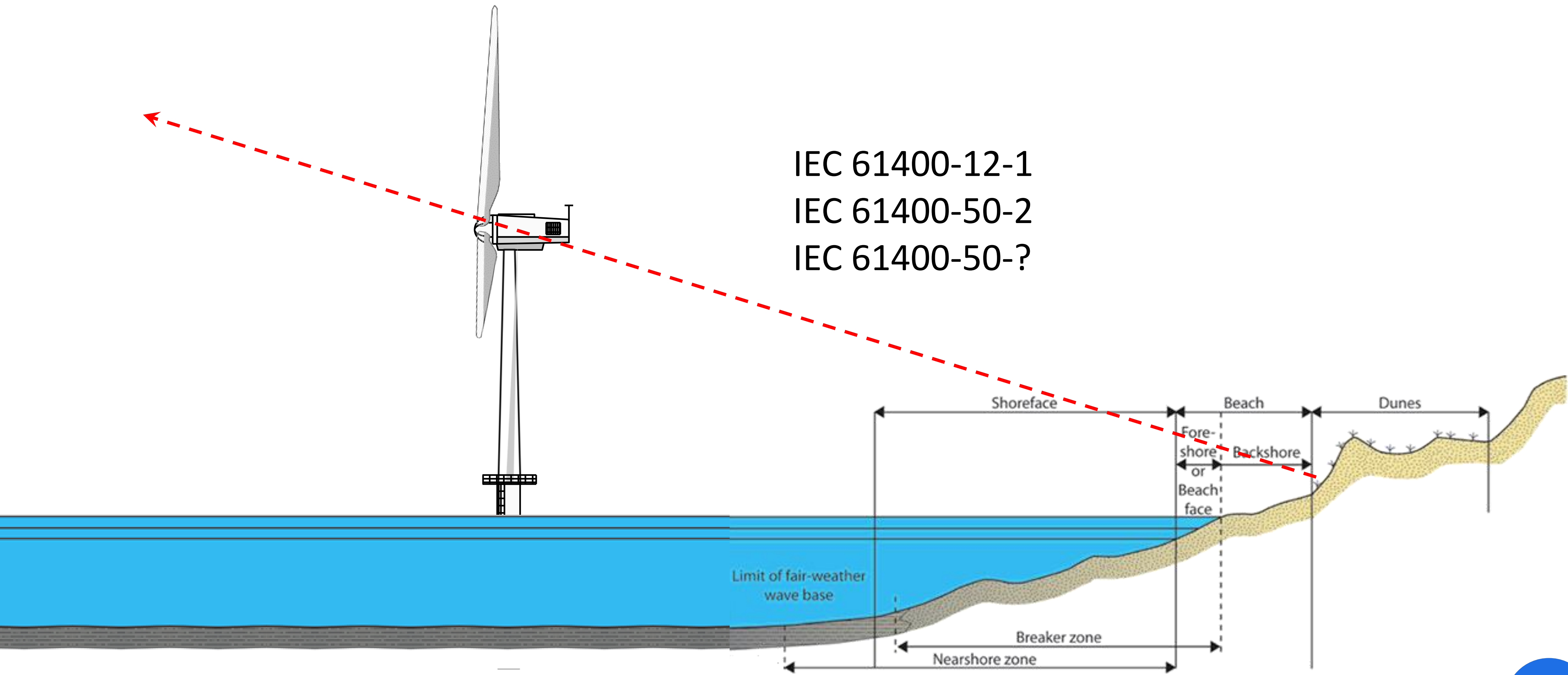


IEC 61400-50-4
IEA RP18
CT Roadmap

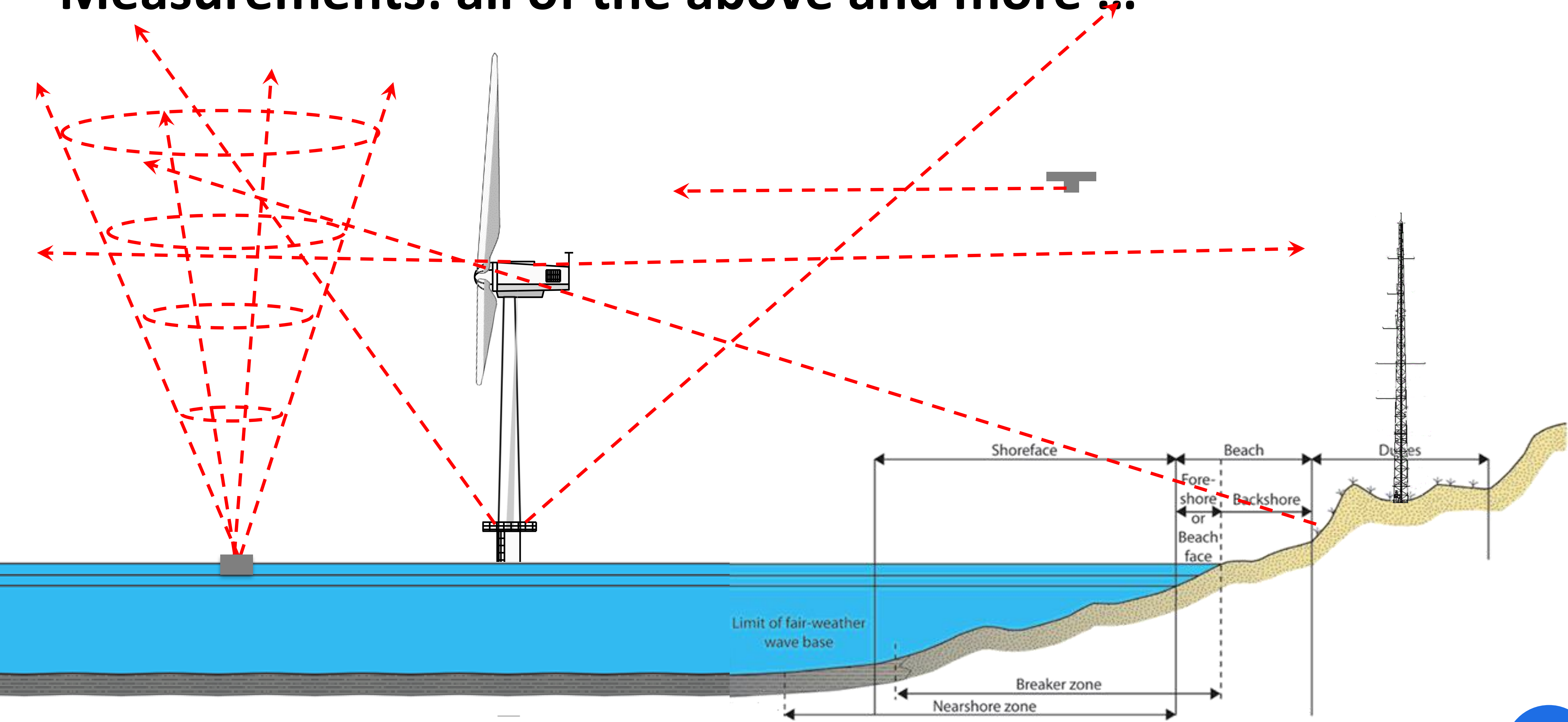


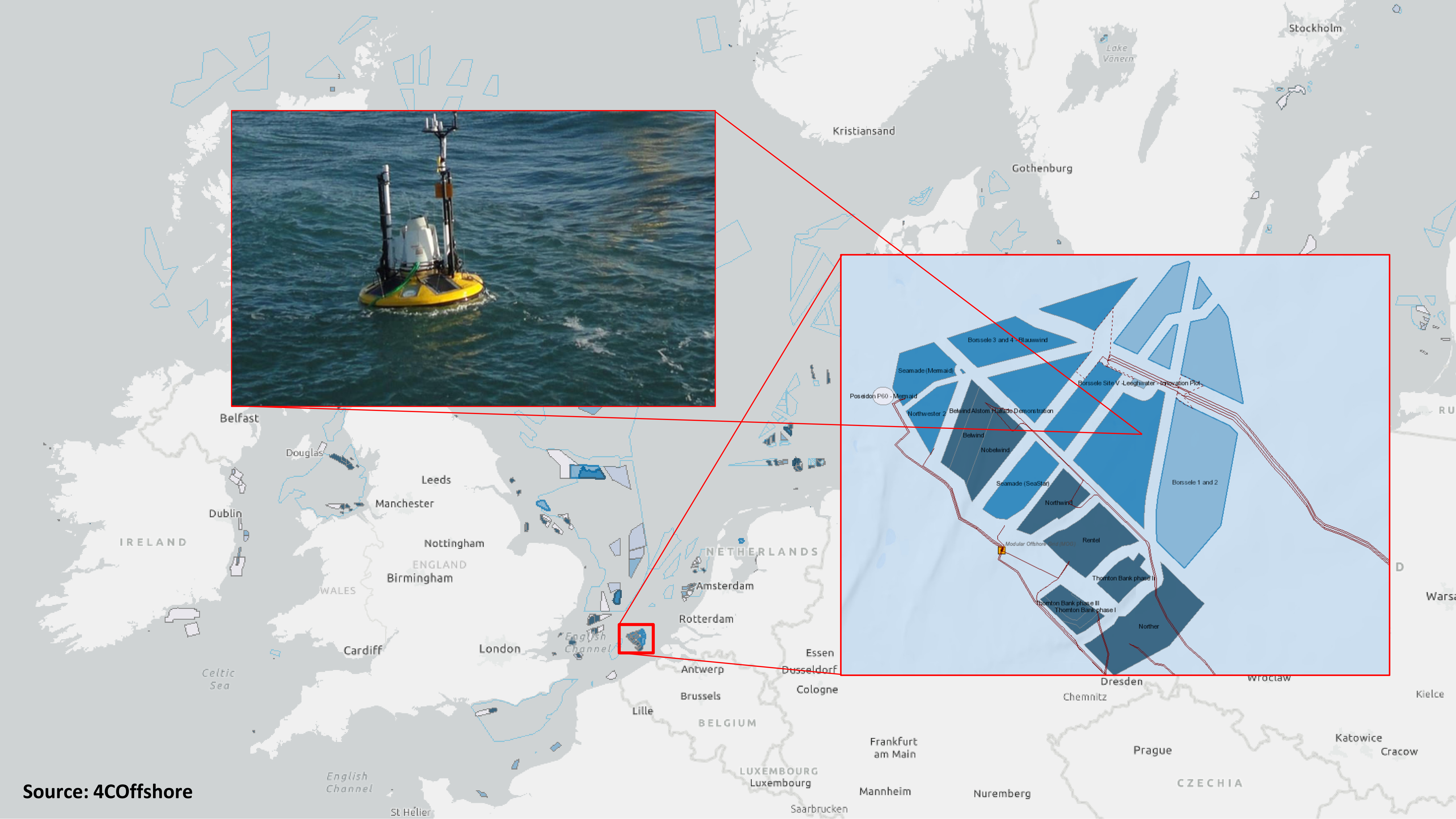
Measurements: onshore-to-offshore

IEC 61400-12-1
IEC 61400-50-2
IEC 61400-50-?

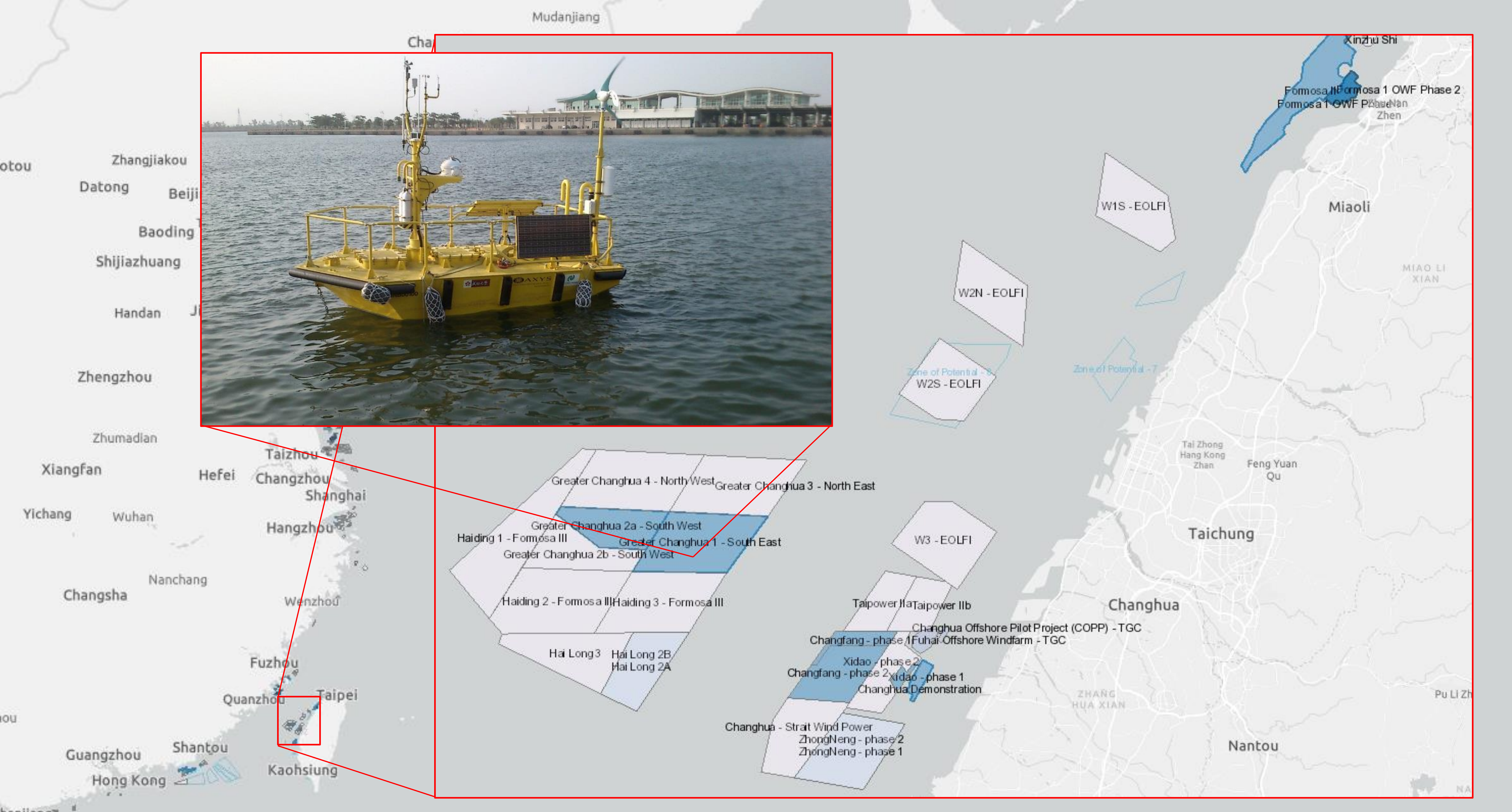


Measurements: all of the above and more …

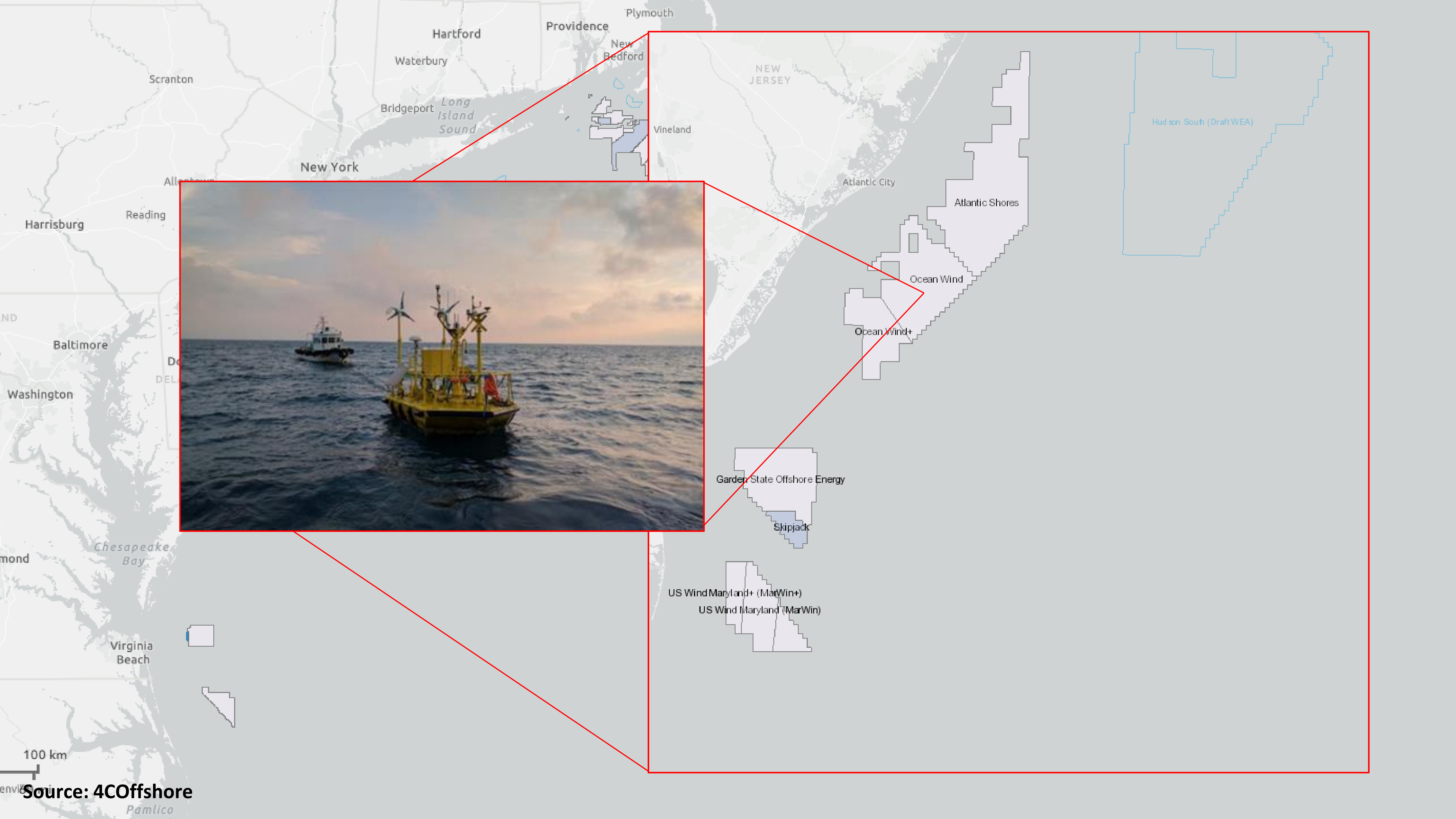




Source: 4COffshore

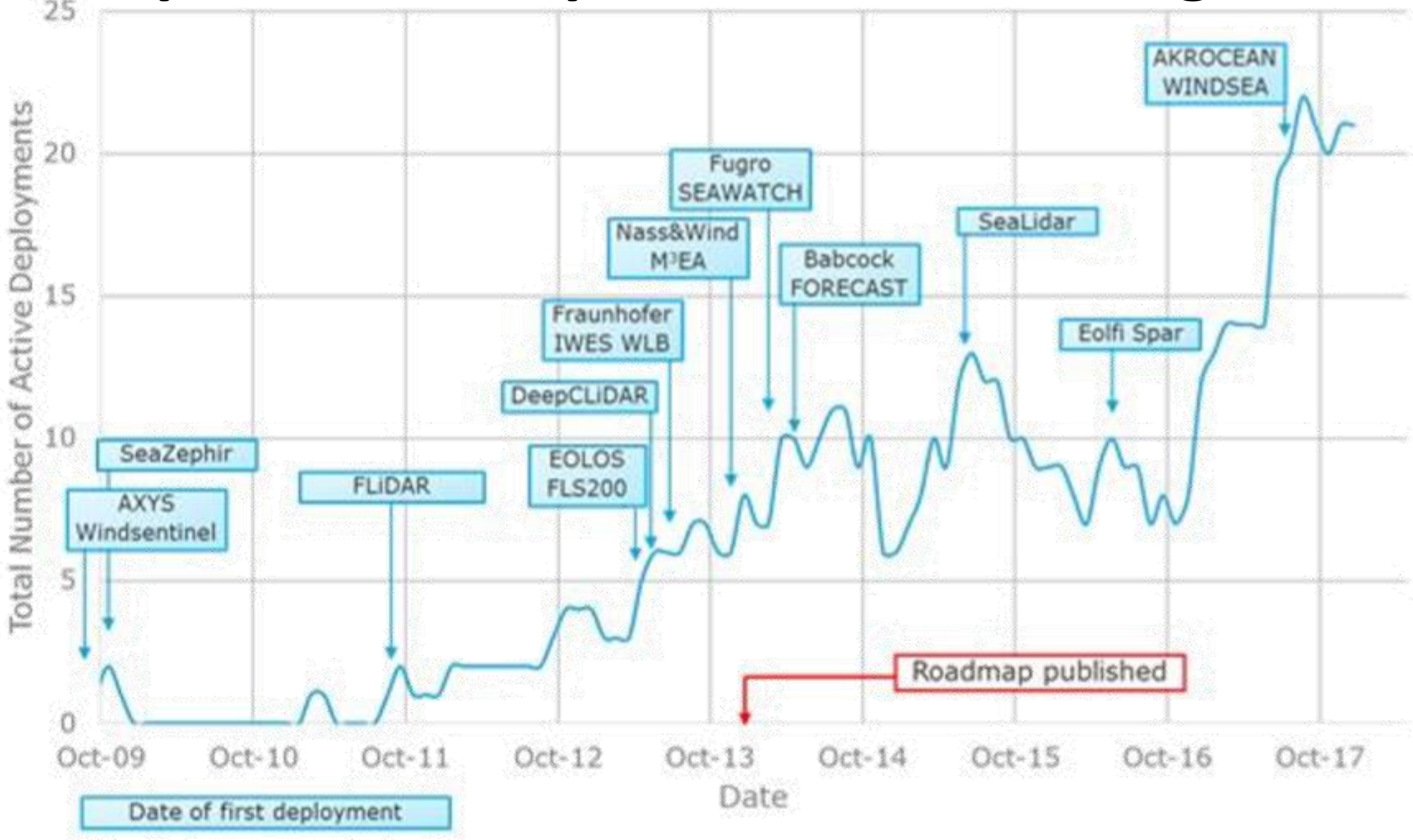


Source: 4COffshore



Source: 4COffshore

Industry Adoption and Experience of Floating Lidar



Source: Carbon Trust OWA “Deployments of Floating LiDAR Systems” (2018)

Industry Adoption and Experience of Floating Lidar

System Name	First Deployment	LiDAR Used	Independently Reported Maturity Stage
AXYS FLiDAR WindSentinel	2009	ZephIR 300, Windcube v2	Stage 2
SeaZephir	2009	ZephIR 300	
AXYS FLiDAR 4M (FLiDAR)	2011	ZephIR 300, Windcube v2	Stage 2
EOLOS FLS200	2013	ZephIR 300	Stage 2
DeepCLiDAR	2013	Windcube v2	Stage 2[1]
Fraunhofer IWES Wind LiDAR Buoy	2013	Windcube v2, ZephIR 300	Stage 2
Nass&Wind M3EA	2014	Windcube v2	
Fugro Oceanor SEAWATCH	2014	ZephIR 300	Stage 2
Babcock FORECAST	2014	ZephIR 300	Stage 2
SeaLIDAR	2015	ZephIR 300	
Eolfi Spar	2016	Diabrezza (Mitsubishi Electric) or other	
AKROCEAN WINDSEA	2017	Windcube v2, Zephir 300	
DEWI with Leosphere	2017	Windcube v2	

Source: Carbon Trust OWA "Deployments of Floating LiDAR Systems" (2018)

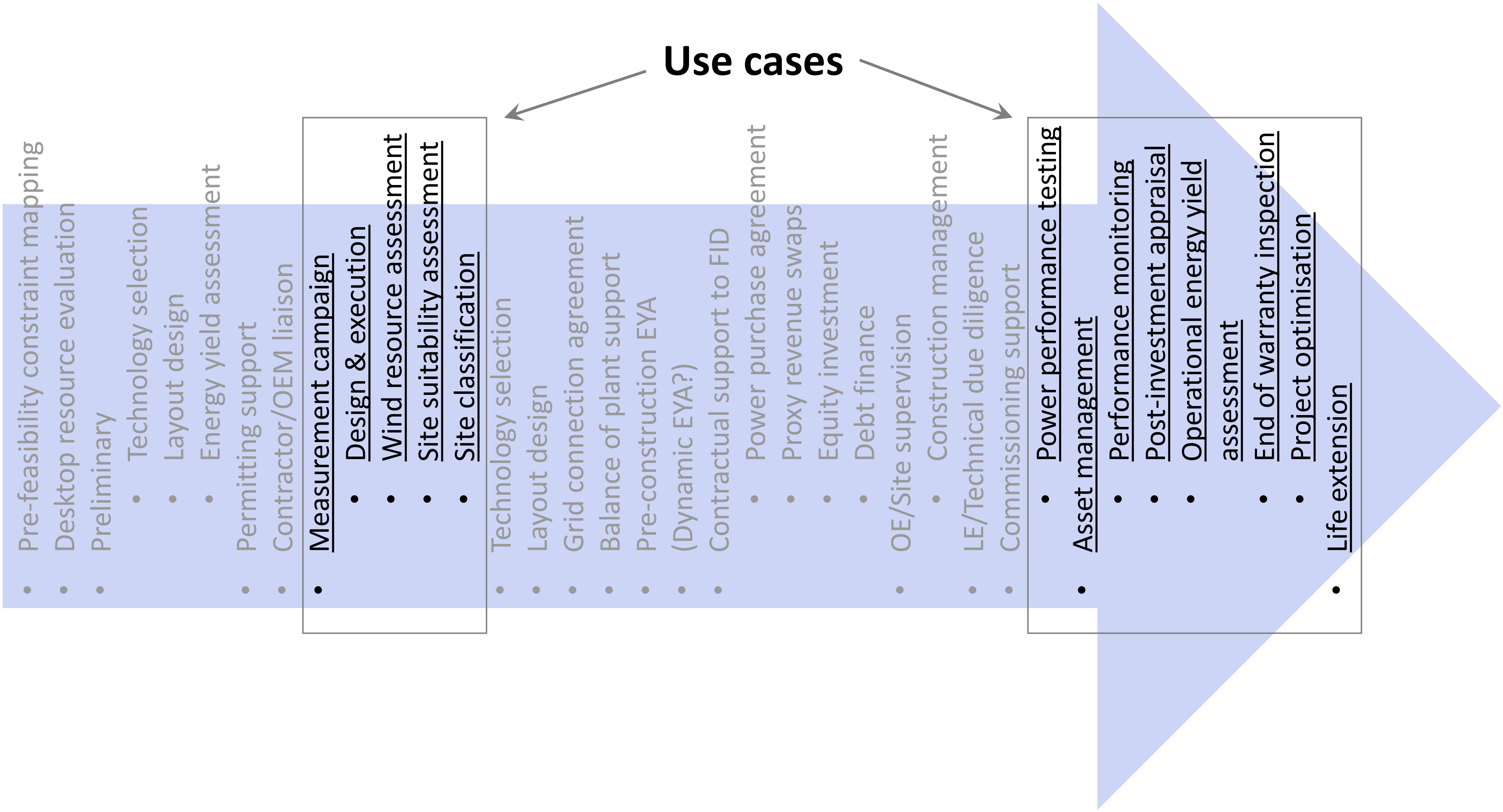
Industry Adoption and Experience of Floating Lidar

Source: Carbon Trust OWA "Deployments of Floating LiDAR Systems" (2018)

Use cases

- Pre-feasibility constraint mapping
- Desktop resource evaluation
- Preliminary
  - Technology selection
  - Layout design
  - Energy yield assessment
- Permitting support
- Contractor/OEM liaison
- Measurement campaign
  - Design & execution
  - Wind resource assessment
  - Site suitability assessment
  - Site classification
- Technology selection
- Layout design
- Grid connection agreement
- Balance of plant support
- Pre-construction EYA
- (Dynamic EYA?)
- Contractual support to FID
  - Power purchase agreement
  - Proxy revenue swaps
  - Equity investment
  - Debt finance
- OE/Site supervision
  - Construction management
- LE/Technical due diligence
- Commissioning support
  - Power performance testing
- Asset management
  - Performance monitoring
  - Post-investment appraisal
  - Operational energy yield assessment
  - End of warranty inspection
  - Project optimisation
- Life extension

Use cases



Use cases
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Preliminary
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Layout design
Energy yield assessment
Permitting support
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- Life extension

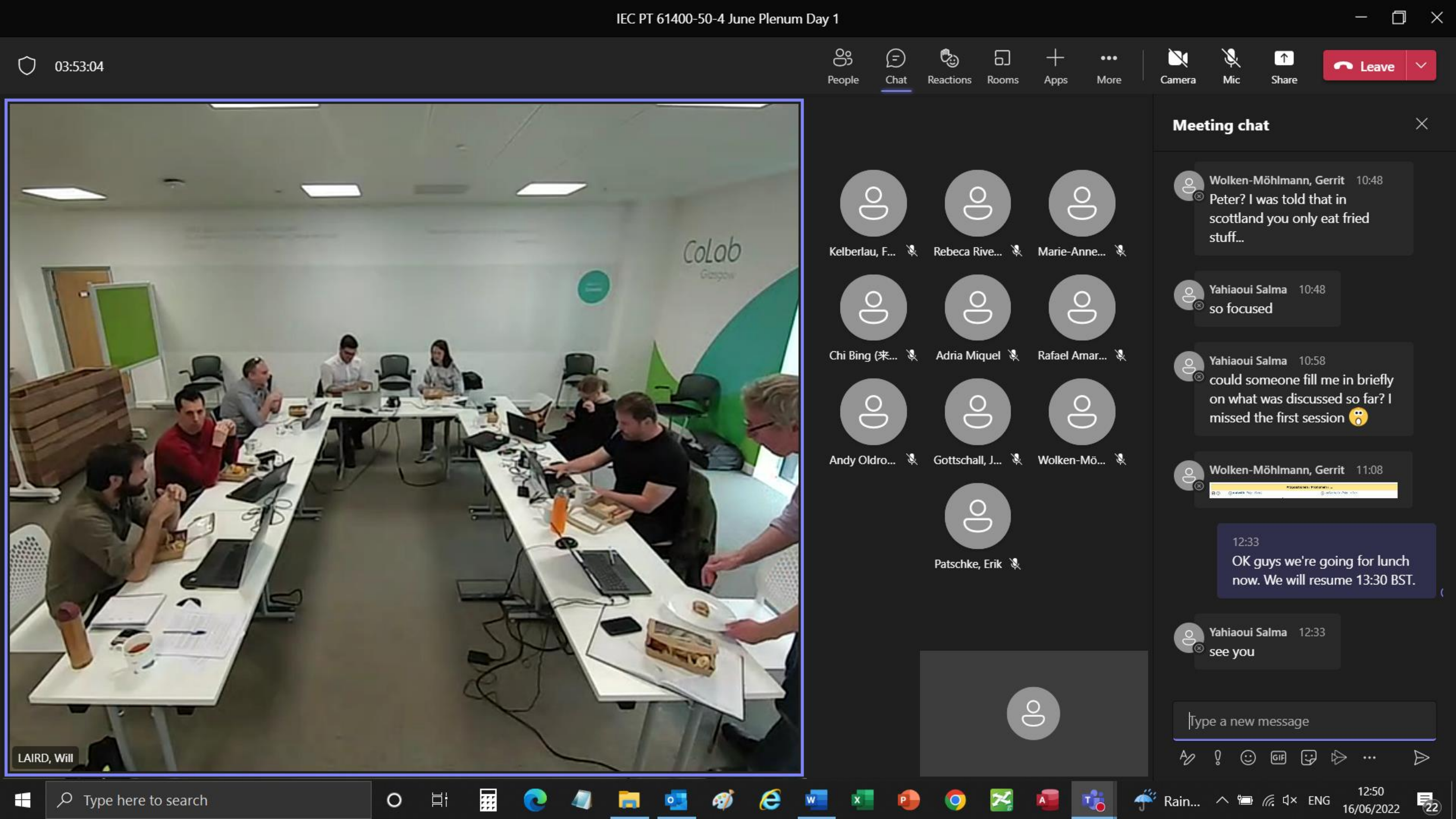
IEC TS 61400-50-4 considers pre-construction resource assessment as the paradigmatic use case being supported

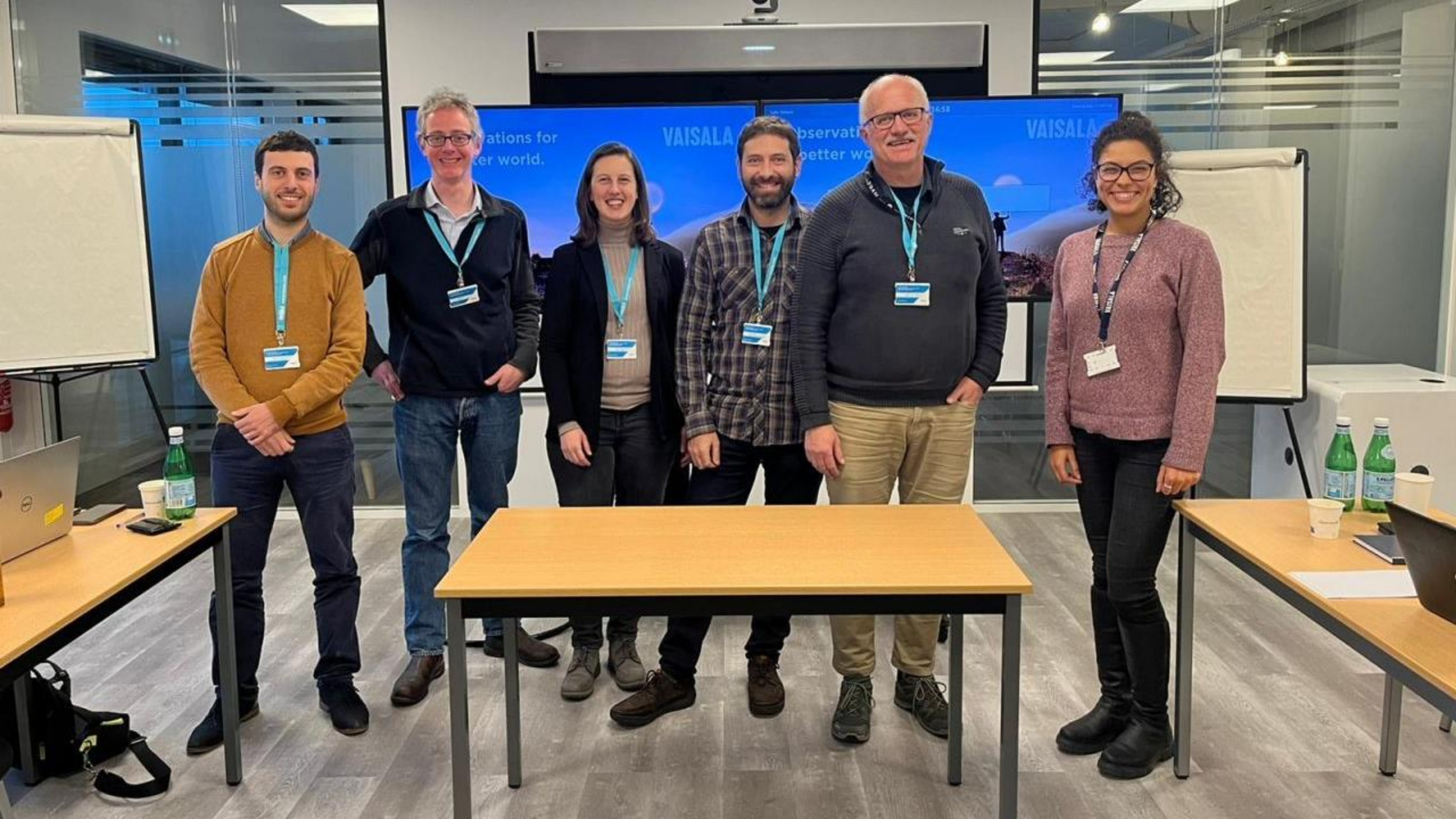
Existing standards and guidance

- IEC guidance for measurements historically has been part of IEC 61400-12-1, 2nd edition (2017). This guidance is now disaggregated into:
  - Use cases (e.g. power curve tests IEC 61400-12-1, load assessment IEC 61400-13, wind resource assessment & site suitability assessment IEC 61400-15, etc.)
  - Measurement methods (the IEC 61400-50 series)
- Pre-normative guidance for FLS includes
  - IEA Wind Recommended Practices 18. (RP18) Floating Lidar Systems, 1st edition (2017)
  - OWA Lidar Uncertainty Standard Review (LUSR) (2018)
  - OWA Roadmap for the Commercial Acceptance of Floating Lidar Technology, 2nd edition (Roadmap2) (2018)

“In the course of developing this recommended practice document the authors are aware that this is a ‘stepping stone’ on the way to a normative standard”

(IEA Wind RP 18 Floating Lidar Systems,
Section 9. Recommendations for Further Work)


IEC PT 61400-50-4 June Plenum Day 1
03:53:04
People
Chat
Reactions
Rooms
Apps
More
Camera
Mic
Share
Leave
CoLab
LAIRD, Will
Kelberlau, F...
Rebeca Rive...
Marie-Anne...
Chi Bing (来...
Adria Miquel
Rafael Amar...
Andy Oldro...
Gottschall, J...
Wolken-Mö...
Patschke, Erik
Meeting chat
Wolken-Möhlmann, Gerrit 10:48
Peter? I was told that in scottland you only eat fried stuff...
Yahiaoui Salma 10:48
so focused
Yahiaoui Salma 10:58
could someone fill me in briefly on what was discussed so far? I missed the first session
Wolken-Möhlmann, Gerrit 11:08
12:33
OK guys we're going for lunch now. We will resume 13:30 BST.
Yahiaoui Salma 12:33
see you
Type a new message
Type here to search
Rain...
ENG
12:50
16/06/2022

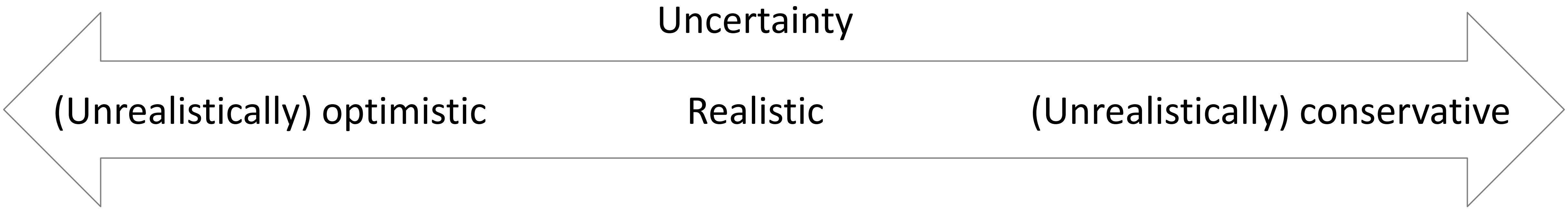

VAISALA
VAISALA

Outline of IEC TS 61400-50-4

- Clause 6: system requirements
- Clause 7: calibration
- Clause 8: classification
- Clause 9: uncertainty
- Clause 10: measurement procedure
- Clause 11: reporting

- Annex A: the instrument qualification cycle
- Annex B: turbulence intensity
- Annex C: specific measurement campaign
- Annex D: hierarchy of uncertainties

Challenges



Realism

- Comparison between instruments reflect genuine differences in performance with respect to accuracy, rather than non-physical artefacts of our procedures
- Needed to establish trusted references: this is important with RSDs and FLSs in particular as we need to compare between different technologies when classifying and calibrating
- Realism also supports incentivisation of growth of database / evidence base

Challenges

- **50-2:** vertically profiling ground based RSDs – accuracy tests based on
  - "Black box" scrutiny of final variables
- **50-3:** nacelle mounted lidars – accuracy tests based on
  - "White box" scrutiny of intermediate variables, plus
  - An evidence base that supports confidence in the performance of the WFR algorithm (given the challenges associated with routinely testing the final variables).
  - Guidance is restricted to cases where the evidence base indicates no significant influence of environmental variables on the performance of the WFR algorithm (zero classification)

Challenges

- **50-4:** floating lidar systems (FLS)
  - Accuracy tests based on
    - "Black box" observations of final variables (like 50-2), plus
    - An evidence base that supports confidence in the WFR (like 50-3).
    - Also, we cannot limit ourselves to cases where we have an evidence base indicating satisfactory performance, as *many deployments will take place outwith the EOC associated with the available evidence base*.
    - This incentivises growing the evidence base and sharing information to increase the EOC and thus reduce classification uncertainties that would otherwise accrue due to operation outwith the EOC

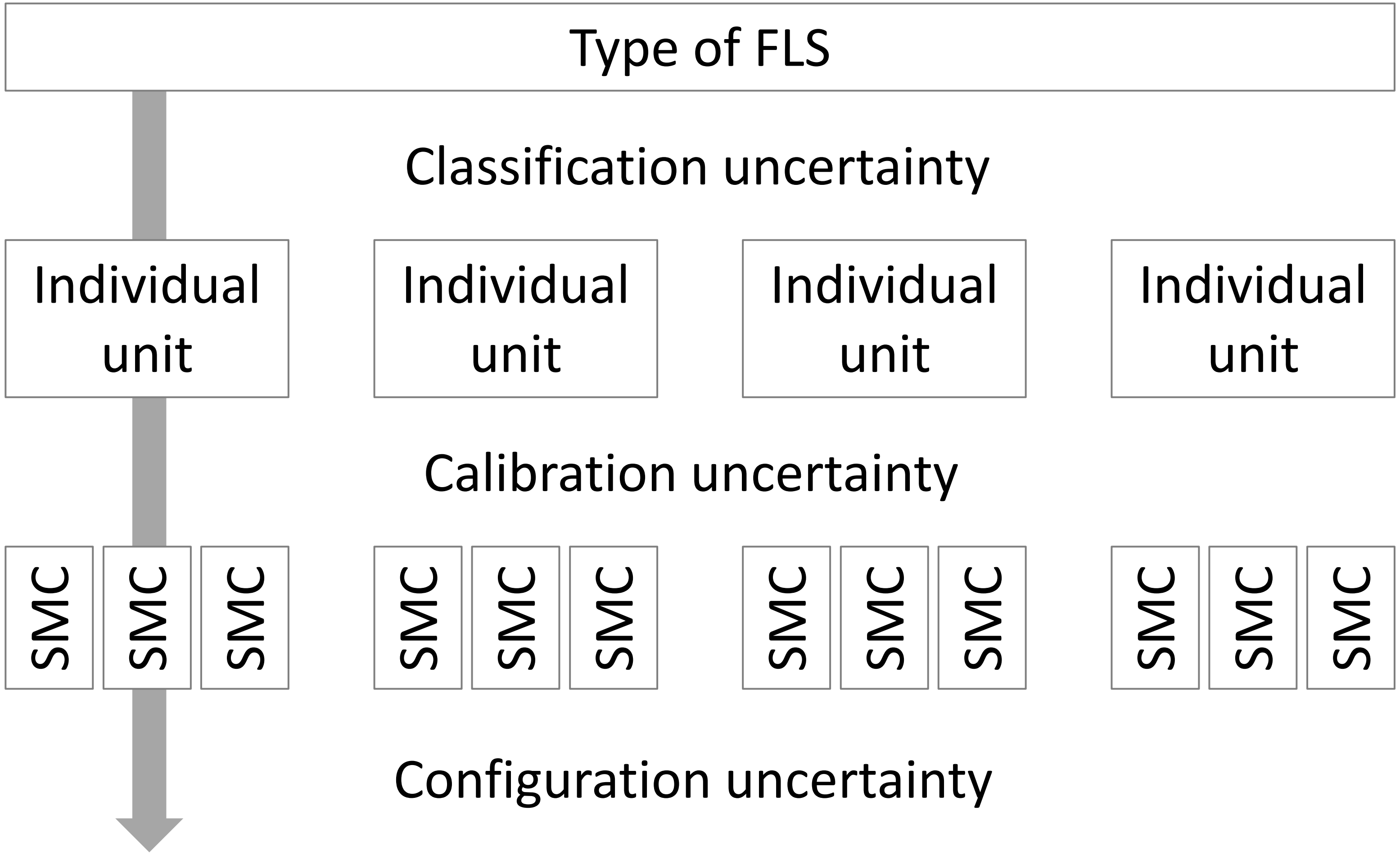
Challenges

- Develop an approach to instrument classification that
  - Supports confidence in the same way as stages of commercial acceptance
  - Is compatible with uncertainty evaluation methodologies in other standards
- Discrete acceptance stages are replaced by evidence based EOCs
  - Classification uncertainty is zero within the EOC, and depends on sensitivities to environmental variables outwith it
  - This provides a robust systematic approach based on measurements and observation that supports *realistic* rather than *conservative* evaluations of uncertainty
  - *Growing the evidence base increases the range of EOCs in which we can justify the application of lower uncertainties*

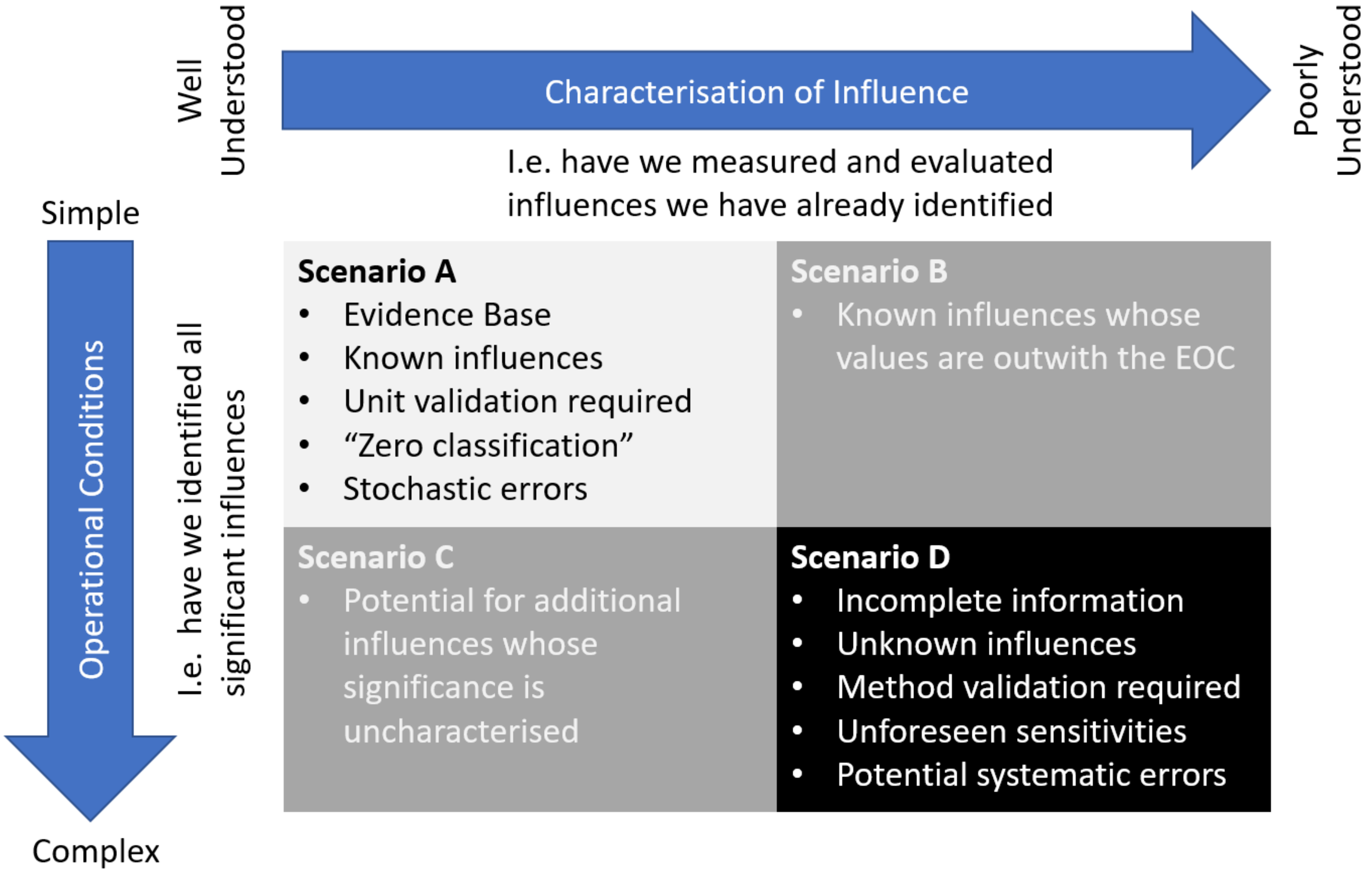
Hierarchy of uncertainties

- No uncertainty budget can be complete: you cannot assign a likelihood to an unforeseen influence on accuracy
- The budget should be “as complete as reasonably achievable” (ACARA): if an unforeseen influence is observed, it should not have been reasonably foreseeable
- Therefore, a systematic approach to identifying contributions to uncertainty is required to accommodate what is reasonably foreseeable

Hierarchy of uncertainties

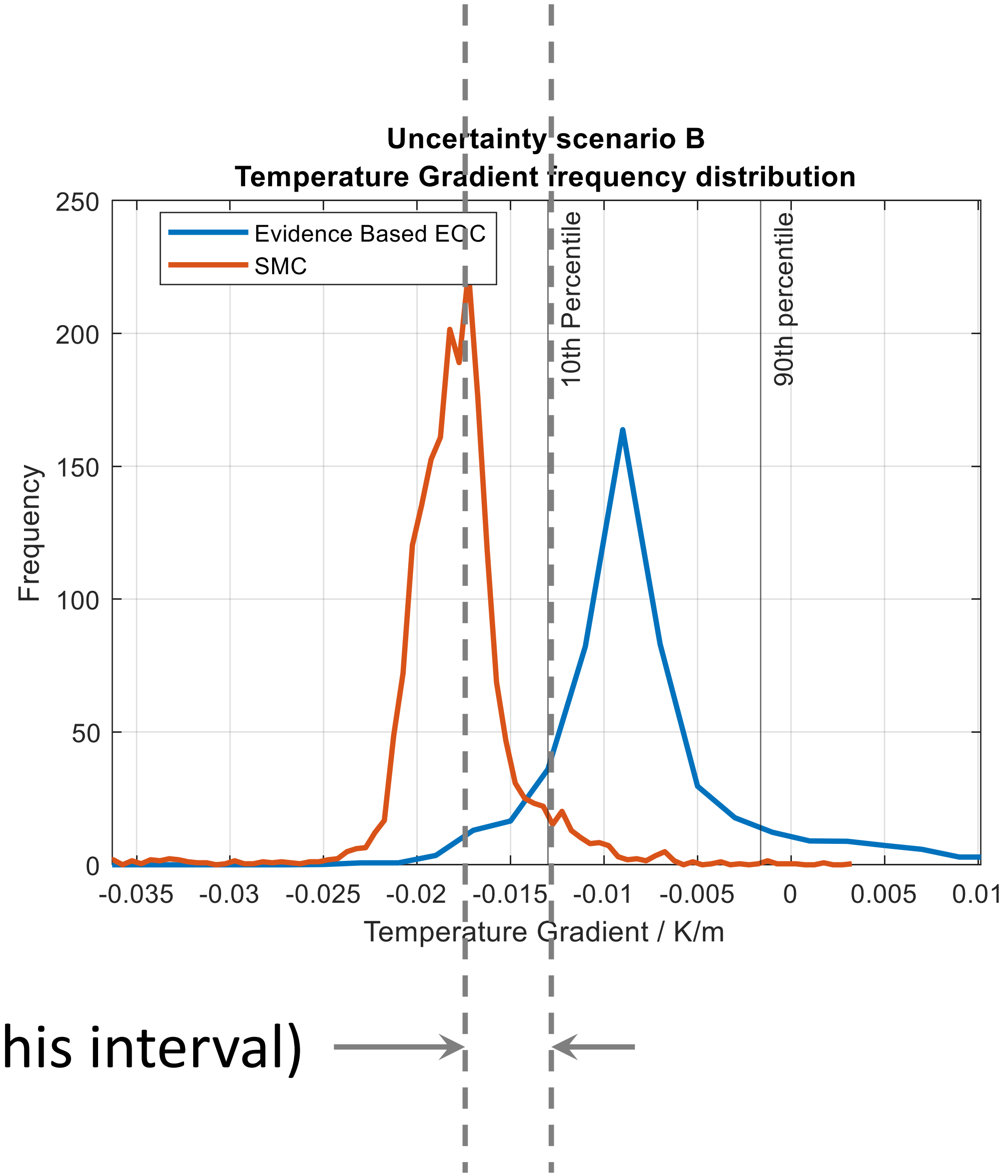


Uncertainty for an SMC = Classification + Calibration + Configuration


Well Understood
Characterisation of Influence
Poorly Understood
I.e. have we measured and evaluated influences we have already identified
Simple
Operational Conditions
Complex
I.e. have we identified all significant influences
Scenario A
Evidence Base
Known influences
Unit validation required
"Zero classification"
Stochastic errors
Scenario B
Known influences whose values are outwith the EOC
Scenario C
Potential for additional influences whose significance is uncharacterised
Scenario D
Incomplete information
Unknown influences
Method validation required
Unforeseen sensitivities
Potential systematic errors

Classification

- Develop evidence base from long-term tests to support confidence in satisfactory performance within the envelope of operational condition (EOC) represented by the evidence base
- Zero classification uncertainty applies within this EOC (Scenario A, c.f. IEC 61400-50-3)
- Outwith this range classification uncertainty due to each EV is calculated from the sensitivity of accuracy to that EV in the same way as in IEC 61400-50-2 (Scenario B)



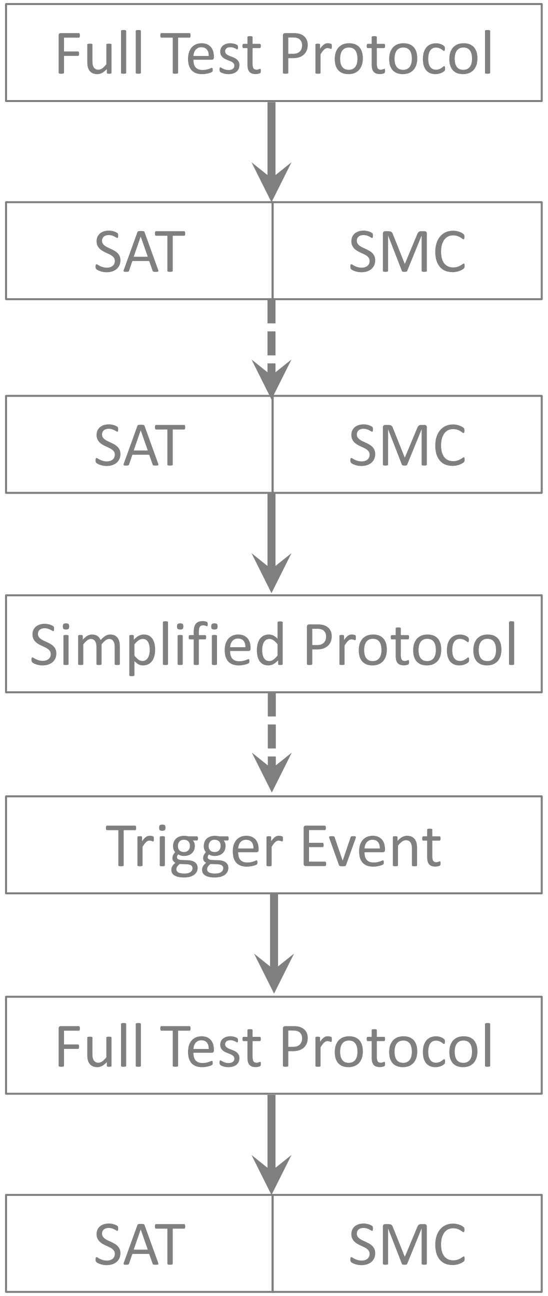
(Sensitivity applied to this interval)

Evidence base

- Long-term test
  - At least 3 months continuous measurement
  - At least 8640 data points
  - 80 data points in each 1 m/s bin from 4 m/s to 12 m/s
  - 80 data points in each 2 m/s bin from 12 m/s to 16 m/s
- Evidence base:
  - At least 3 long-term tests, at least 2 of which are in open sea conditions
  - 3 PV tests may be combined to be equivalent to 1 long-term test
- Environmental variables include (but are not limited to):
  - Atmospheric: TPH and density, TI, shear, veer, precipitation, flow inclination
  - Oceanographic: significant wave height and peak period, wave direction and steepness, current and tide
  - FLS related: rotational and translational motions (pitch, roll, yaw)
  - Lidar related: data coverage, SNR / CNR

Calibration

- Comparison with a trusted reference
- Full and simplified protocols available
- Full test required before first SMC
  - 40 data points per 1 m/s bin, 2 m/s to 12 m/s
  - 40 data points per 2 m/s bin, 12 m/s to 16 m/s
- Remains valid if
  - SAT includes quayside spot check
  - Routine (biannual) onshore lidar test
  - Other requirements fulfilled (e.g., Chapter 10)
- Simplified test permitted within EOC
- Full test trigger by material change to FLS, e.g.,
  - Installation of new WFR method
  - Change in motion compensation
  - Any modification or incident that affects performance



Calibration: trusted reference

- "A Trusted Reference System is a fully characterized measurement system such that a defined measurement uncertainty with coverage factor is provided and valid for all measurements for which the comparison is to take place“

- Can be a met mast or an RSD, including an FLS

- Characterised in accordance with the relevant guidance
  - i.e., IEC 61400-50-1, -2, -3, or -4

Calibration: simplified protocol

Data completion criteria

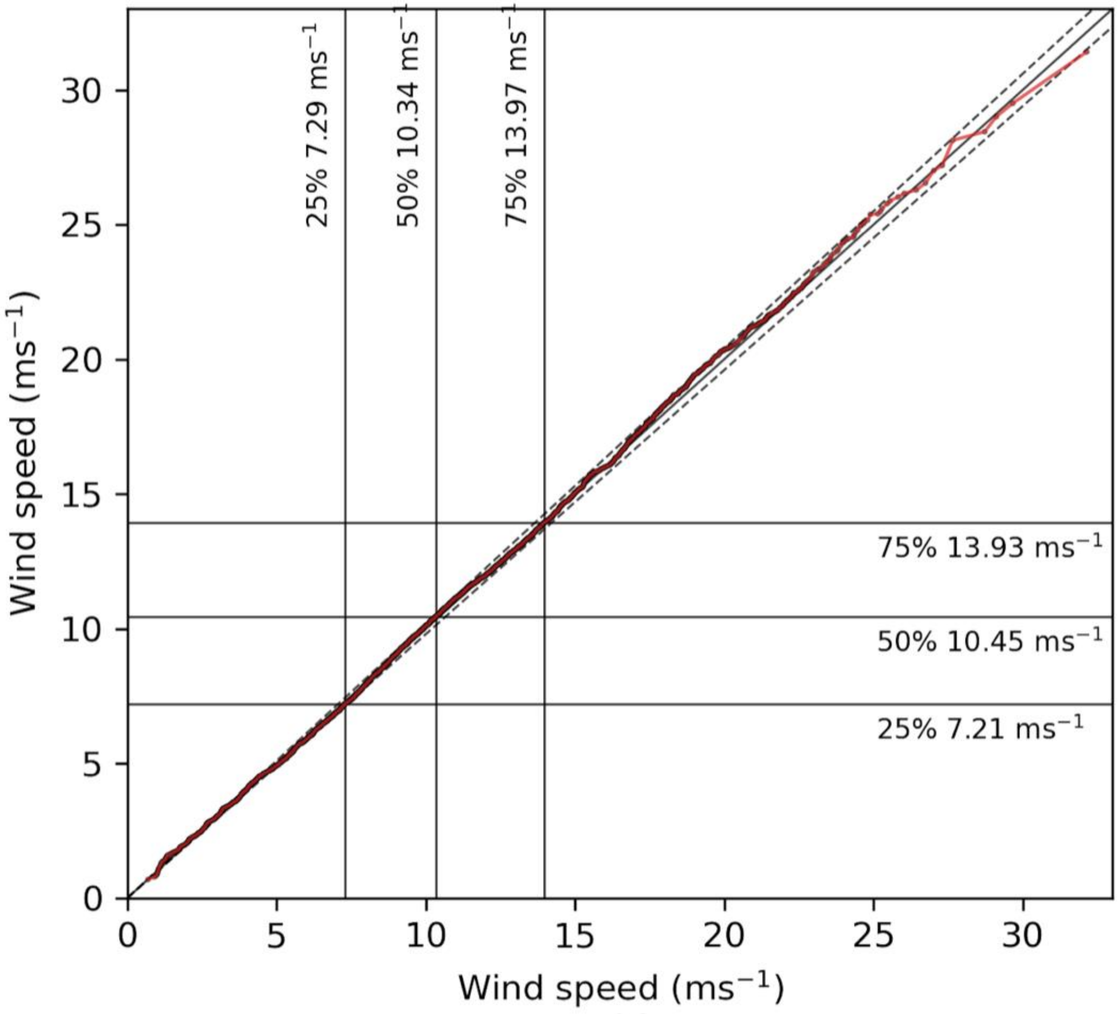
- Minimum duration 14 days
- >1440 data points > 2m/s

Data compared to 1:1 line on a Q-Q plot

Acceptance criteria

- Mean deviation < uncertainty estimated during the most recent full test

If extended until completion criteria of full test fulfilled (and other requirements met) database can be used for a full (re)test



Uncertainty

- Uncertainty follows closely the recommendations of LUSR
  - Preserves the principles of traceability of uncertainty
  - Adopts a simplified calibration uncertainty calculation
  - Identifies overly conservative assumptions
  - Classification uncertainty
    - Determined by sensitivities to and variations in environmental variables (EVs)
      - Scenario B in 50-4
    - Allows for zero classification
      - Scenario A in 50-4, supported by an EOC

Further information

- *In situ* monitoring method based on
  - Monitoring ratios of average values measured by the FLS and provided by remote reference e.g. reanalysis
  - Using Student's t-test to compare pre- and post-populations for each ratio averaging interval to establish equivalence
- *Informative* annex regarding turbulence:
  - Lidars are not considered sufficiently mature as a turbulence instrument
  - FLS less mature than onshore instruments
  - Requires further industry experience
  - Proposal that the CFARS onshore TI benchmarking methodology is adapted and adopted for offshore measurements to advance understanding first

Conclusions

- The objectives of Roadmap2, in terms of defining stages of commercial acceptance, are accommodated in an evidence based classification scheme that
  - Supports confidence in measurements within an EOC
  - Provides a mechanism for reducing uncertainty by growing the evidence base and corresponding EOC
  - Articulates these aims and methods in a way compatible with the broader context of other IEC measurement standards

Conclusions

- IEC TS 61400-50-4 will provide
  - Normative guidance for consistent inter-comparable FLS measurements to support confidence in offshore wind measurements
  - Clear division of responsibilities and reporting requirements in relation to measurement campaign activities, supporting smooth, safe deployment and operation
  - Uncertainty evaluations that accommodate realistic assessments of instrument performance, allowing the elimination of reliance on conservative estimates
  - A basis for reliable offshore wind measurements to support the growing pipeline of projects

Conclusions

- We need more test sites!
  - The reduction in uncertainty achieved by growing the evidence base to be representative of operational conditions in a wider range of sites is a powerful incentive to build test sites in emerging markets
  - The benefits of reducing uncertainty far exceed the cost of the test sites
  - Scanning lidar techniques discussed yesterday provide opportunities for low cost testing … IEC 61400-50-5, -6, etc.? ☺

Discussion.

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Some definitions

- Terms defined at the end of the presentation
    - Use case
    - Specific Measurement Campaign
    - Intermediate and final variables
    - Wind Field Reconstruction (WFR)
    - Envelope of Operational Conditions (EOC)
    - Hierarchy of Uncertainty
        - Type qualification and classification uncertainty
        - Unit qualification and calibration uncertainty
        - Campaign qualification and configuration uncertainty

Some definitions

- **Use case** – the application, comprising
  - **Data requirements:** outcome-driven data requirements
  - **Measurement method:** instrument and technique used
  - **Operational conditions:** circumstances that affect performance
- **Specific Measurement Campaign** – a particular implementation of the use case. An individual deployment of an instrument under a specific set of circumstances in the context of a particular project.

Some definitions

- **Intermediate variables** - directly measured quantities e.g. line of sight wind speed, lidar beam orientation, range gate
- **Final variables** - quantities derived from intermediate variables that satisfy the data requirements of the measurement use case e.g. wind speed, direction
- **Wind field reconstruction (WFR)** - the model or algorithm used to derive final variables from intermediate variables, which entails assumptions about the wind field allows one to establish a relationship between them
- **Envelope of Operational Conditions (EOC)** - the range of values a selection of environmental variables take within an evidence base