16th NEDO-ADEME Seminar

Introduction of NEDO project "Establishment of offshore wind resource assessment method“

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National Institute of Advanced Industrial Science and Technology
ClassNK
E&E Solutions Inc.
Japan Meteorological Corporation
(supported by Japan Wind Energy Consulting Inc.)

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Background and Project objective

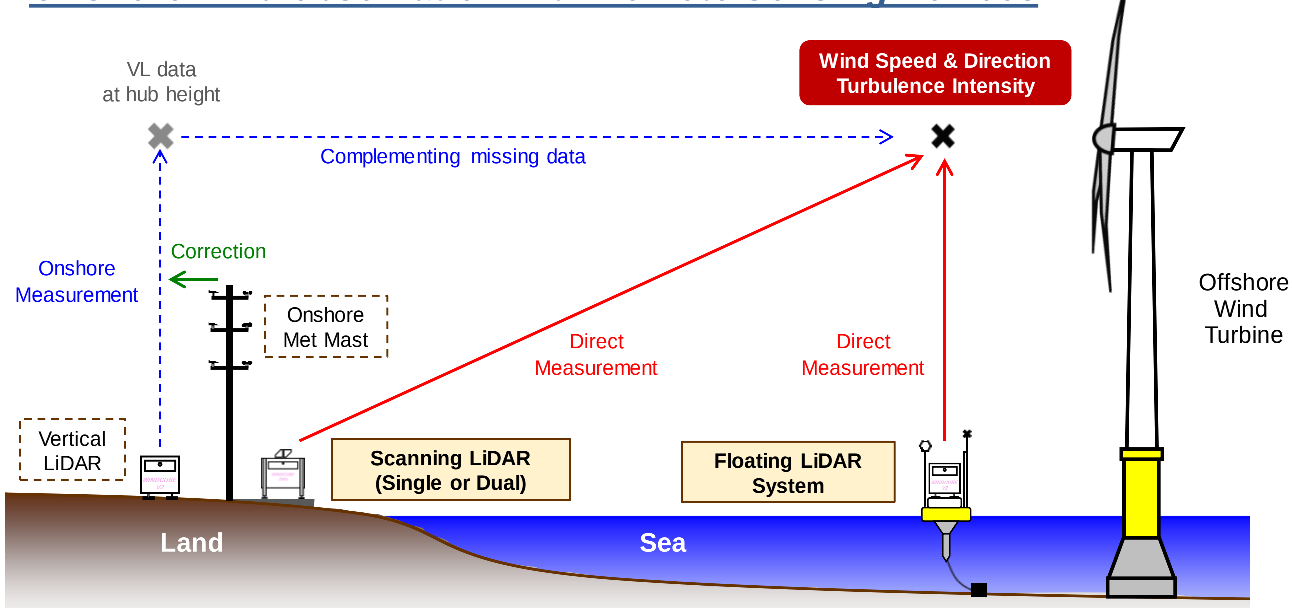
➢ **Background**

Since wind data are necessary in various stages of an offshore wind project, from planning to design, construction, operation and maintenance, it is crucial to obtain accurate wind data. However, installing a met mast offshore —the most ideal method— is not only costly but also impossible for deep waters, alternative methods using remote sensing technologies have been a topic of much discussion these days.

➢ **Project objective**

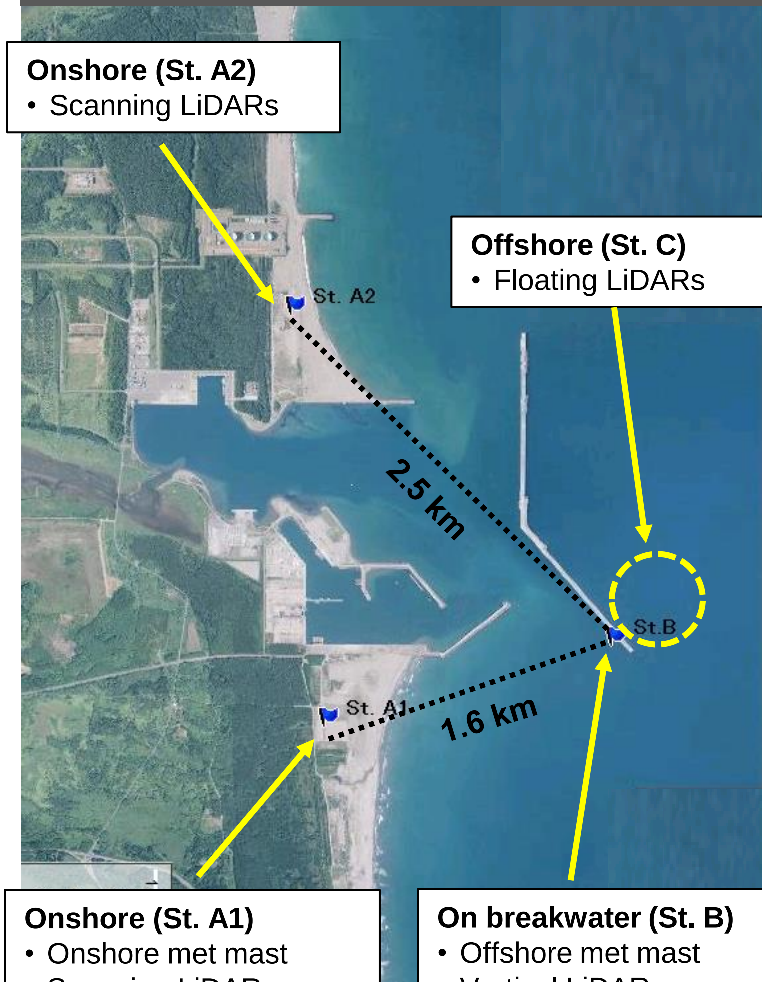
This NEDO project (2019–2022) is developing technology to establish rational methods of observing offshore wind conditions in Japanese sea areas using the remote sensing devices — a scanning LiDAR and floating LiDAR system.

Offshore wind observation with Remote Sensing Devices



In-situ observation site: Mutsu-Ogawara Port

Mutsu-Ogawara Port
Rokkasho Village, Aomori Prefecture



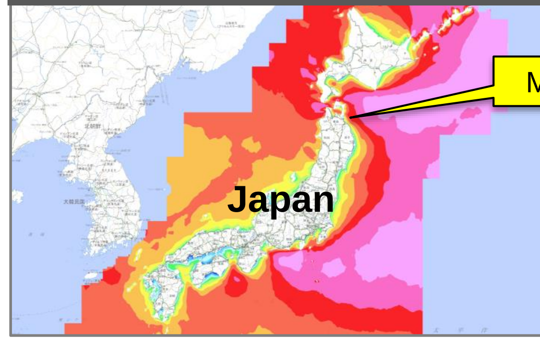
Onshore (St. A2)
- Scanning LiDARs

Offshore (St. C)
- Floating LiDARs

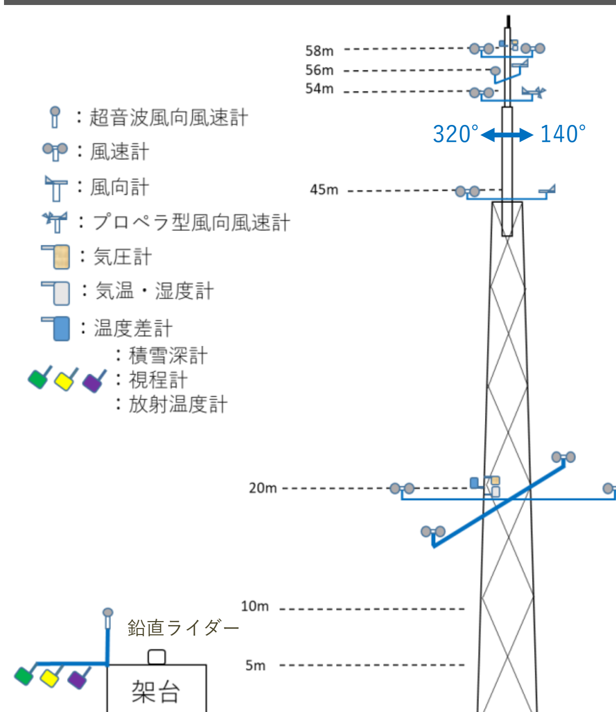
Onshore (St. A1)
- Onshore met mast
- Scanning LiDARs
- Vertical LiDAR
- Various meteorological instruments

On breakwater (St. B)
- Offshore met mast
- Vertical LiDAR
- Various meteorological instruments

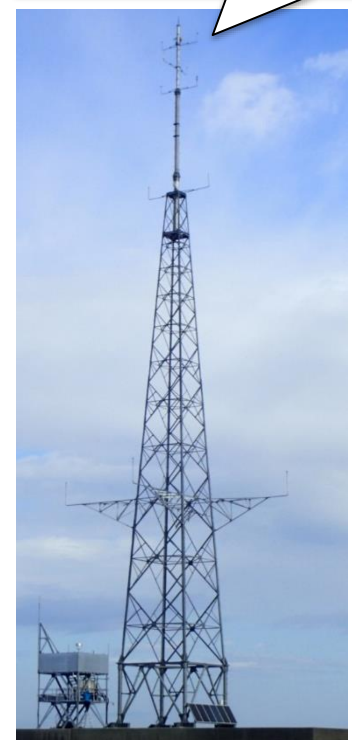
Wind Resource Map (NeoWins)



Met Mast at St.B (63m amsl.)



Verification with:
- Cup anemometer (63m)
- Weather vane (61m)

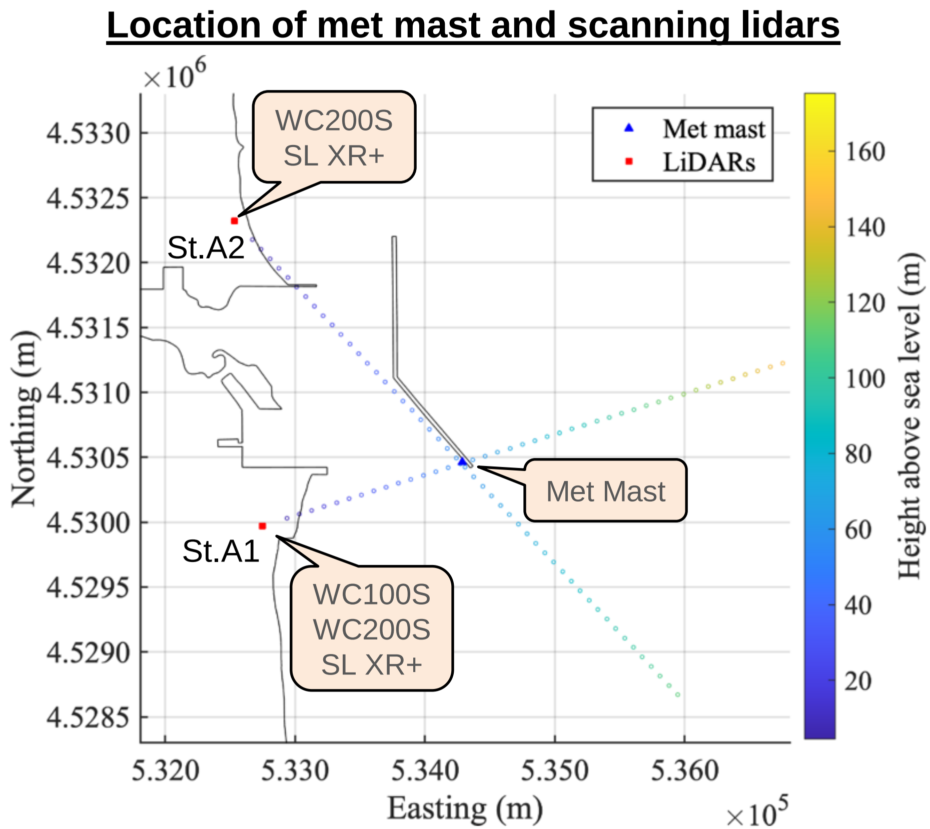


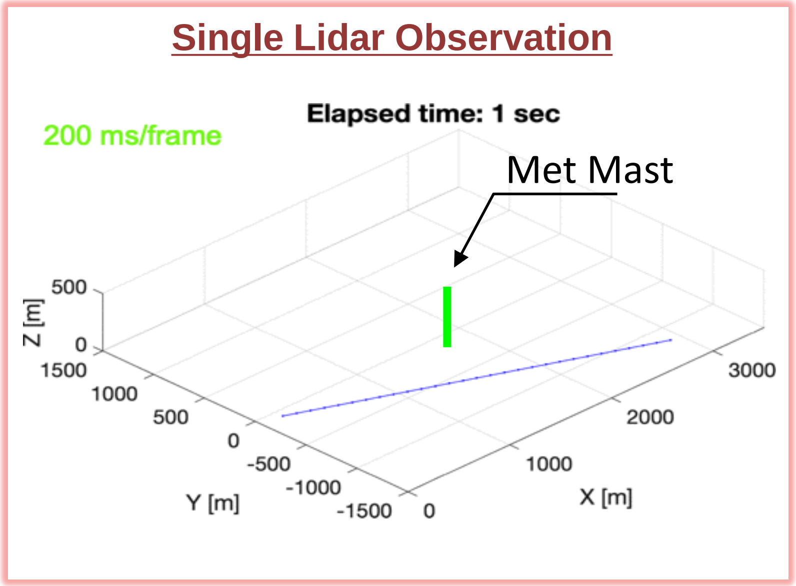
Scanning LiDARs used in the project

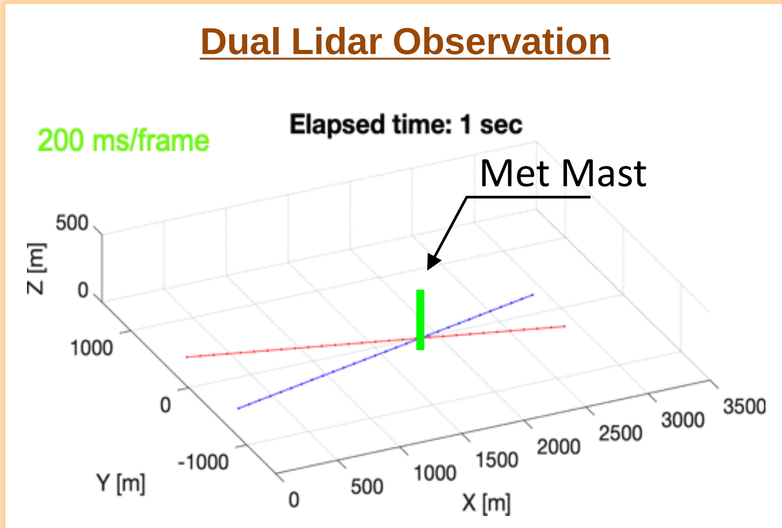
Models of scanning LiDAR

	WindCube 100S / 200S (Leosphere, France)	StreamLine XR+ (HALO Photonics, UK)
Appearance		
# of units	200S × 2 units, 100S × 1 unit	XR+ × 2 units
Light source	Pulse wave, 1.55 μm	Pulse wave, 1.54 μm
Dimensions	0.8×1.0×1.2 m	0.63×0.53×0.9 m
Weight	232 kg	89 kg
Power consumption	500 W – 1,600 W	150 – 570 W
Measurement distance	50 m – 6,000 m	50 m±10 m – 12,000 m
Range resolution	25 m – 100 m	18 m – 120 m
Measurement range	-30 m/s – +30 m/s	-38 m/s – +38 m/s

Measurement conditions of scanning LiDARs







- **Observation period:** Nov. 2020 to Oct. 2021
- **Method:** Single observations (WC100S, SL XR+) and Dual observations (WC200S ×2, SL XR+ ×2)
- **Verification data:** 1 Hz measurements of wind speed (at 63m amsl.) and direction (at 61m) on the met mast

KPI used for accuracy and performance evaluation

- Accuracy and performance of LiDARs is evaluated based on Carbon Trust (2018)'s KPIs.

KPIs for observation accuracy

Parameter	KPI	Definition	Acceptance Criteria	
			Best practice	Minimum
Mean Wind Speed	X_{mws}	Slope (from a single variant regression)	0.98 – 1.02	0.97 – 1.03
	R^2_{mws}	Coefficient of Determination	> 0.98	> 0.97
Mean Wind Direction	M_{mwd}	Slope (from a two-variant regression)	0.97 – 1.03	0.95 – 1.05
	OFF_{mwd}	Offset (from a two-variant regression)	< 5°	< 10°
	R^2_{mwd}	Coefficient of Determination	> 0.97	> 0.95

KPIs for system performance

Parameter	KPI	Definition	Acceptance Criteria	
			Stage 3	Stage 2
System Availability	MSA_{1M}	Monthly System Availability	≧ 95%	≧ 90%
	OSA_{CA}	Overall System Availability	≧ 97%	≧ 95%
Data Availability	$MPDA_{1M}$	Monthly Post-Processed Data Availability	≧ 85%	≧ 80%
	$MPDA_{CA}$	Overall System Availability	≧ 90%	≧ 85%

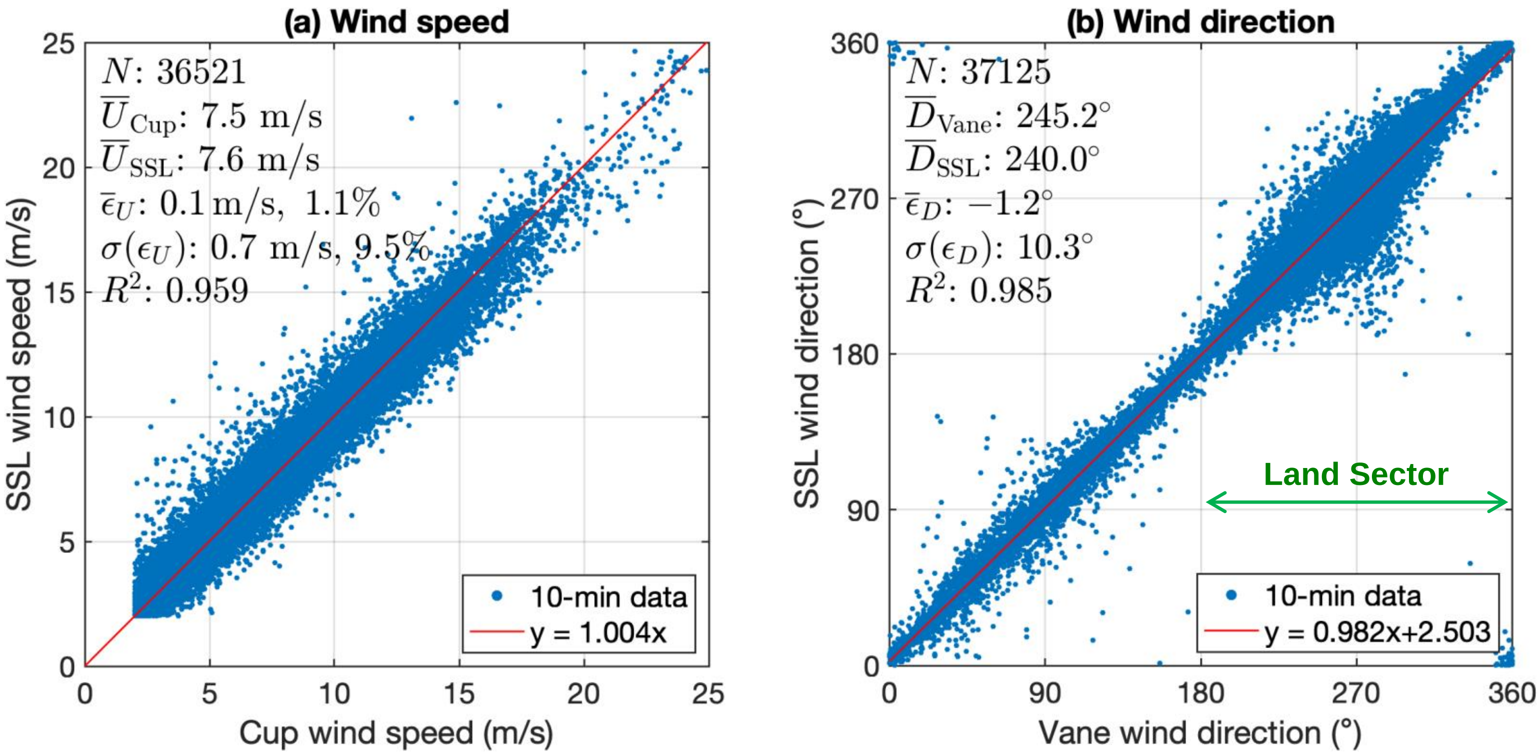
- In addition, accuracy verification is also conducted for turbulence intensity:

$$(Turbulence\ Intensity\colon\ TI) = \frac{(Standard\ deviation\ of\ wind\ speed)}{(10\text{-}minute\ mean\ wind\ speed)}$$

The 90 percentile for each bin of wind speed are evaluated in this project.

Mean wind speed and direction from Single-SL observation

Accuracy of 10-min mean wind speed and direction (WindCube 100S)

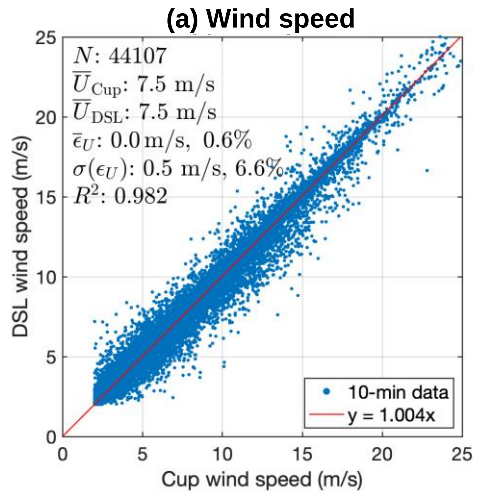


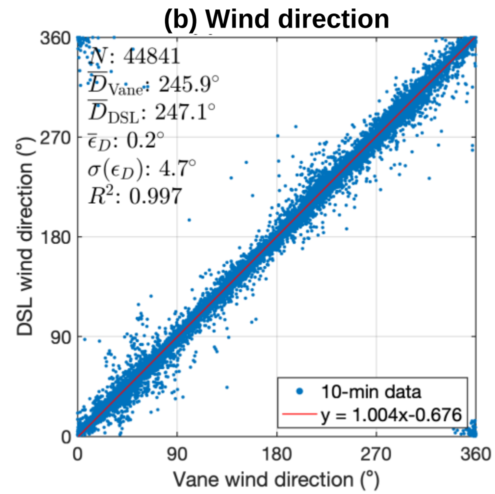
- In the Single-SL observation, the accuracy of mean wind speed is slightly below the Carbon Trust's acceptance criteria of "minimum".
- Mean wind direction meets the criteria of "best practice", though the accuracy tends to be worse for the land-sector winds due to the inhomogeneity of wind field.

Mean wind speed and direction from Dual-SL observation

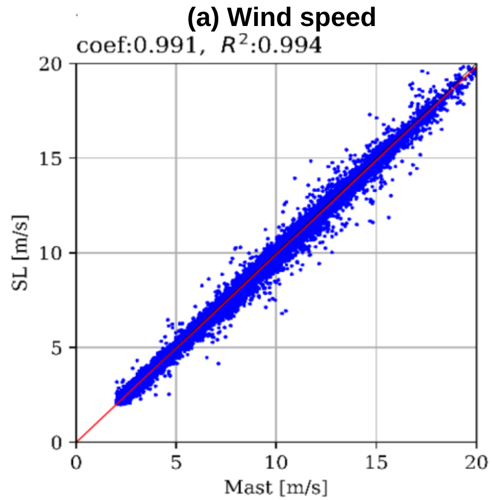
Accuracy of 10-min mean wind speed and direction

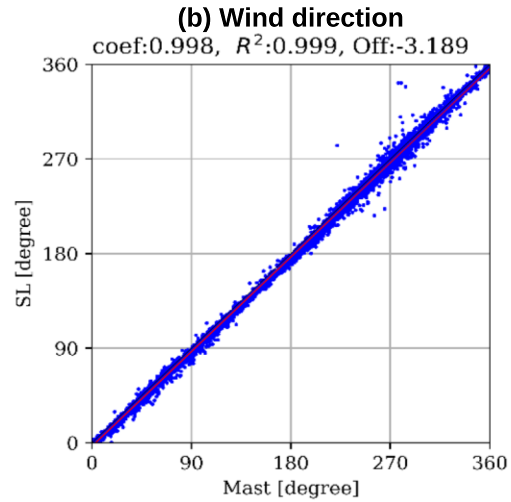
WindCube 200S





StreamLine XR+

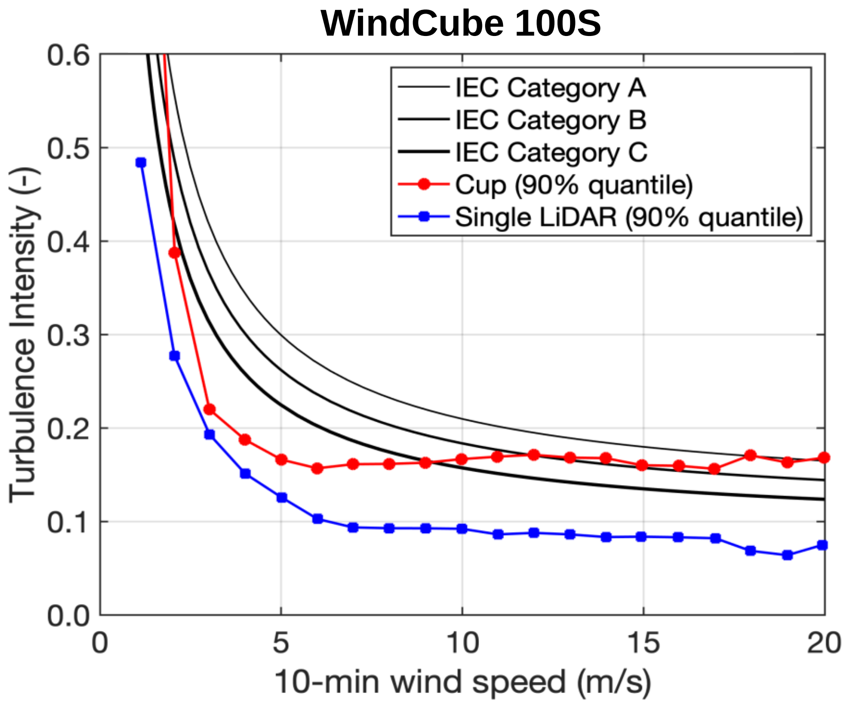




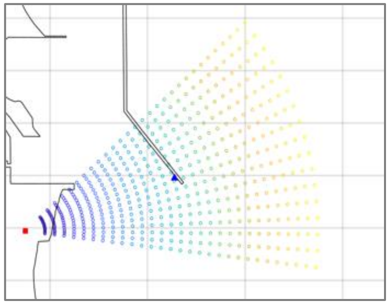
◆ In the Dual-SL observation, both of WindCube 200S and StreamLine XR+ can measure mean wind speed and direction in the criteria of "best practice".

Turbulence intensity from single-SL observation

Turbulence intensity (90percentile): Cup vs. single scanning LiDAR



Scanning area of S-SL

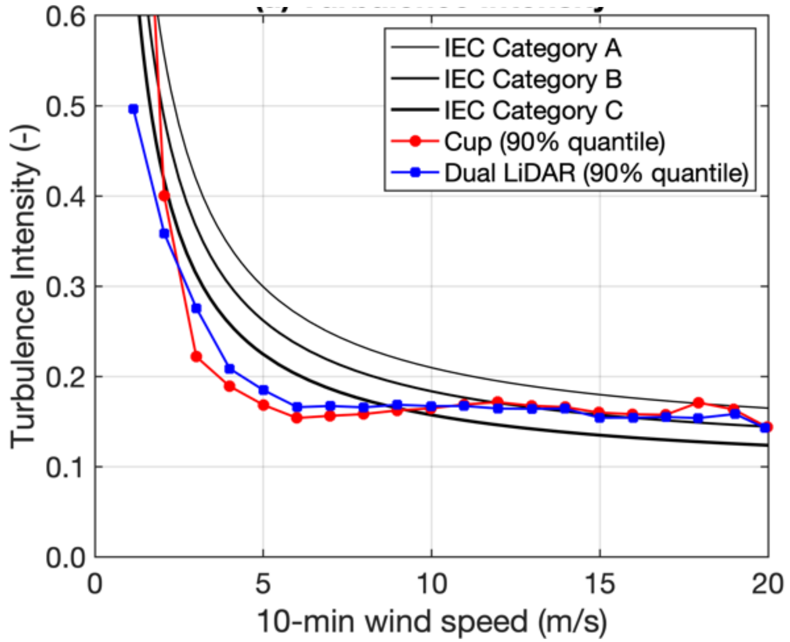


- Single Scanning LiDAR observation greatly underestimates TI, and the tendency becomes remarkable as wind speed increases.
- The overestimation is caused by the underestimation of the standard deviation due to the assumption of the homogeneity of wind filed within the scanning area.

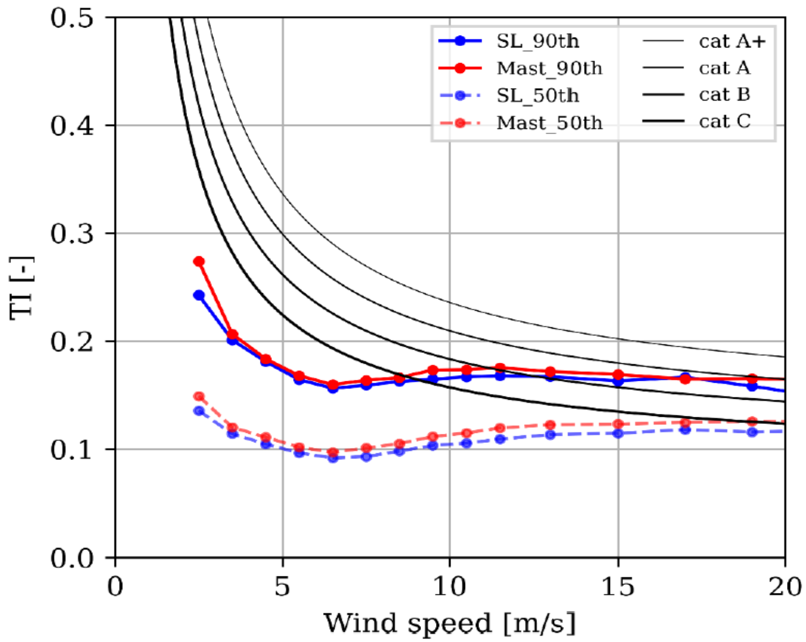
Turbulence intensity from dual-SL observation

Turbulence intensity (90percentile): Cup vs. Dual scanning LiDARs

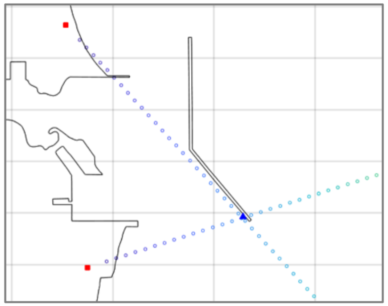
a) WindCube 200S **(Nov. 2020–Oct. 2021)**



b) StreamLine XR+ **(Nov. 2020–Jul. 2021)**



Lines-of-sight of D-SL



- TI from the dual WindCube 200S observation matches well with the cup TI, though it tends to be slightly overestimated in the range below 10 m/s.
- TI from the dual StreamLine XR+ observation is also in good agreement with the cup TI.

Floating LiDAR systems used in the project

Three Floating LiDAR Systems (FLSs)

	SEAWATCH (Fugro, Netherlands)	WindSentinel (AXYS, Canada)	MIA (5 companies in Nagasaki Pref., Japan)
Appearance			
Type	Round	Boat	Spar
Dimensions	Height: 7.2 m Diameter: ⌀2.8 m	Height: 9 m Length: 6 m Width: 3.1 m	Height: 26 m Diameter: ⌀1.0 m (AWL) / ⌀2.15 m (BWL) Width of platform: 5.5 m (max)
Weight	Approx. 2.2 tons	Approx. 9 tons	Approx. 46 tons （Floater: 44 tons＋Platform: 2 tons）
Draft	Approx. 3 m	Approx. 2 m	Approx. 14.5 m
Materials	Polyethylene, Aluminum and Steel	Aluminum and Steel	Steel and Concrete
Mooring method	1-point catenary with mid float	1-point catenary	3-point catenary
Swing radius	Approx. 100 m	Approx. 120 m	Approx. 20 m
Doppler LiDAR(s)	ZX300M (ZX LiDARs) →FZX	ZX300M (ZX LiDARs) →AZX WINDCUBE V2.0 (Leosphere) →AWC	DIABREZZA (Mitsubishi Electric) →MDB
Met parameters	Wind speed & direction, Temperature, and Humidity	Wind speed & direction, Temperature, Humidity, Pressure, Precipitation, and Irradiance	Wind speed & direction, Temperature, Humidity, and Irradiance
Ocean parameters	Water temperature, Wave height & period & direction, Current speed & direction	Water temperature, Wave height & period & direction, Current speed & direction	Water temperature
Power supply	Fuel cell, Solar cell	Diesel generator, Micro wind turbine, Solar cell	Fuel cell, Solar cell

Measurement conditions of floating LiDAR systems

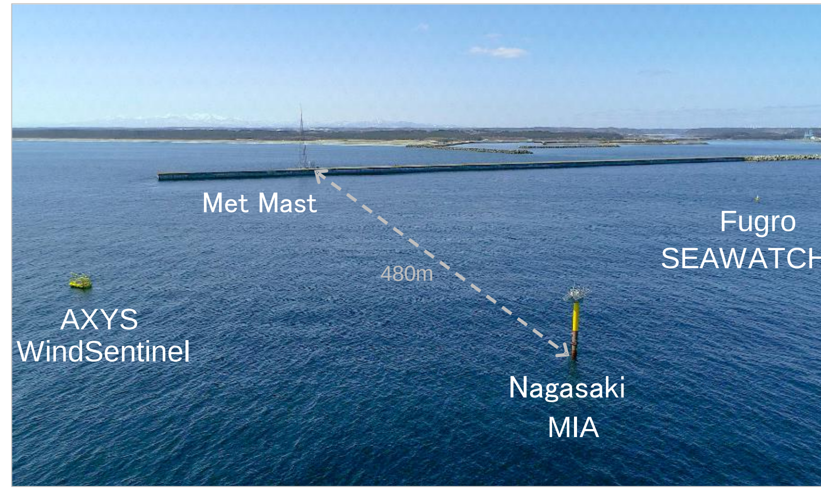
- **Observation period:** Nov. 2020 to Nov. 2021
- **Floating LiDAR systems:** 4 units

  Fugro-ZX, AXYS-ZX, AXYS-WC, and MIA-DB
- **Verification data:**

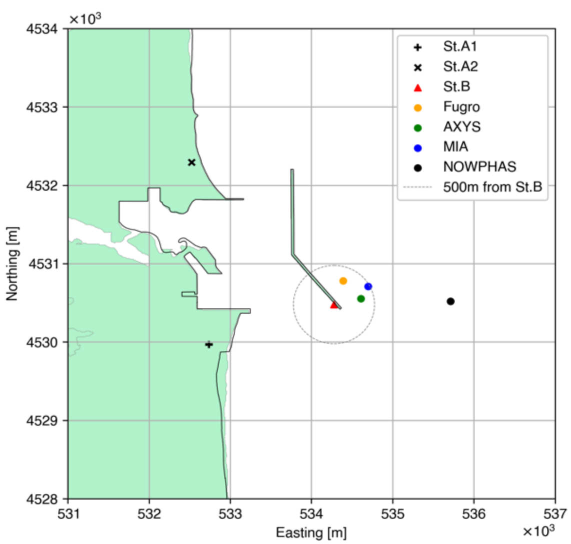
  ① Met mast: 1 Hz measurements of wind speed (at 63m amsl.) and direction (at 61m)

  ② Vertical LiDAR: 1 Hz measurements of wind speed and direction at heights from 40 to 250m (mainly, 63m, 120m, 180m)
- **Target:** Winds from the sea sector (0 - 180°)

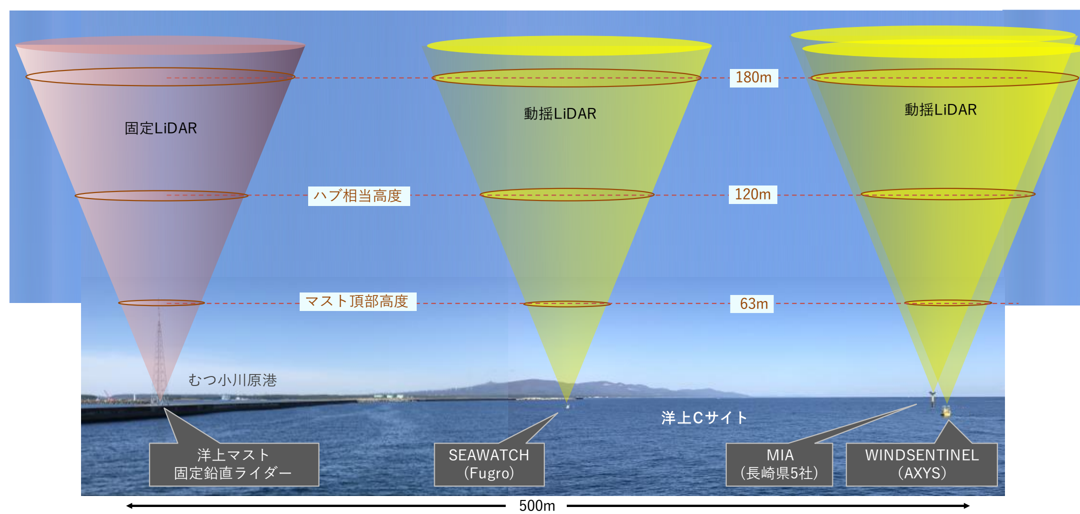
Installation situation of three FLSs



Location of Floating LiDAR systems



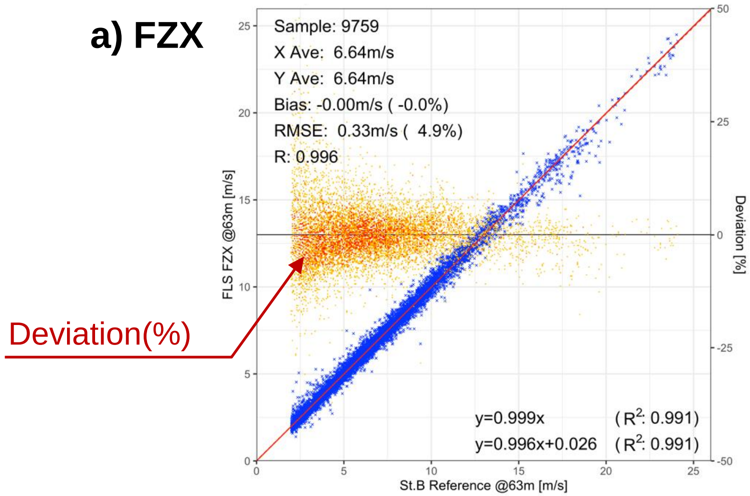
LiDAR observation heights



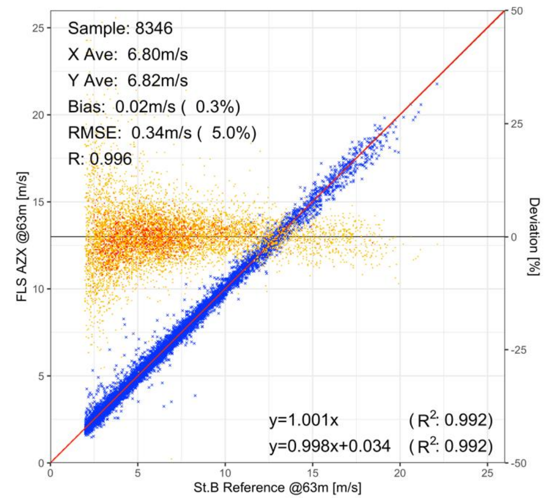
Mean wind speed from floating LiDAR systems

Accuracy of 10-min mean wind speed (> 2m/s, only sea sector)

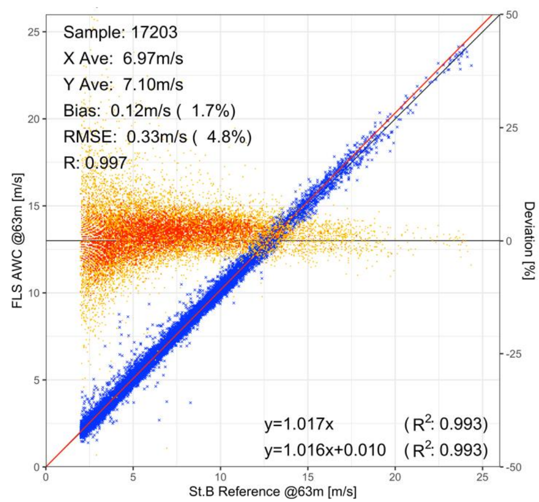
a) FZX



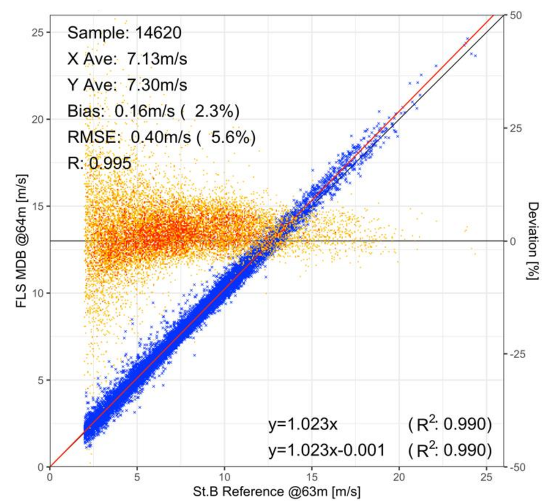
b) AZX



c) AWC



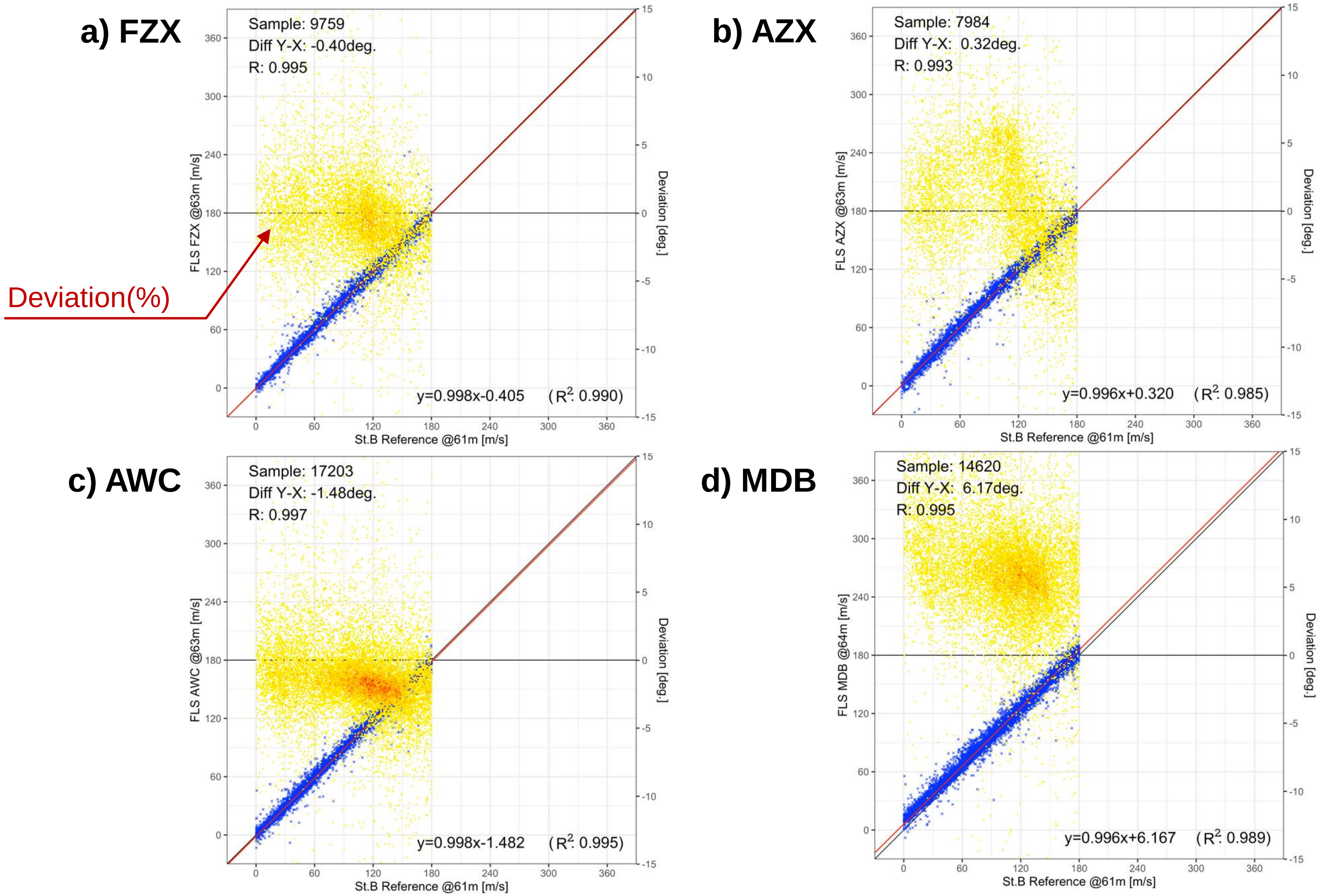
d) MDB



◆ All of the LiDARs can measure mean wind speed in the criteria of “best practice”, except the slope X_{mws} of MDB (meeting “minimum”), which could be due to the distance to mast.

Mean wind direction from floating LiDAR systems

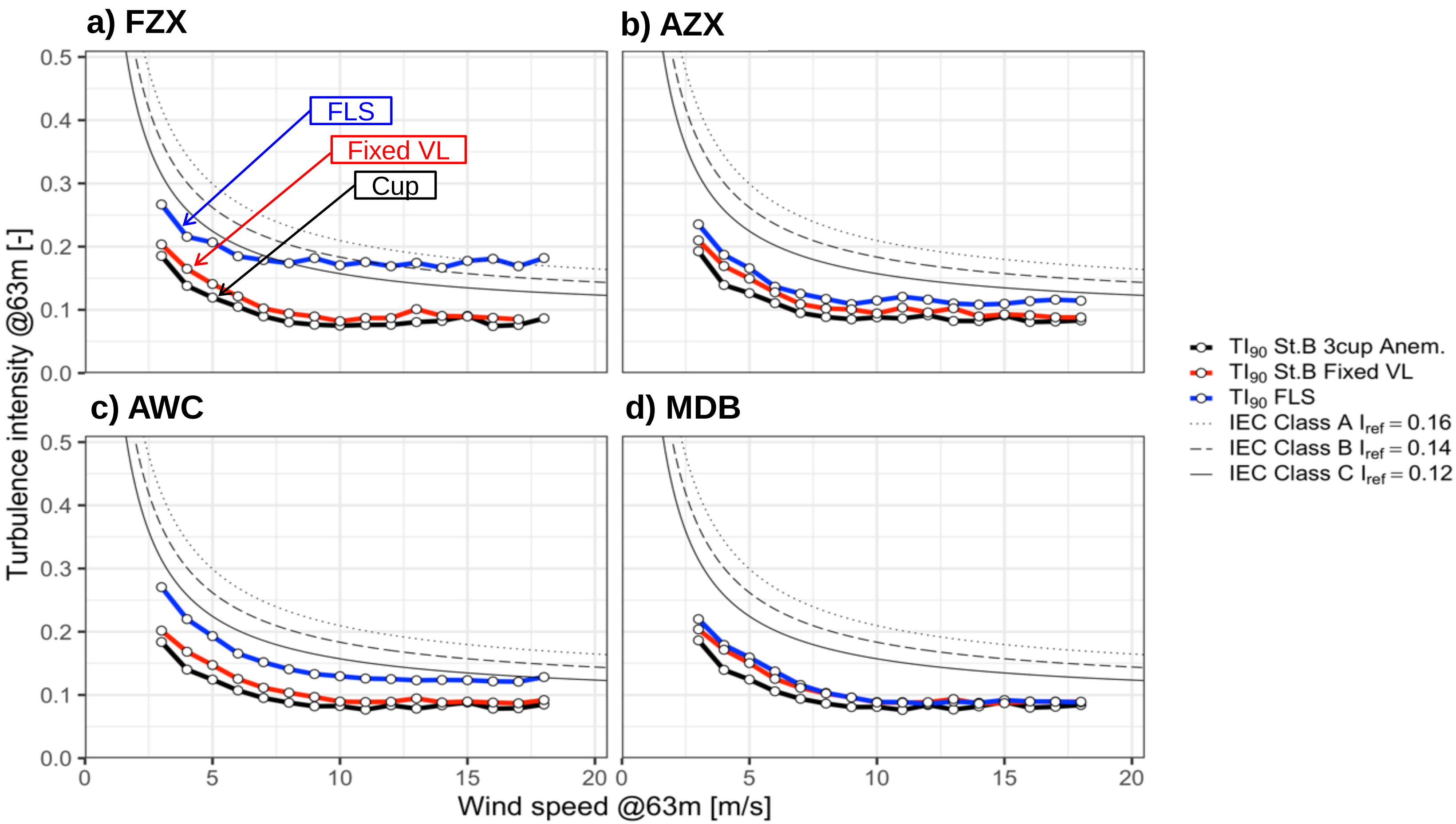
Accuracy of 10-min mean wind direction (only sea-sector, wind speed > 2m/s)



- All of the LiDARs can measure mean wind speed in the criteria of "best practice", except the offset value OFF_{mwd} of MDB (meeting "minimum") .

Turbulence intensity from floating LiDAR systems

Comparison of TI (90 percentile) between Cup, Fixed-VL and FLS



- Small FLSs (FZX, AZX and AWC) overestimate TI due to the motion of the floating body.
- TI from MIA －low-motion FLS－ exhibits the best agreement with that from the fixed VL.
- The difference caused by motion is smaller than that between the vertical lidar and cup.

Brief summary of observation accuracy

Evaluation of offshore wind observation methods in terms of accuracy

(Note that this result is still tentative and it may be revised in the final report of the project)

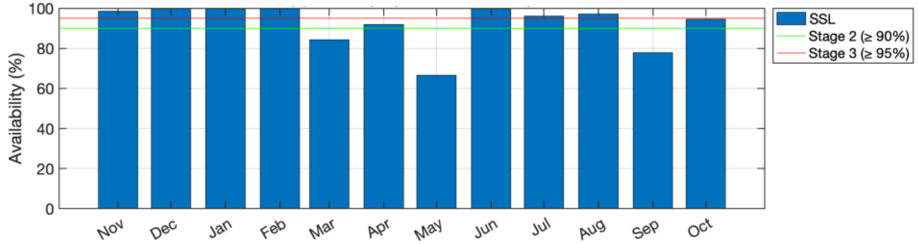
Area (Distance to shore: L)	Observation Elements	Observation Method					Promising Method (Excl. MM+VL)
		[Reference] Met Mast ＋ Vert. LiDAR (MM+VL)	Scanning LiDAR (SL)		Floating LiDAR System (FLS)		
			Single (SSL)	Dual (DSL)	Small (S-FLS)	Large (L-FLS)	
Nearshore (L<3–4 km)	Wind Speed/Direction	Excellent	Fair	Good	Good	Good	DSL, FLS
	Turbulence Intensity	Excellent	Poor	Good	Poor	Fair	DSL
Offshore (L>3–4 km)	Wind Speed/Direction	Excellent	-	-	Good	Good	FLS
	Turbulence Intensity	Excellent	-	-	Poor	Fair	(None)

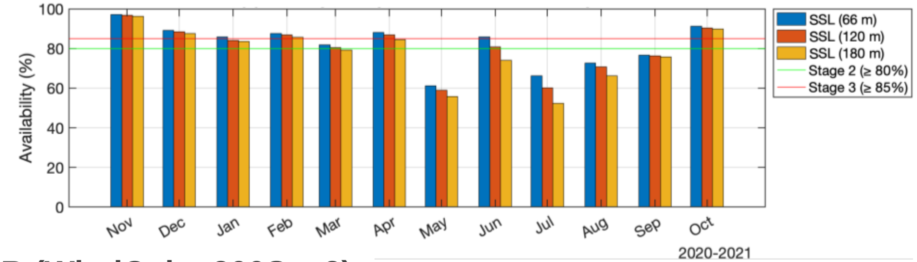
- Wind speed and direction can be measured with Dual-SL or FLS in the accuracy within the Carbon Trust's acceptance criteria, in Japan as well.
- The accuracy of Single-SL is somewhat less accurate than those of Dual-SL and FLS.
- There is no method for turbulence intensity in the offshore area where Dual-SL cannot be used. A low-motion Large-FLS could be the only solution.

System availability and data availability

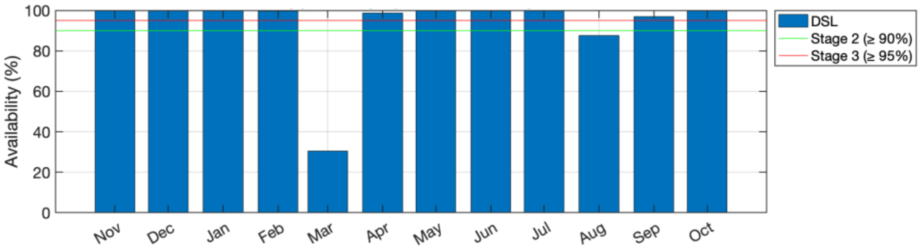
Monthly System availability | **Monthly post-processed data availability**

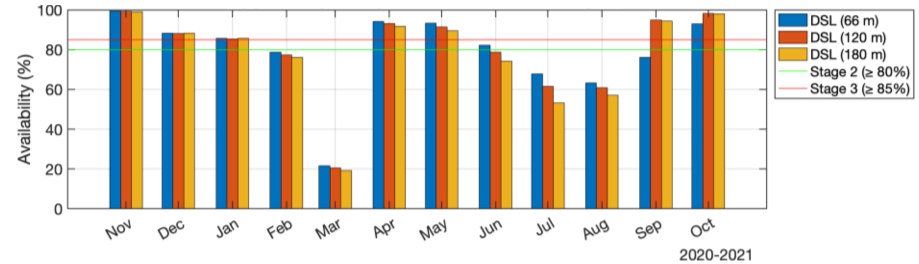
a) Single Scanning LiDAR (WindCube 100S)



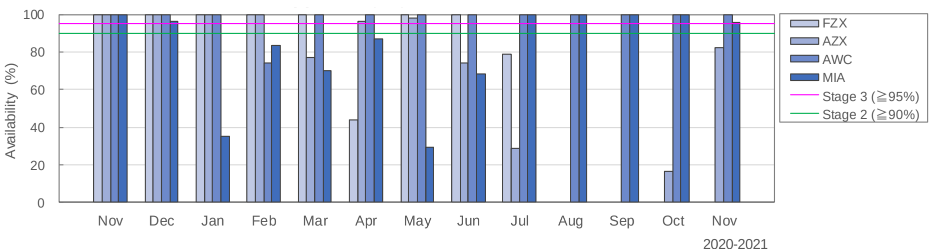


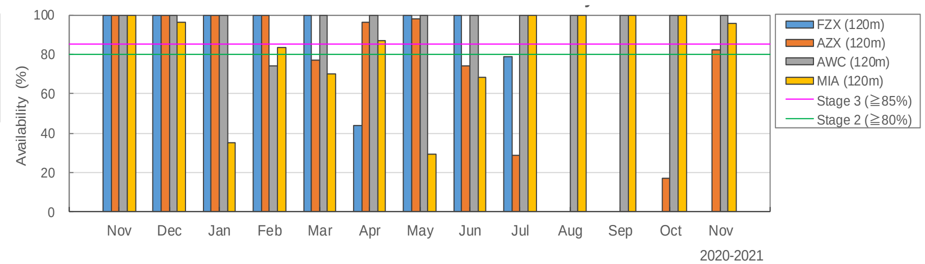
b) Dual Scanning LiDAR (WindCube 200S × 2)





c) Floating LiDAR Systems (FZX, AZX, AWC, MIA)





- Data availabilities at 120m of Single-SL, Dual-SL, and each FLS meet the criteria of "Stage 2" in only 7-11 months in the year. The low data availability needs to be improved.
- In FLS, the system availability (SA) and data availability (DA) take almost the same value, so it is important not to drop SA by thorough maintenance in order to improve DA.

Summary

- In this presentation, we introduced the NEDO project "Establishment of offshore wind resource assessment method" and reported the main research results on the performance of remote sensing devices ー a scanning LiDAR (SL) and a floating LiDAR system (FLS).
- In brief summary, the results are as follows:
  - In nearshore areas (< 3–4 km from the shore), Dual-SL seems to be the most promising, including TI observation. In offshore areas (> 3–4 km), FLS is promising for mean wind speed and direction observation.
  - There is no observation method for TI in the offshore area where SL cannot be used. It seems that developing a low-motion large FLS could be the only solution.
  - In both of SL and FLS observations, low data availability is currently a problem, but it could be overcome by well-performing data complementation from land.
- Toward the end of the project on September 2022, we are currently compiling the research results and preparing the final version of the guidebook on offshore wind observations, which is planned to be published in this fiscal year.

Acknowledgments

This presentation introduces the NEDO "Project for Supporting the Introduction of Wind Power Generation/Project for Supporting the Development of Bottom-Fixed Offshore Wind Farms/Project for Supporting the Development of Bottom-Fixed Offshore Wind Farms (Establishment of Offshore Wind Resource Assessment Method)." Mutsu-Ogawara Port Offshore Windpower Development Co., Ltd. is assisting with field observations at Mutsu-Ogawara Port. Fugro Japan Co., Ltd., the Nagasaki Marine Industry Cluster Promotion Association and four other companies in Nagasaki Prefecture are assisting with floating LiDAR observations. We would like to thank them and the other construction-related companies.