Offshore Wind Measurement Guidebook

March 2023

New Energy and Industrial Technology Development Organization

Introduction

In the Fifth Strategic Energy Plan adopted by the Japanese Cabinet on July 3, 2018, it was decided that the government will continue to take the measures necessary for the utilization of wind power as a large-scale power source in the future, such as speeding up environmental assessments and reconsidering scale requirements, and that it will also work on the promotion of competition and efficiency through the use of the FIT system. For offshore wind power in particular, it is written that, “Measures will be taken to support the introduction of offshore wind power generation through the preparation of rules for the use of sea areas and the introduction of a bidding system. With reference to the measures in Europe, where there has been a rapid reduction of costs in recent years, we will combine efforts for coexistence with the local regions through the establishment of rules for the use of sea areas and system constraints, action for base ports and harbors, the acceleration of related procedures, and price bidding.” In response to this, the Marine Renewable Energy Utilization Act* was enacted on April 1, 2019. The Sixth Strategic Energy Plan, approved by the Cabinet on October 22, 2021, calls for the promotion of offshore wind power generation as “a trump card for making renewable energy the main power source” and a further expansion of its introduction is expected from now on.

When considering a business plan for an offshore wind farm, it is important to obtain accurate wind condition data in order to evaluate the business feasibility. However, the installation of a meteorological mast at sea generally requires coordination with the local community, permission and authorization procedures, and high costs, so measurements using Doppler LiDAR and other remote sensing technologies are being conducted in Japan and overseas. However, with the current remote sensing technology, there have not yet been methods established to observe the turbulence component of wind speed or the vertical distribution of wind speeds offshore.

The New Energy and Industrial Technology Development Organization’s “Project to Support Fixed-Bottom Offshore Wind Farm Development (Establishment of offshore wind resource assessment method)” aims to develop technologies to establish a rational measurement method for offshore wind conditions in Japan's ocean areas by utilizing remote sensing technologies such as those mentioned above, and to compile a guidebook of information that can be used as a practical reference for persons implementing wind measurement.

This “Offshore Wind Measurement Guidebook” (hereinafter referred to as the “Guidebook”) has been compiled based on the results of this project and with reference to the latest knowledge in Japan and overseas. It presents the recommended methods (recommended practice) of offshore wind measurement for persons conducting the wind measurement necessary for offshore wind farm business planning and wind turbine design.

The structure of this Guidebook is as follows.

Chapter 1 describes the positioning and basic concept of this Guidebook and gives an outline of offshore wind measurement. Chapter 2 describes the measurement of wind conditions and the evaluation of wind conditions. From there, Chapter 3 describes measurement using offshore meteorological masts, Chapter 4 describes measurement using dual scanning LiDAR, Chapter 5 describes measurement using single scanning LiDAR, Chapter 6 describes measurement using vertical LiDAR, and Chapter 7 describes measurement using a floating LiDAR system. Chapter 8 explains methods for complementing data and evaluating accuracy when measurement data are missing and Chapter 9 describes the items to be included in reports.

*Act on Promoting the Utilization of Sea Areas for the Development of Marine Renewable Energy Power Generation Facilities

Members of Technical Committee on Establishment of Offshore Wind Resource Assessment Method

Committee member	Affiliation
Akihiro Honda (Chairperson)	Hirosaki University Professor, Institute of Regional Innovation
Takeshi Ishihara	The University of Tokyo Professor, Department of Civil Engineering, Graduate School of Engineering
Hiroyuki Kusaka	University of Tsukuba Professor, Center for Computational Sciences
Shigehito Nakamura	Japan Wind Power Association Managing Director
Fumiyo Harada	Development Bank of Japan Managing Executive Officer

(Japanese syllabary order, honorifics omitted)

Revision History

Revision Number	Revised Date	Revised Sections	Reason for Revision
-	2022.06	-	Published as interim report
-	2022.09	-	Prepared as the deliverable against the project for “Establishment of offshore wind resource assessment method”
0	2023.03	-	Newly published
0.1	2023.06	4.3.3	Corrected a typo of the equation (4.3)
		Reference	Unified a notation (no change of contents)

Table of Contents

1. Outline

In this Guidebook, the matters to be satisfied are described in the frames at the beginning of each section. The details outside of the frames supplement and explain the matters to be satisfied.

1.1 Scope

The scope of this Guidebook is the wind measurement necessary for the planning and development of offshore wind farms.

In the planning of offshore wind power generation, in order to achieve the purposes below, it is important to understand the wind condition characteristics of the installation sea area and to obtain accurate wind measurement data for the site.

- Consideration of business feasibility
- Consideration of wind turbine design conditions
- Obtaining permissions and authorizations for construction plans, etc., submitted based on the Electricity Business Act

The wind measurement data obtained from a site is essential for the reduction of the project risk and the improvement of the profitability of a project. It is also recommended that wind measurement be conducted for long period after the operation of an offshore wind farm is started.

The methods for measuring offshore wind conditions are classified into the “direct measurement” using by cup anemometers and wind vanes, and the “indirect measurement (remote sensing)” performed using technology such as LiDAR. At present, the use of a fixed-bottom metrological mast can be described as the measurement method with the highest accuracy, sufficient empirical proof, and possibility of quantifying uncertainty. However, the installation of a meteorological mast at sea generally requires coordination with the local community, permission and authorization procedures, and high costs, so it is desirable that a low cost measurement method using a remote sensing device (RSD) be established. In addition, the establishment of a measurement method using a floating wind measurement system is desirable for deep sea areas where floating offshore wind generation is assumed.

This Guidebook only covers the wind measurement devices which are judged to be technically usable at the present time, and other measurement devices are excluded.

This Guidebook has been produced with reference to the latest Japanese and overseas research, guidelines, and international standards related to offshore wind measurement, and is positioned as a resource that persons implementing wind measurement can refer to in their work. It has been compiled based on the latest knowledge with the aim of presenting measurement methods to assist in the optimum wind measurement from the viewpoints of reliability and economic efficiency.

1.2 Contents and relationship of each chapter

The contents and relationship of each chapter of this Guidebook are as shown in Table 1.1.

Table 1.1 Contents of each chapter and relationship with other chapters

Chapter	Contents	Explanation	Chapters to be referenced
2	Wind measurement and wind condition evaluation	・This chapter summarizes the items to be satisfied as the evaluation of the wind conditions, regardless of the requirements for the wind measurement and the measurement method adopted.	Select from Chapters 3 to 7 Chapters 8 and 9
3	Measurement using meteorological mast	・This chapter summarizes the requirements when adopting a measurement mast as the wind measurement method. ・This is the most reliable measurement. ・High accuracy measurement of turbulence intensity is possible.	Chapters 2, 8, and 9
4	Measurement using Dual Scanning LiDAR (DSL)	・This chapter summarizes the requirements when adopting DSL (a method of measurement using two scanning LiDARs (SL)) for indirect measurement (remote sensing) as the wind measurement method. ・It is possible to install the equipment on land and perform offshore measurement, but the observable range is limited. ・High accuracy measurement of turbulence intensity is possible by reducing the elevation angle to below the threshold.	Chapters 2, 8 and 9, Annexes A, B and C
5	Measurement using Single Scanning LiDAR (SSL)	・This chapter summarizes the requirements when adopting SSL (a method of measurement using just one scanning LiDAR (SL)) for indirect measurement (remote sensing) as the wind measurement method. ・It is possible to install the equipment on land and perform offshore measurement, but the measurable range is limited.	Chapters 2, 4, 8 and 9, Annexes A, B and C
6	Measurement using vertical LiDAR (VL)	・This chapter summarizes the requirements when adopting VL for indirect measurement (remote sensing) as the wind measurement method. ・To perform offshore measurement, it is necessary to install the equipment on a fixed or floating platform.	Chapters 2, 8, and 9
7	Measurement using a Floating LiDAR System (FLS)	・This chapter summarizes the requirements when adopting an FLS equipped with VL (a method of measurement using VL installed on a floating buoy, etc.) for indirect measurement (remote sensing) as the wind measurement method. ・This can be installed in a wide area ranging from shallow sea areas to deep sea areas.	Chapters 2, 6, 8 and 9, Annex D

8	Complementation methods and accuracy verification when measurement data are missing	・This chapter summarizes the requirements for complementing the measurement data when using any of the measurement methods in Chapters 3 to 7.	Chapters 2, 3 to 7, and 9
9	Reporting	・This chapter summarizes the contents included in reports on wind measurement and wind condition evaluation.	Chapters 2 to 8
A	Hard target adjustment	・This section summarizes the method of hard target adjustment for RSD.	Chapters 4 and 5
B	Pre-deployment verification of accuracy	・This section summarizes the method of the pre-deployment verification of RSD accuracy.	Chapters 4 and 5
C	Data acquisition rate check	・This section summarizes the method of checking the RSD data acquisition rate.	Chapters 4 and 5
D	Example of FLS installation work	・This section summarizes of example of FLS installation work	Chapter 7

1.3 Relevant laws and regulations

1.3.1 Relevant laws, regulations and ordinances, and their interpretations and explanations

- Ministerial Ordinance Prescribing Technical Standards for Wind Power Generation Facilities (Ordinance of the Ministry of International Trade and Industry No. 53 of 1997)
- Ministerial Ordinance Prescribing Technical Standards for Electric Facilities (Ordinance of the Ministry of International Trade and Industry No. 52 of 1997)
- Interpretation of Technical Standards for Wind Power Generation Facilities (Ministry of Economy, Trade and Industry, No. 20140328, Bureau of Commerce No. 1, 2014)
- Annotations to the Ministerial Ordinance Prescribing Technical Standards for Wind Power Generation Facilities and its Interpretation (2021, Ministry of Economy, Trade and Industry, partially revised on June 21, 2021)
- Regulation for Enforcement of the Port and Harbor Act (Ministry of Transport Order No. 98 of 1951)
- Ministerial Ordinance Prescribing Technical Standards for Port Facilities (Ordinance of the Ministry of Land, Infrastructure, Transport and Tourism No. 15 of 2007)
- Public Notice Establishing Necessary Matters Concerning Standards for Publicly Offered Facilities, etc. and Their Maintenance and Management Methods (Public Notice of the Ministry of Land, Infrastructure, Transport and Tourism No. 858 of 2016)
- Public Notice Prescribing Details of Technical Standards for Port Facilities (Public Notice of the Ministry of Land, Infrastructure, Transport and Tourism No. 395 of 2007)
- Regulation for Enforcement of the Act on Promoting the Utilization of Sea Areas for the Development of Marine Renewable Energy Power Generation Facilities (Ordinance of the Ministry of Land, Infrastructure, Transport and Tourism and Ministry of Economy, Trade and Industry No. 1 of 2019)
- Public Notice Establishing Necessary Matters Concerning Standards for Marine Renewable Energy Power Generation Facilities and Their Maintenance and Management Methods (Ministry of Land, Infrastructure, Transport and Tourism Notice No. 388 of 2020)

- Technical Standards for Floating Offshore Wind Power Generation (Safety Policy Division, Maritime Bureau, Ministry of Land, Infrastructure, Transport and Tourism, No. 194, 2020)

1.3.2 Japanese standards and guidelines related to laws and regulations

- Recommendations for Loads on Buildings (2015, Architectural Institute of Japan)
- Guidelines and explanation for the design of support structures of wind power generation facilities (2010, Japan Society of Civil Engineers)
- Recommendations for Design of Building Foundations (2019, Architectural Institute of Japan)
- Recommendations for Design of Chimney Structures (2007, Architectural Institute of Japan)

1.3.3 Technical standards

- JIS C 1400-1: 2017 Wind Energy Generation systems -- Part 1: Design requirements
- IEC 61400-1:2019 Wind energy generation system - Part1: Design requirements
- IEC 61400-3-1:2019 Wind energy generation system - Part3-1: Design requirements for offshore wind turbines
- IEC TS61400-3-2:2019 Wind energy generation system - Part3-2: Design requirements for floating offshore wind turbines
- JIS C 1400 -12 -1: 2010 Wind turbines- Part 12-1: Power performance measurements of electricity producing wind turbines
- IEC 61400-12-1:2017 Wind energy generation system – Part12-1: Power performance measurements of electricity producing wind turbines
- IEC 61400-50-1(RFDIS) Wind energy generation system – Part50-1: Application of meteorological mast, nacelle and spinner mounted instruments
- IEC 61400-50-2(TPUB) Wind energy generation system – Part50-2: Application of Ground Mounted Remote Sensing Technology
- IEC 61400-50-3:2022 Wind energy generation system – Part50-3: Use of nacelle-mounted lidars for wind measurements
- IEC 61400-50-4(ACD) Wind energy generation system – Part50-4: Use of floating lidars for wind measurements

1.3.4 Guidelines and recommended standards

- MEASNET, Evaluation of site-specific wind conditions, Version 2, April 2016.
- IEA Wind Expert Group Report on Recommended Practices 18. Floating LIDAR systems, First Edition, 2017.
- Carbon Trust Offshore Wind Accelerator Roadmap for the Commercial Acceptance of Floating LiDAR Technology, Ver.2.0, 2018.
- Carbon Trust, Remote Wind Measurements Offshore Using Scanning LiDAR Systems, 2014.
- NEDO Guidebook of Bottom Fixed Offshore Wind Turbine Introduction, 2018.
- NEDO Guidebook of Floating Offshore Wind Turbine Technology, 2018.
- Ministry of Economy, Trade and Industry Manual for the Introduction of Floating Offshore Wind Power

Generation, 2019.

- Committee on Study of Developing Offshore Wind Power Generation Facilities Official Explanation of Technological Standards for Offshore Wind Power Generation Facilities, 2020
- Ministry of Land, Infrastructure, Transport and Tourism Maritime Bureau Technical Standards for Floating Offshore Wind Power Generation Facilities, 2020.
- Japan Coast Guard Guidelines for the Installation and Management of Navigational Aids, November 2021.
- Nippon Kaiji Kyokai NKRE-GL-WFC01 Wind Farm Certification Onshore Wind Power Plant Edition, July 2021 edition
- Nippon Kaiji Kyokai NKRE-GL-FOWT01 Guidelines for Floating Offshore Wind Power Facilities, December 2021 edition.

1.4 Terms and abbreviations

The definitions of the main terms and abbreviations used in this Guidebook are given in Table 1.2 and Table 1.3, respectively.

Table 1.2 Terms

Term	Definition and description	Idiom or synonym
Wind shear	The change in wind speed on a plane perpendicular to the direction of the wind.	Wind shear, shear
Wind shear exponent	The exponent of the exponential law (power law) for wind shear.	Exponent, α
Wind shear law	The mathematical representation assumed for changes in wind speed relative to the height above ground. Usually the logarithmic law or exponential law is used.	
Wind profile	Vertical distribution of wind speed.	Height distribution of wind speed
Wake	The flow with velocity defects that occurs in the flow behind an object. In the field of wind power generation, it often refers to the flow that occurs behind a wind turbine for power generation. If a meteorological mast is in a position where it enters a wind turbine wake, it is affected by a decrease in the speed and an increase in the turbulence.	
Aerosol	A mixture of small liquid or solid particles suspended in a gas and the surrounding gas.	
Offset	Offset b of the linear equation ($y = ax + b$) for correlation analysis	Intercept
Cup anemometer	Hemispherical or conical cups (wind cups) arranged in three or four directions around a vertically supported axis of rotation. It rotates when the wind hits the wind cups and the wind speed is measured by counting the rotations. In the field of wind power generation, the standard is the measurement method using a cup anemometer.	
Carrier to noise ratio	An indicator of the quality of the carrier (carrier wave) of an optical or electrical signal, also referred to as the CN ratio. The power of the carrier divided by the power of the noise is usually expressed in dB, with higher values indicating better quality.	

Term	Definition and description	Idiom or synonym
Elevation angle	The angle formed by the installation surface of the scanning LiDAR and the line connecting the laser line of sight and the measurement point.	
Radial velocity	The component of the wind velocity in the direction of the laser light emission.	
Ambient turbulence intensity	The value that is the standard deviation of the main wind direction component of the wind speed divided by the wind speed.	Degree of turbulence
Scanning lidar	The component of the wind velocity in the direction of the laser light emission (the radial velocity) is measured by measuring the Doppler shift of the waves reflected due to aerosols in the air, and then the horizontal wind speed is calculated from the results of radial velocity measurements in a plurality of directions. A scanning LiDAR measures the wind speed by scanning the laser in the horizontal direction or the vertical direction.	
Sector size	The azimuth (sector) angle when the azimuth angles of the wind direction are divided by a certain angle.	Wind direction bin width
Double bias correction	One of the models used in the MCP method for turbulence intensity.	
Dual scanning lidar	A measurement system that uses two scanning LiDAR units to determine the wind velocity vector from the radial velocity at the intersection of two lasers. It is also possible to measure multiple points in the height direction.	
Hard target	A physical target used to determine the intersection of the two lasers in dual scanning LiDAR.	
Hub height	The height of the center of the swept area of a wind turbine rotor above the ground.	Hub height
Filtering	The analysis process in which the observer determines whether the radial velocity is valid or invalid, separately from the status information. The abnormal values are sorted from the radial velocity or CNR output raw values from the LiDAR. The standard deviation and quantile values for 10 minutes are used to judge the abnormal values.	
Meteorological mast	A freestanding mast that is installed for the measurement of wind speed and direction. Cup anemometers and wind vanes, etc., are installed at multiple heights. Refer to IEC 61400-12-1 and the Measnet guidelines for the method of equipment installation.	Weather mast, weather measurement mast, wind measurement tower
Floating lidar system	A system in which a vertical LiDAR is installed on a floating buoy, etc.	
Wind vane	A vertically supported rotating shaft that is equipped with a horizontal bar that has a weight and a plate installed at its two ends. It is an instrument for measuring wind direction.	
Vertical lidar	The component of the wind velocity in the direction of the laser light emission (the radial velocity) is measured by measuring the Doppler shift of the waves reflected due to aerosols in the air, and the horizontal wind speed is calculated from the results of radial velocity measurement in a plurality of directions. A vertical LiDAR rotates the laser around an upward vertical axis.	
Environmental condition	Characteristics of the environment (wind, altitude, temperature, humidity, etc.) that may affect the behavior of the wind turbine.	

Term	Definition and description	Idiom or synonym
Flow inclination angle	The inclination of the air current to the horizontal.	Blowup angle, flow tilt angle
Slope	The slope a of the linear equation (y = ax + b) for correlation analysis.	Slope
Verification	To confirm that the specified requirements are satisfied by providing objective evidence. For example, that the manufacturer's specifications are satisfied.	Verification
Calibration	The act of comparing the value from a standard measuring instrument with the value indicated by the measuring instrument being evaluated to determine how much variation exists.	
Swept area	The plane drawn by the rotor during one revolution projected perpendicular to the direction of the wind.	
Key performance indicator (KPI)	A quantitative indicator for the measurement and monitoring of the degree to which the performance targets for a device are being achieved, in order to evaluate the performance of that device.	
Obstacles	The objects such as buildings and trees that shield the wind and cause distortion in the airflow.	
Accuracy	The degree of agreement between the measurement results and the true values of the item being measured.	
Atmospheric stability	The degree to which the atmosphere is affected by the temperature difference between the upper and lower layers.	
Surface roughness	This means the roughness of the ground surface. Surface roughness is divided into the four categories of I to IV.	
Roughness length	The extrapolated height at which the mean wind speed is zero when it is assumed that the vertical wind profile varies logarithmically with respect to height.	
Annual average	This is an average calculated from measurement data sets with a sufficient amount of data collected over a sufficient period of time, and can be used to estimate the expected value of the item being measured. It is desirable that the period for calculating the average be an integral multiple of whole year units, in order to smooth out transient effects such as seasonal differences.	
Annual average wind speed	The wind speed averaged according to the definition of the annual average.	
Uncertainty	A parameter that characterizes the variability of values that are reasonably tied to a target quantity.	
Wind speed distribution	A probability distribution function used to describe the distribution of wind speeds over a long period of time. The functions that are frequently used are the Rayleigh distribution function and Weibull distribution function.	Frequency distribution by wind speed class, wind speed distribution
Mean wind speed	The statistical average of instantaneous values of wind speed averaged over a given period of time, which may range from seconds to years.	
Flow model	A model that represents the motion of airflow numerically.	Wind condition simulation, wind condition analysis
Turbulence intensity	The ratio of the standard deviation of the wind speed to the mean wind speed.	Degree of turbulence
Turbulence standard deviation	The standard deviation of the main wind direction component of the wind speed.	

Term	Definition and description	Idiom or synonym
PPI (Plan-Position-Indicator) measurement	A method of fan-shaped scanning in which the elevation angle is fixed and the azimuth angle is varied. There is also RHI (Range Height Indicator) measurement. RHI measurement is a method of scanning in which the azimuth angle is fixed and the elevation angle is varied. PPI scans are used to obtain high resolution samples in the azimuth angle direction. RHI scans are used to obtain high resolution samples in the elevation angle direction.	
Roll angle	The angle of rotation about the north-south axis when a scanning LiDAR is installed on a platform.	
Tilt angle	The angle of rotation about the east-west axis when a scanning LiDAR is installed on a platform.	

Table 1.3 Abbreviations

Abbreviation	Definition	Term
CNR	Carrier to Noise Ratio	
DBC	Double Bias Correction	
DBS	Doppler Beam Swinging	
DSL	Dual Scanning LiDAR	
FLS	Floating LiDAR System	
GNSS	Global Navigation Satellite System	Global Navigation Satellite System
KPI	Key Performance Indicator	Key Performance Indicator
LiDAR	Light Detection and Ranging	LiDAR
MM	Met Mast	Meteorological mast
MCP	Measure-Correlate-Predict	MCP (Measure-Correlate-Predict) method
MEASNET	Measuring Network of Wind Energy Institutes	
MSL	Mean Sea Level	Mean Sea Level
OWA	Offshore Wind Accelerator	
PPI	Plan-Position Indicator	Horizontal scan
RHI	Range Height Indicator	Vertical scan
RSD	Remote Sensing Device	Remote Sensing Device
SL	Scanning LiDAR	
SSL	Single Scanning LiDAR	
TSL	Triple Scanning LiDAR	
VL	Vertical LiDAR	

2. Wind measurement and wind condition evaluation

2.1 Wind measurement items and evaluation items

For the planning of offshore wind farms, Table 2.1 shows the items that are to be evaluated based on offshore measurements as the wind conditions necessary for the prediction of the energy yield and for the wind turbine design. The measurement equipment that can be used for the measurement of the offshore wind conditions is (a) meteorological masts (MM) and dual scanning LiDAR (DSL), and (b) single scanning LiDAR (SSL), vertical LiDAR (VL) and floating LiDAR systems (FLS). In order to evaluate the items described in Table 2.1, the measurement of the offshore wind is performed with either of (a) or (b) shown in Table 2.2, or with a combination thereof. Measurement data are recorded continuously and statistical values based on the 10-minute values obtained from the measurement data are used as the wind condition evaluation data necessary for the prediction of the energy yield and the wind turbine design.

Table 2.1 Wind condition evaluation items
necessary for power generation prediction and wind turbine design

Evaluation item	Explanation	Measurement devices that can be used*1
Mean wind speed	Annual average wind speeds per direction and in all directions	(a), (b)
Wind speed distribution	Weibull parameters direction and in all directions	(a), (b)
Appearance frequency distribution by wind direction	Appearance frequency distribution per direction	(a), (b)
Turbulence intensity	Ambient turbulence intensity per direction and in all directions (90% quantile)	(a)
Wind shear exponent	Wind shear exponent per direction and in all directions	(a), (b)
Flow inclination angle	Flow inclination angle per direction and in all directions	- *2

*1: Equipment that is judged to be technically usable at the current time.

*2: In the case of offshore measurement, 0 degrees is acceptable.

Table 2.2 Wind measurement items

(a) Meteorological Mast (MM) and Dual Scanning LiDAR (DSL)

Measurement item	Statistical value	Number of measurement points
Wind speed	Mean, standard deviation	Multiple heights (Three or more heights)
Wind direction	Mean value	Multiple heights (Three or more heights)

(b) Single Scanning LiDAR (SSL), Vertical LiDAR (VL) and Floating LiDAR System (FLS)

Measurement item	Statistical value	Number of measurement points
Wind speed	Mean value	Multiple heights (Three or more heights)
Wind direction	Mean value	Multiple heights (Three or more heights)

The increase in the size of wind turbines has made it necessary to observe the wind conditions at high heights, and reasons such as the expensive cost of using a meteorological mast for measurement at high heights have meant that the use of remote sensing devices (hereinafter referred to as RSD) is advancing. In particular, smaller sizes and lower costs have been achieved for LiDAR equipment that measures the wind with a laser, and this is becoming the main equipment used. The LiDAR technology measures the wind by irradiating the aerosols in the air with a laser and measuring the laser scattering.

The RSD covered in this Guidebook are dual scanning LiDAR (DSL), single scanning LiDAR (SSL), vertical LiDAR (VL) and floating LiDAR systems (FLS) that have VL installed on a floating platform. DSL means measurement by two scanning LiDARs, and SSL means measurement by one scanning LiDAR.

The use of three scanning LiDARs in triple scanning LiDAR (TSL) makes it possible to observe three components, so, in principle, it is possible to measure the turbulence intensity. However, if the elevation angle is reduced to the threshold value or less, then even just two scanning LiDARs can measure the turbulence intensity with high accuracy (two components in the horizontal plane), so this Guidebook deals only with DSL and just introduces reference documents for TSL[1)].

Figure 2.1 shows examples of the RSD measurement modes. It shows the PPI measurement mode, which is scanning in the azimuth angle direction with the elevation angle fixed, RHI measurement mode, which is scanning in the elevation angle direction with the azimuth angle fixed, fixed measurement mode, in which both the elevation angle and the azimuth angle are fixed, and DBS measurement mode, where a vertical profile is scanned for each of the north, east, south, and west directions.

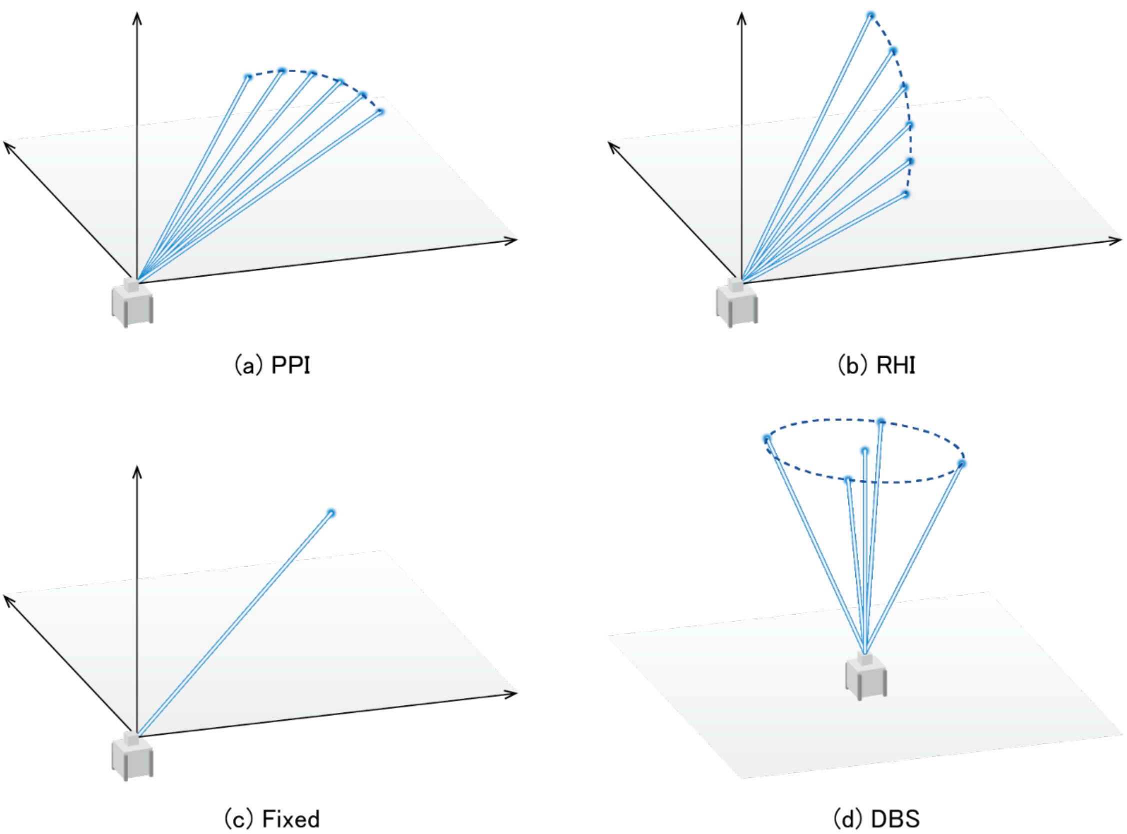


Figure 2.1 Examples of the RSD measurement modes

At present, the technologies that can measure with sufficient accuracy for the turbulence intensity evaluation necessary for wind turbine design are a cup anemometer installed on a meteorological mast and DSL. To perform the turbulence intensity evaluation that is necessary for wind turbine design, examples include an offshore meteorological mast satisfying 2/3 or more of the hub height, an offshore meteorological mast that is at less than 2/3 of the hub height combined with a VL installed on the mast platform, and offshore measurement using DSL installed on land.

Measurement errors occur in the measurement of turbulence intensity by VL, so it is necessary to correct this by the method proposed by Yamaguchi et al[2)].

With an FLS, in addition to the turbulence intensity errors of vertical LiDAR, there is also an effect from the swaying motion, so the measurement error becomes larger than that of a cup anemometer. Several previous studies have been conducted on motion compensation to eliminate this effect[3) -4)]. However, correction is necessary for the same reason as for the VL described above.

There is also a problem with the accuracy of turbulence intensity measurement using SSL.

The wind condition evaluation items necessary for the prediction of the energy yield and the wind turbine design are as shown in Table 2.1. Together with these, it is also desirable to include energy density distribution per direction.

For the measurement heights, at least three heights must be used in order to properly evaluate the wind shear on the wind turbine rotor plane.

From the viewpoints of reducing the uncertainty in the calculation of wind measurement data statistics, redundancy (measures in case of failure, etc.), and the evaluation of atmospheric stability, it is better to have a large number of measurement points. However, increasing the number of measurement devices increases the power consumption and leads to an increase in the measurement costs, so the information given here shows the minimum number of measurement points necessary.

Temperature and air density are also important in the wind condition evaluation necessary for the prediction of the energy yield and the wind turbine design, but this Guidebook only covers wind measurement.

Table 2.3 shows examples of wind measurement items on offshore meteorological masts in Japan. At all of the measurement sites, vertical LiDAR measurements were also conducted adjacent to the meteorological mast. At the Choshi meteorological mast, an SSL measurement demonstration was conducted. In this project, the demonstration of measurement by DSL, SSL and an FLS is being carried out.

Table 2.3 Examples of wind measurement items on offshore meteorological masts in Japan

Measurement item	NEDO Mutsu Ogawara offshore meteorological mast	NEDO Choshi fixed-bottom meteorological mast	NEDO Kitakyushu fixed-bottom meteorological mast	METI Fukushima floating type meteorological mast
Wind speed	Cup anemometers: － 63 m high, two directions － 59 m high, one direction － 50 m high, one direction － 25 m high, four directions Ultrasonic anemometer: － 61 m high, one direction	Cup anemometers: － 90 m high, three directions － 80 m high, three directions － 70 m high, three directions － 60 m high, three directions － 50 m high, three directions － 40 m high, three directions － 30 m high, three directions － 20 m high, one direction Ultrasonic anemometers: － 80 m high, one direction － 60 m high, one direction － 40 m high, one direction	Cup anemometers: － 80 m high, two directions － 70 m high, two directions － 60 m high, two directions － 50 m high, two directions － 40 m high, two directions － 30 m high, two directions Ultrasonic anemometers: － 80 m high, one direction － 60 m high, one direction － 40 m high, one direction － 20 m high, one direction	Cup anemometers: － 60 m high, three directions － 50 m high, three directions － 40 m high, three directions
Wind direction	Wind vanes: － 61 m high, one direction － 50 m high, one direction Ultrasonic anemometer: － 61 m high, one direction	Wind vanes: － 95 m high, one direction － 90 m high, three directions － 80 m high, three directions － 70 m high, three directions － 60 m high, three directions － 50 m high, three directions － 40 m high, three directions － 30 m high, three directions － 20 m high, one direction Ultrasonic anemometers: － 80 m high, one direction － 60 m high, one direction － 40 m high, one direction	Wind vanes: － 80 m high, one direction － 70 m high, two directions － 60 m high, one direction － 50 m high, two directions － 40 m high, one direction － 30 m high, two directions Ultrasonic anemometers: － 80 m high, one direction － 60 m high, one direction － 40 m high, one direction － 20 m high, one direction	Wind vanes: － Apex － 60 m high, three directions － 50 m high, three directions － 40 m high, three directions

2.2 Representativeness of wind conditions and selection of measurement points

Conduct offshore wind measurement at one or more offshore points that are representative of the planned site, either by using cup anemometers and wind vanes installed on meteorological masts, or by using a remote sensing device (RSD) that has the point(s) as the measurement position(s). Use measurement devices that have had their accuracy verified in advance.

The period of the offshore wind measurements must be a sufficient period to evaluate annual statistics and must be at least one year, to allow for seasonal effects. In addition, in order to obtain the statistical values based on 10-minute values that are the wind condition evaluation data necessary for the prediction of the energy yield and the wind turbine design, the measurement height used must be 2/3 or more of the planned wind turbine hub height, and the measurement must be conducted at a total of three or more heights in order to properly evaluate wind shear. One measurement point can represent the planned wind turbines within 10 km of that point.

It is necessary for the wind measurement plans for a site to provide enough quality information for the power generation and wind condition evaluations for all the wind turbines in the wind farm. The measurement devices used must have been verified in advance in accordance with the existing standards (including documents under development). Table 2.4 shows the IEC standards for wind measurement by various measurement devices. The IEC standards for wind measurements were published in the 61400-12 series, and the text of the 61400 series was reconstructed. The only document in Table 2.4 that has been issued at the current time is IEC61400-50-3. There is no previous applicable standard for prior accuracy verification by scanning LiDAR, so follow this Guidebook.

Table 2.4 IEC standards for wind measurement

Measurement device		Fixed platform	Floating platform
Meteorological mast		IEC61400-50-1	-
RSD	Vertical LiDAR	IEC61400-50-2 *1	IEC TS61400-50-4
	LiDAR mounted on nacelle	IEC61400-50-3	-
	Scanning LiDAR	-	-

*1: The scope of this is RSD installed on land, so it is not limited to vertical LiDAR.

It is recommended that the wind measurement planning (measurement devices, heights, positions, sensor arrangements, etc.) be carried out based on analysis of the site-specific influencing factors, which is influencing factors such as the topographic factors, geographical factors, and meteorological factors of the planned wind farm site.

When predicting the wind conditions at each wind turbine position in the planned wind farm, if the distance from the wind turbine position in the wind farm to the measurement point is within the representative radius, then it is assumed that it will be within the range of allowable uncertainty.

When using RSD, it is desirable to use the planned hub height as the measurement height to obtain statistical values based on 10-minute values, which are the wind condition evaluation data necessary for the prediction of the energy yield and the wind turbine design. In addition, for the measurement heights added for the evaluation of wind shear, it is desirable to perform measurements of an appropriate height within the rotor plane above and below the hub height of the planned wind turbine. However, the specific heights are set according to the situation of the field measurements.

Although the representative radius is considered to be greatly dependent on the site-specific conditions, the value of the representative radius defined by Measnet, etc., for flat topography (10 km) is applied offshore in this document. However, in a sea area close to the coastline, the spatial variation of wind conditions increases due to changes in surface roughness and the influence of the topography in the coastal area, so it is thought that the representative radius becomes smaller than 10 km. Therefore, it is necessary to consider these factors when deciding the number of wind measurement points for a planned wind power plant.

2.3 Measurement data evaluation

1) For the wind condition measurement data to obtain the statistical values based on 10-minute values that are the data used as the wind condition evaluation data necessary for the prediction of the energy yield and the wind turbine design, the wind measurement data should be data for a period of one year or a multiple thereof, and the effective data rate used should be 95% or more.
2) If there is a period in which the wind condition measurement data is missing or shows abnormal values, such as due to a failure of the measurement devices or weather conditions, etc., and the conditions of 1) above cannot be satisfied, perform data compensation using measurement data. However, if compensation using measurement data is performed, verify the accuracy of that complementation and show the validity of the complemented data.

The evaluation items are as shown in Table 2.1.

The details of the complementation method, the accuracy verification method for the data after complementation, the key performance indicator (KPI) for the accuracy verification, and the acceptance criteria are given in Chapter 8. Compared to meteorological masts, RSD are more affected by weather conditions and tend to have a lower effective data rate.

3. Measurement using offshore meteorological masts

3.1 Selection of measurement points

In the case of measurement using offshore meteorological masts, in addition to the details in item 2.2, attention must also be paid to the following matters.

- If the topography and surface roughness are not uniform in the area around the site, the measured values at the measurement point may be affected differently from the wind turbine position. Appropriate prior consideration should therefore be made, such as by conducting airflow analysis at the stage of the measurement point selection.
- If measurements must be made in the vicinity of an existing wind turbine that is in operation, select a point that is not affected by the wake of that wind turbine.

If the planned site is close to the shore, it may be affected by topography such as coastal cliffs and coastal terraces. In such a case, the representative radius of 10 km may not be valid, so it is desirable to consider the installation site in advance with airflow analysis.

According to JIS C 1400-1:2017, when considering the influence of the wake of adjacent wind turbines, if the distance between the wind turbines is 10 times or more the rotor diameter of the wind turbine, the influence of the wake is not taken into account. This is one indicator that can be used for the separation distance when considering the effect of the wake. However, for offshore sites, there is a risk that the wake may have an effect at points further away than the effect on land, so this point should be kept in mind when considering the effects of wake. Figure 3.1 shows the installation site of the offshore meteorological mast on the breakwater of the Mutsu Ogawara Port as a reference.

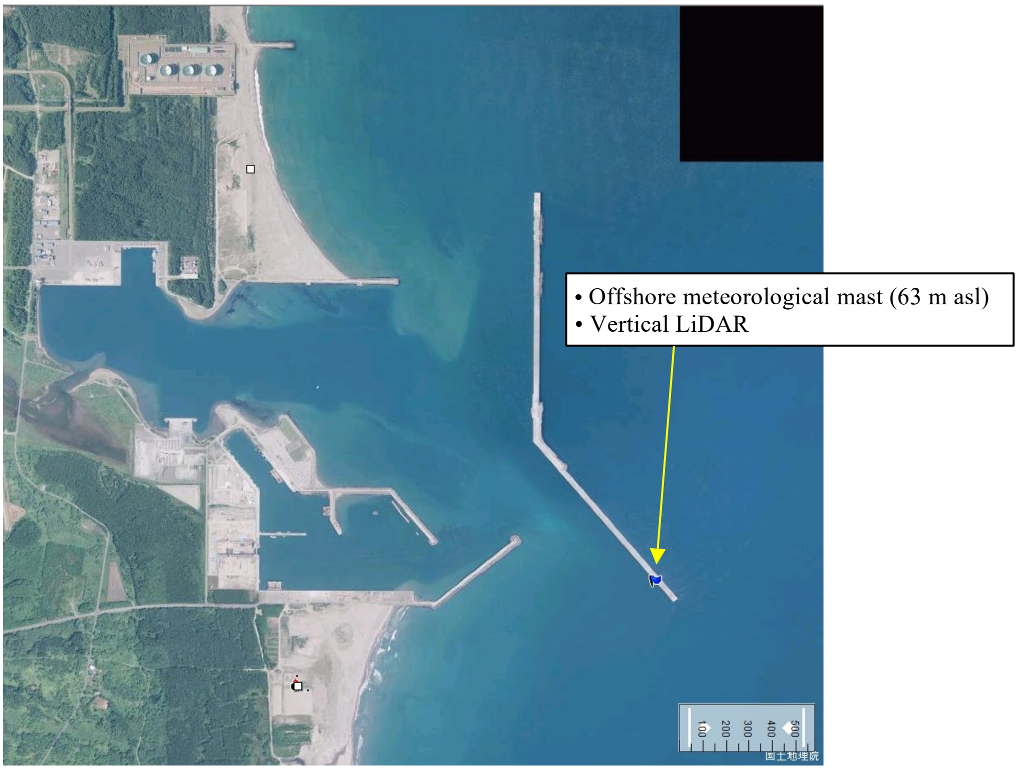


Figure 3.1 Example of offshore wind measurement point (Mutsu Ogawara Port)

3.2 Measurement of wind speed and wind direction

The measurement of wind speed is carried out by a cup anemometer or an anemometer for which the accuracy is guaranteed to be equivalent to a cup anemometer. The cup anemometers used must be calibrated before the measurement period. Perform the calibration of cup anemometers according to the procedure in JIS C 1400-12-1:2010, or in a procedure recognized as equivalent, and attach the calibration results to the report.

Install a cup anemometer at a position that is not less than 2/3 of the hub height from the ground surface. If this is difficult, measurement in combination with RSD will be necessary. However, even in that case, the cup anemometer should be installed at the highest position possible. In order to evaluate the vertical profile of the wind speed at the site, add two or more anemometers below the topmost anemometer at intervals of approximately 10 m.

In the installation of anemometers on the measurement mast, the attachment must be in a manner that minimizes the effects on the anemometer from the meteorological mast and the boom. A lightning rod must be installed in a position where it will not affect the anemometers.

For the wind speed, measure the 10-minute mean value and standard deviation. The sampling frequency used should be 1 Hz or higher.

In cold regions where the temperature of the planned site falls below zero, in order to maintain the response characteristics specified in the anemometer regulations, it is necessary to take measures against freezing, such as the installation of heaters.

Measure the wind direction with a wind vane. In the installation of wind vanes on the measurement mast, the attachment must be in a manner that minimizes the effects on the wind vane from the meteorological mast and the boom.

For the wind direction, measure the 10-minute mean value. The sampling frequency used should be 1 Hz or higher.

It is desirable that the installation of anemometers and wind vanes is performed in accordance with JIS C 1400-12-1:2010 Annex G. The anemometer at the top of an measurement tower is attached to a vertical circular tube of the same external shape as that at the time of calibration. For the direction of the booms to which anemometers are attached, in order to properly evaluate wind shear, it is desirable that all the booms are installed in the same direction. It is desirable to install an anemometer as a backup for the anemometer installed at the top of an measurement tower. The backup anemometer should either be mounted on another boom at the same height, or installed at a height below the boom with a separation of at least 4 m.

For the installation of booms, it is recommended that the boom be installed in a direction 45° from the main wind direction on a cylindrical mast, and at 90° on a truss structure. When the wake effect of the measurement tower is large, it is desirable to install booms in three directions or more to conduct the measurement. It is better to avoid installing other instruments on a boom where an anemometer is installed. When a wind vane is installed, azimuth determination is important in order to direct the north mark to the accurate azimuth.

It is desirable to conduct wind measurements in cold regions in accordance with IEC 61400-12-1:2017 Annex O Power performance testing in cold climate.

When installing a meteorological mast, it is necessary to appropriately evaluate the external conditions at the installation site, and to confirm that the meteorological mast, its supporting structure, platform, and frame are structurally safe against loads due to extreme wind and extreme wave height, and against loads due to wind and wave fluctuations.

Wind measurements at sea are more likely to be affected by salt damage, wave splashing, and sand scattering than those on land, so higher weather resistance is required. Measurement sensors, cables, loggers, and power supply systems (including fuel cells) must have adequate measures implemented for waterproofing, dustproofing, and protection against salt damage (such as shielding, painting, and insulation strengthening), and it is desirable to prepare replacement items to enable a rapid response in the event of a failure.

For the power supply system, assume that access difficulties will occur due to stormy weather, and appropriately implement suitable redundancy measures and emergency response measures.

After the end of an measurement period, the anemometer should be recalibrated as necessary. If the result of the recalibration is different from the calibration result before the start of the measurement period, perform a comparison with other anemometers installed on the mast to identify the time when the difference began to appear. When this is complete, narrow down the evaluation period for the measurement data to the period when the measurement performance of the anemometer is within the allowable uncertainty. If recalibration is not performed, an alternative method is to check that the performance of an anemometer has not deteriorated during the entire measurement period by comparing it with other anemometers installed nearby. This is verified by evaluating any significant correlation changes over time.

Figure 3.1 shows the installation example of the offshore meteorological mast on the breakwater of the Mutsu Ogawara Port as a reference.

Figure 3.2 Example of offshore meteorological mast (Mutsu Ogawara Port)

3.3 Data analysis

Evaluation of the measurement results is conducted in accordance with the items in Table 2.2.

Before performing analysis, perform filtering to remove any abnormal values and calculate the effective data rate. Indicate the data removal method and criteria applied at the time of the calculation in the report.

When the wind measurement is affected by the wake of the tower, appropriately select the anemometers and wind vanes to be used for the analysis according to the wind direction. Examples of methods for selecting the anemometers installed on offshore wind measurement towers include the data processing performed at the Egmond aan Zee offshore wind farm in the Netherlands[5)], the processing performed at FINO3 in Germany[6)], and the processing performed at the site off Choshi, which was evaluated with reference to these two examples[7)].

4. Offshore measurement using Dual Scanning LiDAR

4.1 Selection of measurement points

4.1.1 Selection of measurement points

> Decide the measurement points based on the wind turbine layout and with consideration of the representative radius and the data acquisition rate at the offshore point.
>
> The measurement point in DSL measurement is the point where the laser beams from two SL units intersect. Install the SL in locations where there are no obstacles such as structures and trees along the line of sight between the installation location of each SL and the measurement point.

For the measurement heights, in order to properly evaluate the wind shear on the wind turbine rotor plane, perform measurements for a total of at least three heights.

It is desirable that the angle formed by the two lasers is between 30° and 150°[8),9)], and 90° is ideal.

For the obstacles in the vicinity, care should also be taken to avoid the laser entering the range of motion of objects that are moved by the wind, such as electric wires, guy wires, and tree branches. Figure 4.1 shows an example of an offshore wind measurement point using DSL (Mutsu Ogawara Port).

The effective data rate depends on the measurement distance and the weather conditions, so it is preferable to determine the measurement distance based on the performance of the equipment and the past weather data (such as fog, rain, snow, and aerosols) for the site. The data acquisition rate decreases in dense fog, heavy snow, snowstorms, and heavy rainfall[21)].

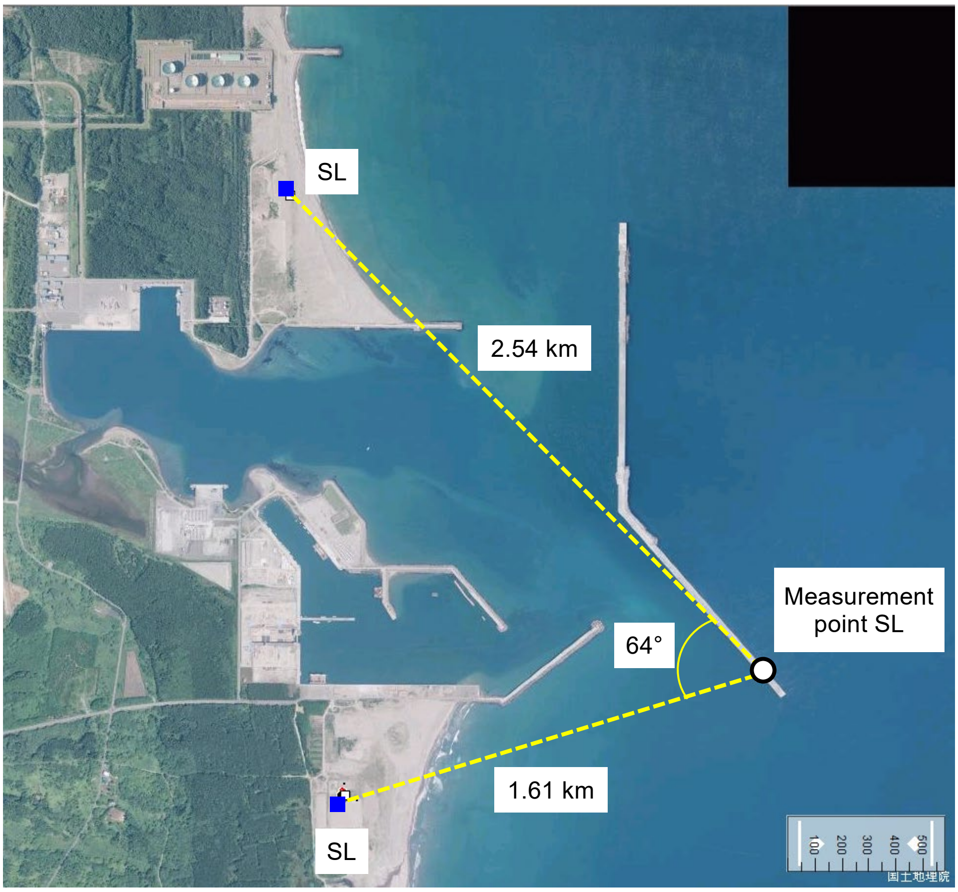


Figure 4.1 Example of an offshore wind measurement point using DSL (Mutsu Ogawara Port)

4.1.2 Installation of equipment

> When installing equipment, ensure that the levelness is maintained. The levelness of the equipment must also be maintained during the measurement period.

A slight deviation in the elevation angle of the laser causes a large deviation in the measurement height, so it is necessary to design the platform on which the equipment is installed so as to maintain the levelness during the measurement period. In Japan in particular, it is necessary to consider the situation regarding earthquakes in the local area.

Also, when installing equipment on a platform , perform adjustment so that the tilt angle and roll angle on the inclinometer inside the equipment become less than ±0.02°, and confirm that these are being maintained during the measurement period. The tilt angle and roll angle definitions are shown in Figure 4.2. (Positive and negative may be reversed, depending on the model.) Fix the equipment to the platform firmly so that it does not shift during the measurement period.

It is desirable to install fences around the equipment and platform so that animals and people other than related staff cannot enter.

If the planned site is an area where snow accumulates, set an appropriate platform height based on past weather records.

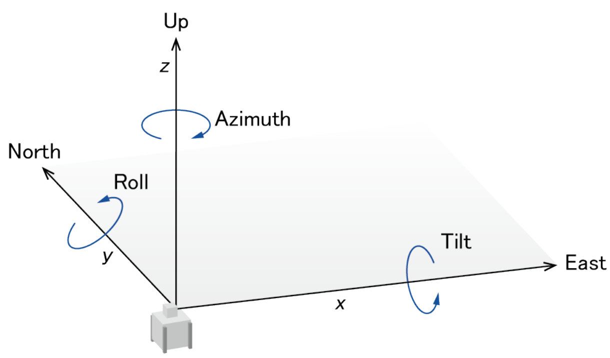


Figure 4.2 Definitions of RSD roll and tilt

4.1.3 Hard target adjustment

> Set the azimuth angle and elevation angle for the laser irradiation from an SL in accordance with the procedures in Annex A and include the results of the verification in the report.

In order to set the azimuth angle and elevation angle accurately, use GNSS surveying equipment to measure the latitude, longitude and height of the SL installation site and the fixed objects (hard targets) to be used for alignment. It is desirable to use three or more hard targets.

If the distance from the SL installation site to a hard target is too short, it is not possible to maintain sufficient positional accuracy. The guideline is to use a distance of around 1 km. The surveying instruments selected should have sufficient measurement accuracy. When the laser beam of the SL hits a fixed object, a strong CNR (carrier-to-noise ratio) value is observed. The offset value to be added to the settings on the SL for the azimuth angle and elevation angle can be calculated by checking the deviation between the azimuth angle and elevation angle of the hard target outputted by SL and the azimuth angle and elevation angle of the hard target (true values) when viewed from the actual SL installation location. This is called hard target adjustment.

4.2 Measurement of wind speed and wind direction

Conduct wind speed and wind direction measurement with devices that have had their accuracy verified in advance and the data acquisition rate confirmed. Perform the pre-deployment verification of accuracy in accordance with the procedures in Annex B and attach the results of the verification to the report. Perform the confirmation of the data acquisition rate in accordance with the procedures in Annex C and attach the results of the confirmation to the report. After the end of the measurement period, confirm that the measurement accuracy has been maintained.

For the measurement height, in order to evaluate the wind shear at the wind turbine rotor plane, set the elevation angle so that measurements are made at three points near the hub height, the rotor top tip height, and the rotor bottom tip height. Set the time intervals used in the switching between each measurement height (or elevation angle) with consideration of the accuracy and the effective data rate. Perform time synchronization so that the two SLs simultaneously observe the same measurement height.

For the wind speed, measure the 10-minute mean value and standard deviation. The SL sampling frequency for the radial velocity should be about 1 Hz or more.

Also, in cold regions where the temperature of the planned site falls below zero, implement measures against snow accumulation and freezing.

It is desirable for the elevation angle for measurement using DSL to be within 5°. Set the measurement height with consideration of the measurement distance and the heights of the hub, the rotor upper tip and the rotor bottom tip on the planned wind turbine.

The data acquisition rate and the measurement accuracy depend on the measurement settings, so the settings for the measurements at the planned site should be the same as the measurement settings (for range gate, integration time, and switching time of measurement heights) used in the pre-deployment verification of accuracy. If the measurement distance or the angle between the two lasers is significantly different between the pre-deployment verification of accuracy and the measurements at the planned site, then there is a risk that the accuracy at the time of the verification will not be guaranteed.

At present, there are cases in which just the standard measures on SL against snow accumulation and freezing (such as the wiper operation settings and wiper washer fluid concentration) do not have a sufficient effect, so it is hoped that solutions will be found in the future. Conduct periodic monitoring and corrective action to ensure that there are no long periods of missing measurement data in the winter.

4.3 Data analysis

4.3.1 Flow of data analysis

Perform the evaluation of the measurement results in accordance with the items related to wind speed and wind direction in Table 2.1. Clearly indicate the procedure for calculating the 10-minute average horizontal wind speed, wind direction, and wind speed standard deviation from the radial velocity obtained from each SL. Also include filtering in the procedure.

An example of the data analysis procedure is shown in Figure 4.3. When there is more than one filtering process, clearly indicate them so that it is possible to know their order.

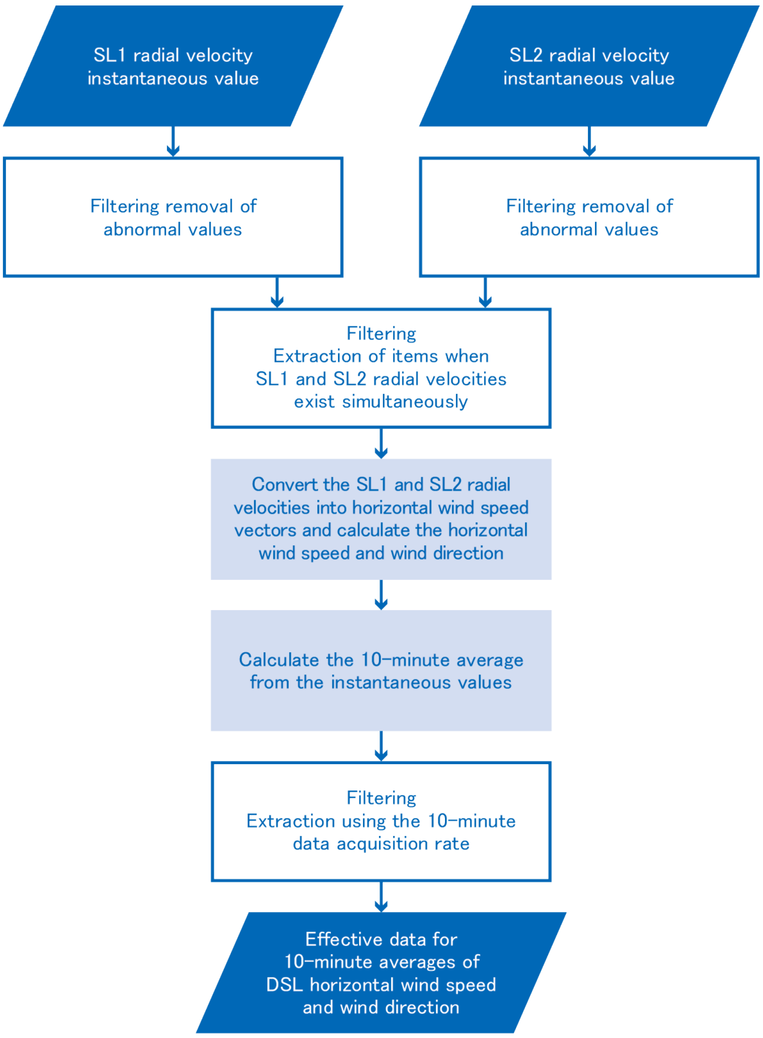


Figure 4.3 Example flowchart of data analysis procedure

4.3.2 Filtering

In order to calculate the 10-minute average horizontal wind speed, wind direction, and wind speed standard deviation, perform filtering to remove abnormal values.

Remove data from the measurement data set if it is data from a time when the equipment was in an abnormal state, from a time when the CNR value exceeded the threshold value, from a time when the radial velocities from the two SL units were not simultaneous, from a time when the instantaneous value of the radial velocity exceeded 3σ, or from a time when the 10-minute data acquisition rate was less than the threshold value. Here, the 10-minute data acquisition rate is the ratio of the number of valid data to the maximum number of data during a 10-minute period. For the 10-minute data acquisition rate, in order to ensure that the wind speed, wind direction and wind speed standard deviation are sufficiently accurate, set a threshold value with consideration of the time intervals used in the switching between each measurement height.

Additional filtering may be performed as needed.

Calculate the effective data rate after the filtering. Describe the filtering performed in the report.

In addition to the above, other possible filtering methods given to remove abnormal values and unreliable data include the use of the quantile value of the radial velocity, and the use of the difference between the maximum value and the average over a 10-minute period[10)-16)].

The 3σ filter is the general method used in quality control to remove abnormal values. An instantaneous value of radial velocity is excluded if it exceeds 3σ from the 10-minute average value or median value[13)].

In addition, it has been reported that high measurement accuracy can be achieved when the threshold value for the 10-minute data acquisition rate is set to 10% or more (so that the number of valid data items for 1 second of sampling must be 60 or more) and the time interval used in the switching between each measurement height is set to 10 to 20 seconds[13)].

4.3.3 Calculation of horizontal wind speed and wind speed standard deviation

Calculate the horizontal wind speed and wind speed standard deviation from the radial velocity of each SL.

The relationship between the radial velocity Vr and the horizontal components u, v and vertical component w of the wind velocity can be expressed by the equation (4.1) using the azimuth angle ϕ and the elevation angle θ.

$$Vr = u \sin\phi \cos\theta + v \cos\phi \cos\theta + w \sin\theta \tag{4.1}$$

Here, the definitions of the radial velocity, azimuth angle and elevation angle are shown in Figure 4.4. The calculation of the horizontal components u, v of the wind velocity from the radial velocity of the two SL units may be performed by omitting the third term on the right-hand side of equation (4.1) and using the following equations (4.2) and (4.3)[9)].

$$u = \frac{Vr_1 \cos\phi_2 \cos\theta_2 - Vr_2 \cos\phi_1 \cos\theta_1}{\cos\theta_1 \cos\theta_2 (\sin\phi_1 \cos\phi_2 - \sin\phi_2 \cos\phi_1)} \tag{4.2}$$

$$v = \frac{Vr_2 \sin\phi_1 \cos\theta_1 - Vr_1 \sin\phi_2 \cos\theta_2}{\cos\theta_1 \cos\theta_2 (\sin\phi_1 \cos\phi_2 - \sin\phi_2 \cos\phi_1)} \tag{4.3}$$

Here, the subscripts indicate the outputs from the first and second scanning LiDAR units.

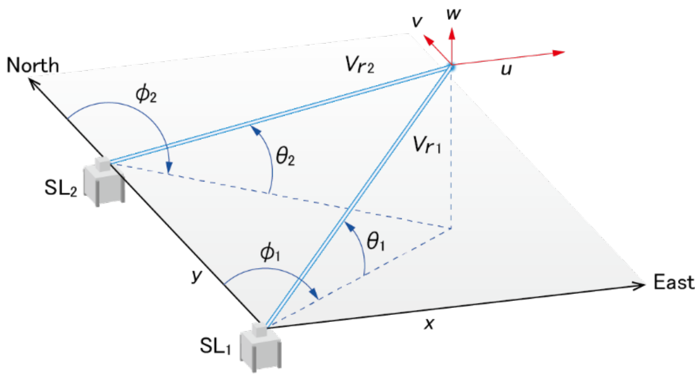


Figure 4.4 Relationship between the radial velocity and the horizontal and vertical components of the wind velocity

The calculation of the scalar wind speed U and the wind direction α from the horizontal component of the wind velocity can be performed using equations (4.4) and (4.5).

$$U = \sqrt{u^2 + v^2} \tag{4.4}$$

$$\alpha = \arctan\left(\frac{u}{v}\right) + \alpha_0$$

$$\alpha_0 = \begin{cases} +180; & for\ \ arctan\left(\frac{u}{v}\right) < 180 \\ -180; & for\ \ arctan\left(\frac{u}{v}\right) > 180 \end{cases} \tag{4.5}$$

The instantaneous values obtained for the scalar wind speed and the wind direction are used to calculate the 10-minute values of the average horizontal wind speed, the average horizontal wind direction, and the wind speed standard deviation. There is a risk that the length of the range gate may lead to an underestimation of the standard deviation of the wind speed[17),18)]. In this case, correction should be performed in accordance with 8.3.3.

5. Offshore measurement using Single Scanning LiDAR

5.1 Selection of measurement points

5.1.1 Selection of measurement points

Decide the measurement points based on the wind turbine layout and with consideration of the representative radius and the data acquisition rate at the offshore point.

The measurement point in SSL measurement is the center of the measurement azimuth sector.

Install the SL in a location where there are no obstacles such as structures and trees along the line of sight between the installation location of the SL and the measurement point.

The measurement azimuth sector should be decided with consideration of the wind direction appearance frequency distribution and the wind speed uniformity at the planned site.

For the measurement heights, in order to properly evaluate the wind shear on the wind turbine rotor plane, perform measurements for a total of at least three heights.

It is desirable that the size of the measurement azimuth sector (the arc range to be scanned) be from 30° to 60°[10].

The measurement error becomes large for wind that is blowing in the direction orthogonal to the laser irradiation, so it is desirable to select an installation location where the direction of the laser irradiation will not be orthogonal to the main wind direction. It is desirable to avoid a laser irradiation direction that is within ±15° of the direction orthogonal to the main wind direction.

In PPI measurement using SSL, in order to assume the uniformity of the wind speed within the measurement azimuth sector, the installation site is selected so that the changes in the topography and surface roughness within a sector are as small as possible.

The other recommendations are the same as in 4.1.1.

5.1.2 Installation of equipment

See 4.1.2.

5.1.3 Hard target adjustment

See 4.1.3.

Two or more hard targets are required in order to estimate the tilt angle and roll angle of the measurement sector plane.

In PPI measurement using SSL, if the tilt angle and the roll angle of the measurement sector plane are known, the azimuth with small inclination can be used for the measurement, and the height correction in the analysis can be considered.

5.2 Measurement of wind speed and wind direction

See 4.2. Set the size of the measurement azimuth sector and the scan speed so that the requirements for accuracy and effective data rate are satisfied.

In measurement using SSL, it is possible to observe the wind speed and the wind direction by using the PPI mode, in which the elevation angle is fixed and the azimuth angle is gradually varied.

Wherever possible, it is desirable that the same measurement conditions (measurement distance, measurement azimuth sector size, and wind speed distribution) be used for the measurements at the planned site and the accuracy verification. In particular, there is a risk that the accuracy at the time of the verification will not be guaranteed if there is a significant difference between the accuracy verification conditions and the measurement distance or wind speed distribution (wind speed uniformity) at the planned site.

At present, there are cases in which just the standard measures on SL against snow accumulation and freezing (such as the wiper operation settings and wiper washer fluid concentration) do not have a sufficient effect, so it is hoped that solutions will be found in the future. Conduct periodic monitoring and corrective action to ensure that there are no long periods of missing measurement data in the winter.

5.3 Data analysis

5.3.1 Flow of data analysis

Perform the evaluation of the measurement results in accordance with the items related to wind speed and wind direction in Table 2.1. Clearly indicate the procedure for calculating the 10-minute average horizontal wind speed and wind direction from the radial velocity obtained from the SL. Also include filtering in the procedure.

An example of the data analysis procedure is shown in Figure 5.1. When there is more than one filtering process, clearly indicate them so that it is possible to know their order.

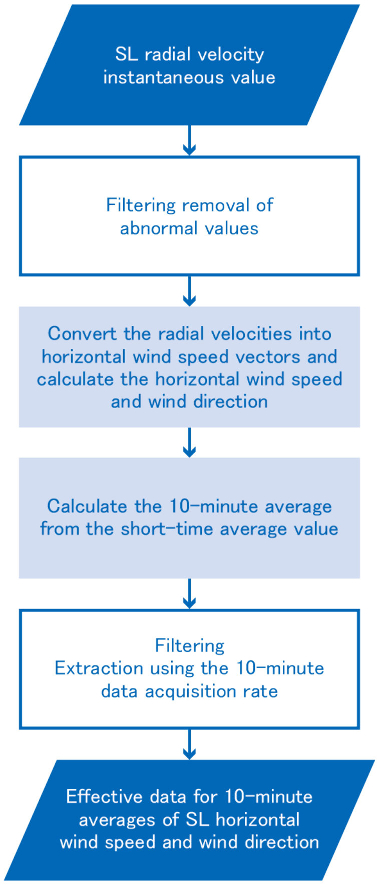


Figure 5.1 Example flowchart of data analysis procedure

5.3.2 Filtering

See 4.3.2. However, it is not necessary to use the item for the removal of data when the radial velocities from the two units are not synchronized.

It has been reported that sufficient measurement accuracy can be achieved when the threshold value for the 10-minute data acquisition rate is set to 10% or more and the number of radial velocity data to be input to equation (5.5) is set to 4 or more[22].

5.3.3 Calculation of horizontal wind speed

The horizontal wind speed is calculated from the radial velocity from the SL.

The calculation of the horizontal components u, v of the wind velocity from the radial velocity Vr may also be performed using PPI[22]. As in the case of DSL measurement, the relationship between the radial velocity and the horizontal components and vertical component of the wind velocity can be expressed using the azimuth angle φ and the elevation angle θ. The calculation formulas include Velocity Volume Processing (VVP) and Velocity Azimuth Processing (VAP)[10]. The example of VVP is shown here.

$$Vr = u \sin\phi \cos\theta + v \cos\phi \cos\theta + w \sin\theta \quad (5.1)$$

Here, if the third term on the right-hand side is omitted, the equation (5.1) becomes:

$$Vr = u \sin\phi \cos\theta + v \cos\phi \cos\theta \quad (5.2)$$

The horizontal components u, v of the wind speed can be calculated using the least squares method from the plurality of sets of observed values of the radial velocity and the azimuth angle that are obtained from one PPI scan. Specifically, if the sum of squares of the estimated error is:

$$J = \frac{1}{2}\sum_{i=1}^{N}\{Vr' - (u \sin\phi + v \cos\phi)\}^2 \quad (5.3)$$

and

$$\frac{\partial J}{\partial u} = 0, \quad \frac{\partial J}{\partial v} = 0 \quad (5.4)$$

are given as conditions, then u and v become:

$$\begin{bmatrix} u \\ v \end{bmatrix} = \frac{1}{\sum \sin^2\phi \sum \cos^2\phi - (\sum \cos\phi \cdot \sin\phi)^2} \begin{bmatrix} \sum \cos^2\phi & -\sum \cos\phi \cdot \sin\phi \\ -\sum \cos\phi \cdot \sin\phi & \sum \sin^2\phi \end{bmatrix} \begin{bmatrix} \sum \sin\phi \cdot Vr' \\ \sum \cos\phi \cdot Vr' \end{bmatrix} \quad (5.5)$$

Here, Vr' is $Vr/\cos\theta$. As in the previous section, the calculation of the scalar wind speed U and the wind direction α from the horizontal component of the wind velocity is performed using equations (4.4) and (4.5).

The short-time average values obtained for the scalar wind speed and the wind direction (for example, the average over 15 seconds if it is a 45° horizontal scan performed at 3° per second) are used to calculate the 10-minute values of the average horizontal wind speed and the average horizontal wind direction.

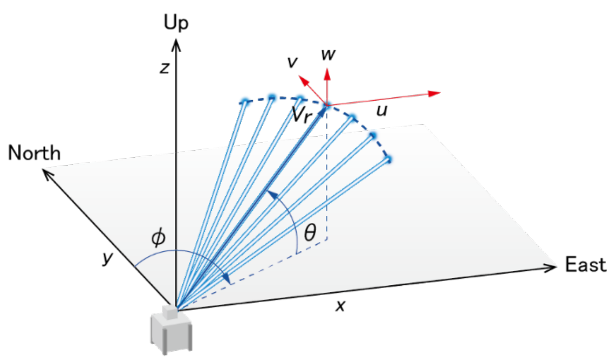


Figure 5.2 Relationship between the radial velocity and the horizontal and vertical components of the wind velocity

6. Offshore measurement using vertical LiDAR

6.1 Selection of measurement points

6.1.1 Selection of measurement points

Select the measurement points based on the wind turbine layout and with consideration of the representative radius. When simultaneous measurement will be performed with a meteorological mast, the installation should be in a location adjacent to the meteorological mast.

It is desirable that measurements by VL be performed in accordance with IEC 61400-12-1:2017 Annex L The application of remote sensing technology. The laser must be installed so that it does not hit an obstacle.

The further the distance from the meteorological mast becomes, the lower the correlation becomes for the wind speeds and wind directions.

6.1.2 Installation of equipment

See 4.1.2.

It is desirable for the installation of VL to be performed in accordance with IEC 61400-12-1:2017 Annex L. When VL is installed, azimuth determination is important in order to direct the north mark to the accurate azimuth. If the north mark is installed in a direction other than north, measure the exact offset value. Also, when installing equipment on a platform, perform adjustment so that the roll angle and tilt angle on the inclinometer inside the equipment become less than ±0.2°, and confirm that these are being maintained during the measurement period. The definitions of the tilt angle and roll angle are the same as in Figure 4.2. Fix the equipment to the platform firmly so that it does not shift during the measurement period.

It is desirable to install fences around the equipment and platform so that animals and people other than related staff cannot enter.

If the planned site is an area where snow accumulates, set an appropriate platform height based on past weather records.

When installing a vertical LiDAR on the platform of an offshore meteorological mast, evaluate the external conditions at the site and take steps to prevent the equipment and power systems being directly hit by high waves or breaking waves. Wind measurements at sea are more likely to be affected by salt damage, wave splashing, and sand scattering than those on land, so higher weather resistance is required. Measurement sensors, cables, loggers, and power supply systems (including fuel cells) must have adequate measures implemented for waterproofing, dustproofing, and protection against salt damage (such as shielding, painting, and insulation strengthening), and it is desirable to prepare so that a rapid response can be made in the event of a failure.

For the power supply system, assume that access difficulties will occur due to stormy weather, and appropriately implement suitable redundancy measures and emergency response measures.

6.2 Measurement of wind speed and wind direction

Conduct wind speed and wind direction measurement with devices that have had their accuracy verified in advance. Perform the pre-deployment verification of accuracy for VL in accordance with the procedure in IEC61400-12-1:2017, or in a procedure recognized as equivalent, and attach the verification results to the report. After the end of the measurement period, confirm that the measurement accuracy has been maintained.

For the measurement height, in order to evaluate the wind shear at the wind turbine rotor plane, set multiple measurement heights that include three points near the hub height, the rotor top tip height, and the rotor bottom tip height.

For the wind speed, measure the 10-minute mean value.

Also, in cold regions where the temperature of the planned site falls below zero, implement measures against snow accumulation and freezing.

For VL, the measurement height is set with consideration of the measurement height of the meteorological mast and the hub height and rotor diameter of the planned wind turbine.

When VL and a meteorological mast are combined to handle the data as measurement data at the hub height and use it as input data for airflow analysis for the calculation of the site wind conditions, it is necessary to satisfy requirements for the effective data rate after complementation that are equivalent to those for cup anemometers and wind vanes.

Also, in cold regions where the temperature of the planned site falls below zero, measures must be taken against freezing, such as the installation of heaters, the installation of wiper blades for winter, the setting of appropriate wiper operation, and the adjustment of the concentration of wiper washer fluid.

Measurement errors occur in the measurement of turbulence intensity by VL, so it is necessary to correct this by the method proposed by Yamaguchi et al[2].

6.3 Data analysis

Perform the evaluation of the measurement results in accordance with the items related to wind speed and wind direction in Table 2.1.

Before performing analysis, perform filtering to remove any abnormal values and calculate the effective data rate. Indicate the data removal method and criteria applied at the time of the calculation in the report.

Example methods for calculating the horizontal wind speed from the radial velocity of VL are the DBS method and the VAD method. The equation shown here is the equation for calculating the horizontal wind speed components *u*, *v* from the radial velocity in the north, south, east, and west directions by the DBS method. In addition, the equation for calculating the vertical wind velocity component *w* is also shown. The definitions of radial velocity and elevation angle are given in Figure 6.1.

$$u = \frac{u_{rE} - u_{rW}}{2 \sin \theta} \quad (6.1)$$

$$v = \frac{u_{rN} - u_{rS}}{2 \sin \theta} \quad (6.2)$$

$$w = \frac{u_{rN}+u_{rS}+u_{rE}+u_{rW}}{4\cos\theta} \tag{6.3}$$

or,

$$w = u_{rZ} \tag{6.4}$$

Where:

u_{rN}: radial velocity in northerly direction, u_{rS}: radial velocity in southerly direction, u_{rE}: radial velocity in easterly direction, u_{rW}: radial velocity in westerly direction, u_{rZ}: radial velocity in vertical direction, θ: elevation angle

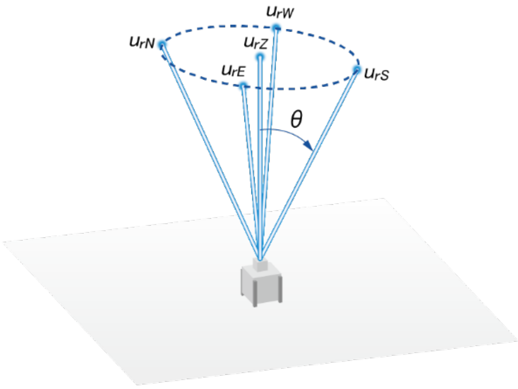


Figure 6.1 Definitions of radial velocity and elevation angle

7. Offshore measurement using a Floating LiDAR System

7.1 Selection of measurement points

7.1.1 Selection of measurement points

Select the measurement points based on the wind turbine layout and with consideration of the representative radius. When simultaneous measurement will be performed with an offshore meteorological mast, the installation should be in a location adjacent to the offshore meteorological mast. In addition to the natural environmental conditions, sufficient consideration should also be given to social environmental conditions such as the volume of vessel traffic, fishing areas, and seabed obstacles.

It is desirable that the selection and installation of FLS measurement points be conducted in accordance with IEA RP 18. Floating LIDAR systems (2017) and Carbon Trust OWA Roadmap for the Commercial Acceptance of Floating LiDAR Technology (2018) (hereinafter referred to as the "Carbon Trust OWA Roadmap for FLS").

In the selection of an FLS, gain a sufficient understanding of the natural environmental conditions at the installation site, such as the weather and sea conditions, water depth, and distance from the shore, and then select a model suitable for the investigation purpose and the application.

When simultaneous measurement is performed with an offshore meteorological mast, the further the distance between the FLS and the offshore meteorological mast becomes, the lower the correlation becomes for the wind speed and the wind direction, so the FLS and the offshore meteorological mast should be placed as close together as possible. When performing FLS accuracy verification or calibration, it is desirable that the distance between the FLS and the offshore meteorological mast be within 500 m. In the same way, a distance of within 500 m is also desirable when an FLS and an offshore meteorological mast are combined to handle the data as measurement data at the hub height and use it as input data for airflow analysis for the calculation of the site wind conditions. It is desirable that the distance between the FLS and the offshore meteorological mast be within the recommended distance described above, but the distance should be set according to the situation of the site measurement such as the local water depth and the mooring system of the FLS.

In FLS measurement, once the measurements have begun at sea, the aspect of access means that it is not easy to carry out maintenance work at the site. For this reason, it is necessary to carefully perform accuracy verification and operation checks for each system to be used on the FLS before installing the FLS in the site sea area.

Figure 7.1 shows an example FLS layout for reference.

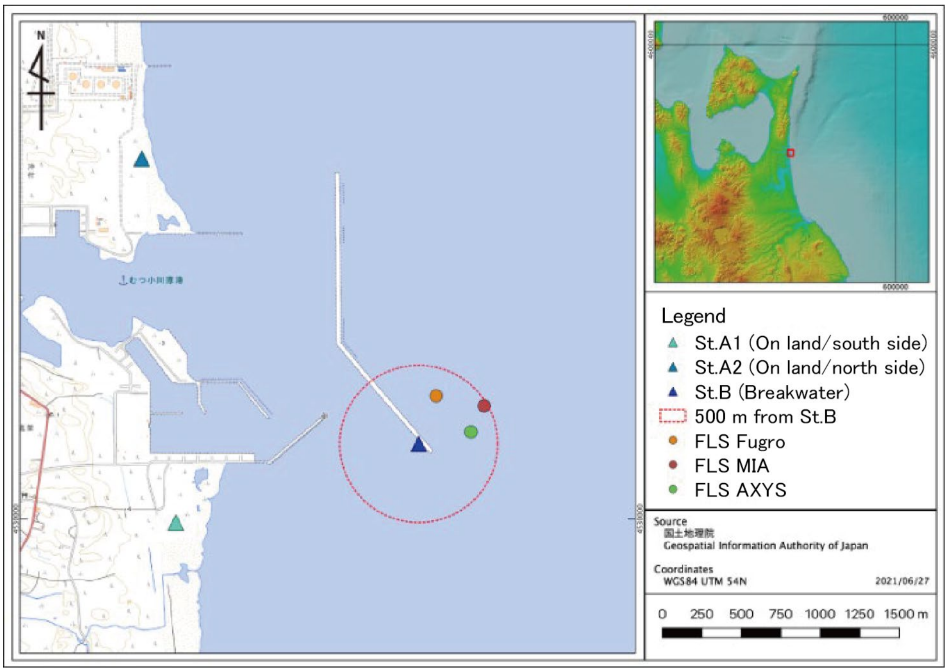


Figure 7.1 Example FLS layout

7.1.2 Installation of equipment

When installing an FLS, it is necessary to conduct the prescribed authorization procedures with the Japan Coast Guard and the relevant prefectural departments. In addition, before installing the equipment, perform sufficient coordination with the users of the sea area, such as those involved in fisheries, harbors, and maritime affairs, and also widely publicize information on the specifications and schedule of the measurements.

The installation work involves various related parties such as the requesting party, the manufacturer, and the contractor conducting the installation work, so it is important to clarify the division of work and the system of instructions at the stage of the execution planning, and to incorporate these into the execution plan, including the safety management aspects.

Constantly monitor the position information for the FLS during the measurement period and put in place an emergency system to immediately respond to any problems such as mooring failure.

An accident of FLS mooring failure could have far-reaching effects in Japan’s coastal waters. In particular, it is necessary to avoid causing damage to other users of the sea area, and this resulting in an impact on the entire power generation business. The following points are important in order to prevent mooring failure accidents, and to minimize the impact if such an accident occurs.

- Gaining an understanding of the sea conditions and weather conditions in the installation sea area
- Implementing a detailed mooring analysis and careful design checks to ensure a high safety factor
- Improving the efficiency of the work on site during the execution and avoiding human error based on a checklist
- Constant monitoring of the FLS position and the construction of an alert communication system in case of mooring failure
- Preparation of a crisis management manual and an emergency contact network and a prompt initial

response in the event of a mooring failure

- Investigation of the impacts of mooring failure and responses for the relevant parties
- Resumption of measurement based on careful investigation of the cause of a mooring failure and consideration of recurrence prevention measures

Figure 7.2 shows an example of the flow of FLS installation work for reference.

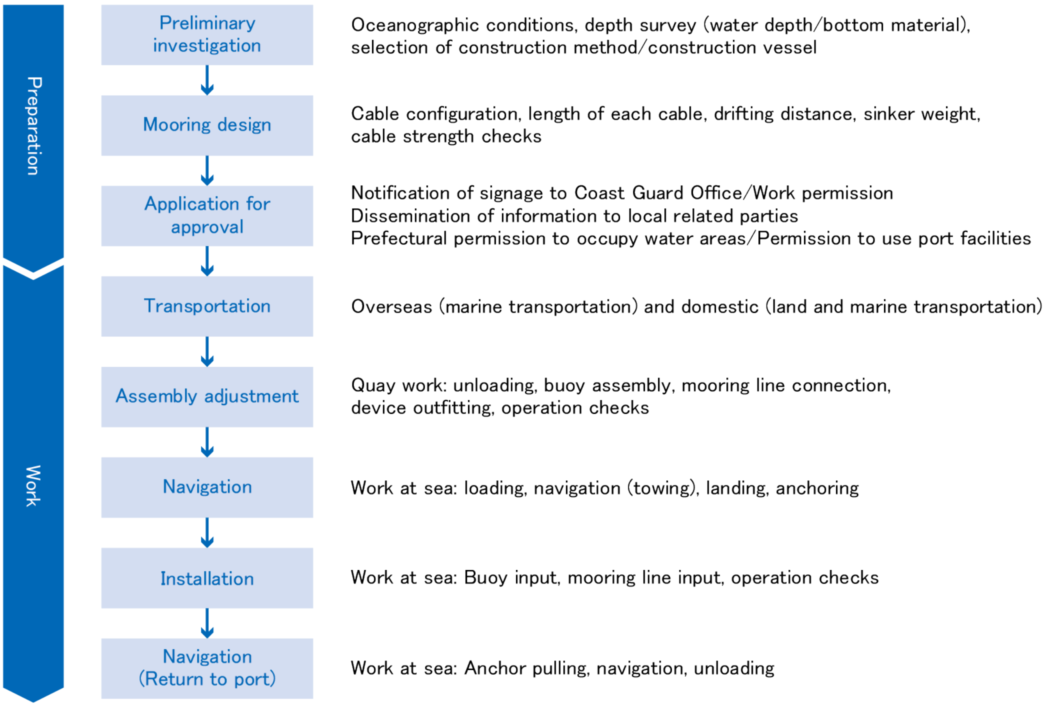


Figure 7.2 Example flow of FLS installation work

Installation and maintenance work at sea often involve periods having to wait on standby due to stormy weather. In FLS measurements, it is desirable to carry out process control with the top priority given to safety and a reasonable schedule for matters such as authorization procedures and the arrangement of various work. Examples of FLS installation work are shown in Annex D.

Table 7.1 shows an example of the flow of authorization procedures for FLS for reference. At present, there are few previous examples of FLS installation, so there are concerns that the procedures may not advance smoothly. It is important to gain an understanding of the local issues through prior consultation.

Table 7.1 Example of the flow of authorization procedures for FLS installation

No.	Item	Counterparty	Contents	Main related laws and regulations
1	Preparation	-	Preparation of FLS installation plan, information survey using NeoWins, etc.*1, understanding of contents of each guidebook, understanding of sea area of installation*2	
2	Prior consultation	Prefecture Coast Guard Office Fisheries cooperative	Explanation of FLS installation plan, check of utilization procedures, understanding the fishery personnel and sea area users Explanation of FLS installation plan, consultation on facility lights, understanding the fishery personnel and sea area users Greetings and explanations to fishery representatives from fishery cooperatives, etc., understanding the situation of the local fishing industry and the sea areas where fishery rights are applicable	Fishery Act
3	Application for permission to install navigational aids*3	Coast Guard Office	Application for installation of permission signs and simplified signs, etc.	Navigation Aid Act
4	Application for permission to occupy a sea area*4	Prefecture	Permission to use a sea area by installing a floating body and mooring lines and the payment of costs	Prefectural ordinances and control regulations
5	Dissemination of information to related parties	Fishery personnel Water area users	Preparation and distribution of materials to disseminate information on the FLS installation plan	
6	Application for construction work permission*5	Coast Guard Office (Station)	Permission application or notification submission for maritime construction, work, etc.	Port Regulations Act or Maritime Traffic Safety Act
7	Application for port facility use	Port administrator	Use of port facilities such as quays and yards	Port and Harbor Act

*1. Use resources such as NeoWins (the NEDO Offshore Wind Conditions Map) to investigate the social and environmental information for the target sea area in advance (such as the fishery rights, port area, fishing port area, passage, Quasi-National Parks, etc.).

*2. The sea areas where FLS are installed are mainly divided into two types: port areas and general sea areas. General sea areas are areas of the territorial sea and inland water that are not a port area or any other area provided for in a relevant law.

*3. A lot of FLS products come from overseas, so the Coast Guard Office procedures for lighting may take some time. It is desirable to make the application with sufficient time. Also, confirm that the communication equipment complies with the Radio Act (the Ministry of Internal Affairs and Communications).

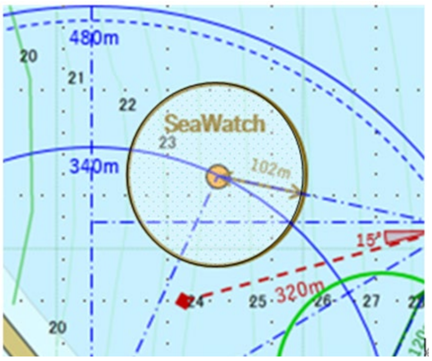
*4. The ordinances and control regulations, etc., enacted by individual prefectures are applied to the permission to occupy general sea areas. Caution is required as the contact point responsible differs from prefecture to prefecture.

*5. The period required for the procedures for No. 3 to No. 6 is about two to three months.

The method for determining the water area occupied depends on the mooring method. The case of the Aomori Prefecture Kamikita District Administration Office is shown below.

Table 7.2 Example methods of occupied area calculation

Mooring type	Contents
Single point catenary mooring buoy	Drifting radius squared x 3.14
Three point catenary mooring buoys	Main body: Drifting radius squared x 3.14 Mooring lines: Width x Length x Quantity Anchors: Length x Width x Quantity

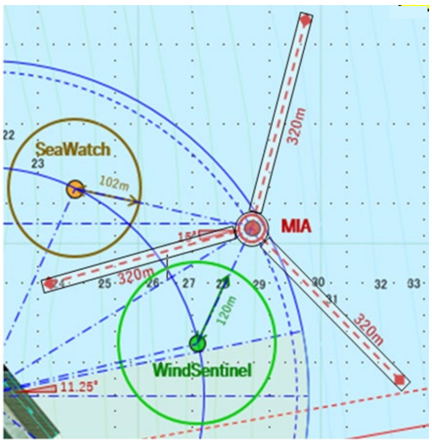


[Example methods of occupied area calculation]

Drifting radius: 102 m

Occupied area: 102 m × 102 m × π = 32,669 m^2

(a) Single point catenary mooring buoy



[Example methods of occupied area calculation]

Drifting radius: 20 m

Occupied area:

(Main body) 20 m × 20 m × π = 1,256 m^2

(Mooring lines) 0.2 m × 320 m × 3 ropes = 1,536 m^2

(Anchors) 5 m x 1.5 m x 3 places = 24 m^2

Total 2,816 m^2

(b) Three point catenary mooring buoy

Figure 7.3 Example methods of occupied area calculation

7.2 Measurement methods

See 6.2.

An FLS is an measurement system in which an measurement part including VL and a floating body platform are integrated. Therefore, the wind condition measurement method using an FLS is the same as the measurement method using VL.

Although the Carbon Trust OWA Roadmap for FLS has established a methodology for evaluating the technical maturity of FLS equipment, there are still not many systems that have achieved Stage 3, which is the highest technical maturity.

The turbulence intensity obtained from an FLS tends to be excessive due to the swaying motion of the floating body. In order to remove this effect, there are FLS that have a function to compensate for the swaying motion, and methods for correction by post-processing the measurement data[3),4)]. Correction is necessary in the same way as for the VL described above[2)].

7.3 Data analysis methods

Perform the evaluation of the measurement results in accordance with the items related to wind speed and wind direction in Table 2.1.

Before performing analysis, perform filtering to remove any abnormal values and calculate the effective data rate. Indicate the data removal method and criteria applied at the time of the calculation in the report.

8. Complementation of missing data and its accuracy verification

8.1 System utilization rate and effective data rate

The system utilization rate ξ [%] during the measurement period is the number of 10-minute data sets when the system was operating divided by the total number of 10-minute periods during the measurement period, and is defined by equation (8.1).

$$\xi = \frac{\text{Number of 10-minute periods the system}}{\text{Total number of 10-minute periods during the measurement period}} \times 100\ (\%) \quad (8.1)$$

The effective data rate during the measurement period after filtering η [%] is the number of 10-minute data sets after applying the aforementioned filter for removing abnormal values from the acquired data, divided by the total number of 10-minute periods during the measurement period, and is defined by equation (8.2).

$$\eta = \frac{\text{Number of 10-minute periods which data is valid}}{\text{Total number of 10-minute periods during the measurement period}} \times 100\ (\%) \quad (8.2)$$

The abnormal values are removed from the measurement data before they are evaluated as the wind conditions necessary for the prediction of the energy yield and for the wind turbine design. As described in 2.3, it is necessary to have an effective data rate of 95% or more after the filtering to remove abnormal values. When the effective data rate does not satisfy 95%, complementation is performed using nearby measurement data.

Compared to meteorological masts, RSD are more affected by weather conditions and tend to have a lower effective data rate, so there is a high necessity for complementation. For the measurement data used for the complementation, it is recommended to use the measurement data from meteorological masts and vertical LiDAR installed on the land in the vicinity of the offshore measurement point. See Chapters 3 and 6, respectively, for the requirements for the meteorological masts and VLs. However, the matters concerning offshore measurement are unnecessary.

8.2 Complementation of missing data

If there is a period in which the wind condition measurement data is missing or shows abnormal values, such as due to a failure of the measurement devices or weather conditions, etc., and the effective data rate does not satisfy 95%, perform compensation using nearby measurement data. The effective data rate after the complementation should be at least 95%. If compensation using measurement data is performed, verify the accuracy of that complementation and show the validity of the complemented data.

It is desirable that there are no particular periods during the year when the wind condition measurement data is missing or is abnormal values.

For reference, Table 8.1 shows the Key Performance Indicators (hereinafter referred to as KPI) and acceptance criteria in the Carbon Trust OWA Roadmap for FLS for the effective data rate after filtering. This KPI here means the key performance indicators for evaluating the RSD system utilization rate, effective data rate, and accuracy.

When evaluating the wind conditions over the year, the recommended value for the monthly effective data rate should be set with reference to Table 8.1.

Table 8.1 KPIs and acceptance criteria for the effective data rate for FLS after filtering

KPI	Acceptance criteria
Monthly effective data rate after filtering	Stage 2: ≥ 80% Stage 3: ≥ 85%
Annual effective data rate after filtering	Stage 2: ≥ 85% Stage 3: ≥ 90%

If the annual effective data rate does not satisfy 95%, perform complementation using measurement data from meteorological masts and VL installed in the vicinity of the measurement point.

The complementation of the wind speed and wind direction is generally performed using the Measure-Correlate-Predict (hereinafter referred to as “MCP”) method. The MCP method is a method in which the missing data of the complementing target is predicted from the data of the complementing source by using a linear regression equation that is calculated using the data of the complementing source and the data of the complementing target when those data exist for the same points in time.

For the correction of the standard deviation of wind speed, as the error of the 90% quantile value of turbulence intensity by the linear regression equation is large, Watanabe[14)] et al. proposed a method using double bias correction (DBC)[26)].

8.3 Accuracy KPIs and acceptance criteria

8.3.1 Wind speed and wind direction

Table 8.2 shows the KPIs and acceptance criteria for wind speed and wind direction accuracy in all wind directions. For wind speed, the KPIs are the regression equation slope and coefficient of determination by correlation analysis. For wind direction, the KPIs are the regression equation slope, intercept, and coefficient of determination. The intercept of the regression equation for the wind direction is the difference between the average value of the reference wind direction and the LiDAR wind direction average.

Table 8.2 Accuracy KPIs and acceptance criteria

KPI		Evaluated item	Accuracy acceptance criteria
Wind speed	Slope of the regression equation	Wind speeds of 4 m/s or more and less than 16 m/s	Minimum: 0.97 to 1.03 Best practice: 0.98 to 1.02
	Coefficient of determination	As above	Minimum: ≥ 0.97 Best practice: ≥ 0.98
Wind direction	Slope of the regression equation	Wind speeds of 4 m/s or more and less than 16 m/s	Minimum: 0.95 to 1.05 Best practice: 0.97 to 1.03
	Intercept of the regression equation	As above	Minimum: < 10° Best practice: < 5°
	Coefficient of determination	As above	Minimum: ≥ 0.95 Best practice: ≥ 0.97

If data complementation is used, check whether the complementation method is appropriate. Evaluate the complemented measurement data by using accuracy KPIs and acceptance criteria.

Accuracy verification methods that take into account the effective data rate of the measurement data include the research by Enoki and Ishihara[25)] and the research by Watanabe et al.[14)].

The wind speed range when performing accuracy verification should be 4 m/s or more and less than 16 m/s. For reference, Table 8.3 shows the wind speed range for accuracy verification in the Carbon Trust OWA Roadmap for FLS. In the Carbon Trust OWA Roadmap for FLS, the purpose is to evaluate the performance of the FLS as a device, so evaluation at 2 m/s or higher is included. In the IEC61400-50-2 classification tests, the range is 4 m/s or more and less than 16 m/s. As described in Chapter 2, the purpose in this Guidebook is the wind condition estimation necessary for the prediction of the energy yield and the wind turbine design, so the range covered is 4 m/s or more and less than 16 m/s, which is the wind speed range that contributes greatly to power generation and load.

Table 8.3 Accuracy KPIs and acceptance criteria in the Carbon Trust OWA Roadmap for FLS

KPI		Evaluated item	Accuracy acceptance criteria
Wind speed	Slope of the regression equation	a) Wind speeds of 4 m/s or more and less than 16 m/s b) 2 m/s or more	Minimum: 0.97 to 1.03 Best practice: 0.98 to 1.02
	Coefficient of determination	As above	Minimum: ≥ 0.97 Best practice: ≥ 0.98
Wind direction	Slope of the regression equation	2 m/s or more	Minimum: 0.95 to 1.05 Best practice: 0.97 to 1.03
	Intercept of the regression equation	As above	Minimum: < 10° Best practice: < 5°
	Coefficient of determination	As above	Minimum: ≥ 0.95 Best practice: ≥ 0.97

8.3.2 Wind speed standard deviation

In the accuracy verification for turbulence intensity, perform evaluation based on the following indices and also present charts comparing the RSD with a cup anemometer regarding the wind speed standard deviation per wind speed class (mean value and 90% quantile value) and the frequency distribution by wind speed class.

The range for the evaluation should be the wind speed data that is 4 m/s or more and less than 16 m/s.

$$\text{90\% quantile of standard deviation of wind speed for } k\text{th bin } (\sigma 90_k) = \overline{\sigma}_k + 1.28 \cdot std(\sigma_k) \quad (7.3)$$

$$\text{Bin weighted average error (-)} = \sum_{k=1}^{N} f_k \cdot \left(\sigma 90_{RSD,k} - \sigma 90_{cup,k}\right) \quad (7.4)$$

Where:

N: Number of wind speed bins (k = 1, 2, ..., N)

$\sigma 90_{RSD,k}$: 90% quantile of the standard deviation of the wind speed of the kth bin of the LiDAR

$\sigma 90_{cup,k}$: 90% quantile of the standard deviation of the wind speed of the kth bin of the cup anemometer

f_k: Frequency ratio of the kth bin of the cup anemometer

$\overline{\sigma}_k$: Average value of standard deviation of wind speed for kth bin

$std(\sigma_k)$: Standard deviation of standard deviation of wind speed for kth bin

In addition to a chart comparing the standard deviations of the wind speeds, it is desirable to also show a chart comparing the turbulence intensities.

8.3.3 Correction of wind speed standard deviation

> If the result of the verification of the turbulence intensity accuracy is that it is an underestimate, correction must be performed. If a correction is made, repeat the verification of the accuracy to show the validity of the corrected data.

The possible correction methods when the DSL turbulence intensity is an underestimate include to add the difference between the standard deviations of the wind speeds of the DSL and cup anemometer by wind speed class[17),18)]. Caution is required if the measurement height at the time of the accuracy verification differs from the measurement height at the offshore measurement point at the planned site, because the error may differ depending on the height.

After a correction, in addition to a chart comparing the standard deviations of the wind speeds, it is desirable to also show a chart comparing the turbulence intensities.

9. Reporting

9.1 Installation and measurement reports

Reports of the measurements at a site and reports of the evaluation of measurement results should comply with IEC61400-12-1 and indicate at least the following items.

(1) Site situation

- Exact coordinates of the measurement points (including datum)
- Photographs taken in a 360° circumference around all the measurement points
- Topographic map of the site showing the measurement points

(2) Description of the measurement system

- Specifications of the measurement devices and data collection systems (including calibration report for the measurement devices and RSD verification results)
- The installation, layout and setting heights of the measurement apparatus (all the sensors and RSDs)
- If a scanning LiDAR is used, a document showing the accuracy of the measurement
- Measurement device layout diagram and drawings including the main dimensions
- Document indicating that the accuracy of the wind speed measurement during the measurement period was maintained

(3) Description of the measurement procedure

- Description of the measurement procedure, sampling frequency, averaging time, measurement period
- Records (dates and times) of all significant events and maintenance during the measurement period

With respect to the install and layout of the instruments, indicate the height level such as the ground level and/or the mean sea level. If an RSD is to be mounted on a platform, the height of the platform should also be indicated, and the height set for the device and the height above the ground should be indicated.

The RSD validation results referred to here are the results of the pre-shipping testing by the manufacturer. If no RSD verification results are provided by the manufacturer, this should be indicated. Section 8.3 describes the report of RSD verification at a site.

It is desirable to indicate the measurement point, the planned wind turbine position, and the separation distance.

9.2 Evaluation report

At least the following items should be included in the evaluation of the measurements.

(1) Effective data rate

- Include the effective data rate for the entire measurement period and for each month. Include the data removal criteria applied when calculating the effective data rate.

(2) Wind direction and wind speed

- Include the average value, minimum value and maximum value of the wind speed in tabular form for the entire measurement period and for each month.
- Include the Weibull shape coefficients and scale coefficients by directional and the frequency distribution by directional in a tabular form (with wind direction sectors that do not exceed 30°). Include a wind rose.

(3) Turbulence intensity

- Include the ambient turbulence intensity by directional in a tabular form (with wind direction sectors that do not exceed 30°).
- Include a comparison of the ambient turbulence intensity with the IEC Turbulence Category (NTM), considering all directions.

The number of measurement heights included in the evaluation report should be at least three heights for wind speed and one height for turbulence intensity.

9.3 Verification report

When an RSD is used, show the results of checks of the requirements for accuracy verification shown in Chapter 7.

(1) Measurement device installation report for the verification site

- Follow section 8.1.

(2) Evaluation report for the measurement data used in the verification

- Follow section 8.2.

(3) Verification results

- Include the results of wind speed and wind direction correlation analysis (parameters and scatter plots) and the results of checks of the requirements.
- Include the results of ambient turbulence intensity comparisons (parameters and figures) and the results of checks of the requirements.

References

1) T Mikkelsen, J Mann and M Courtney: Wind Scanner: A full-scale Laser Facility for Wind and Turbulence Measurements around large Wind Turbines, EWEC2008.
2) Atsushi Yamaguchi, Akifumi Kyomasu, Takeshi Ishihara: Turbulence Measurement by Using Doppler Lidar and its verification by using synthetic turbulent wind field, 44th Wind Energy Symposium, 2022.
3) A.Yamaguchi, T.Ishihara: A new motion compensation algorithm of floating lidar system for the assessment of turbulence intensity, Journal of Physics: Conference Series 753 072034, 2016.
4) F.Kelberlau, V.Neshaug, L.Lønseth, T.Bracchi, J.Mann: Taking the Motion out of Floating LIDAR: Turbulence Intensity Estimates with a Continuous-Wave Wind LiDAR, Remote Sens. 12, 898, 2020.
5) J.Eecen, L.A.H.Machielse, A.P.W.M. Curvers: Meteo- rological Measurements OWEZ Half year report, 01-07-2005-31-12-2005, 2007.
6) D. Kindler and A. Gütschow: The FINO3 Wind Energy Research Platform in the North Sea: First Results & Comparison to Concurrent FINO1 Data, Bremen, 2010.
7) Koji Hayashida, Toru Yamanaka, Kazumasa Okubo, Takeshi Ishihara, Atsushi Yamaguchi, Yukinari Fukumoto: The Wind Measurement for Offshore Wind Power Generation - Off the Coast of Choshi, Journal of Wind Engineering, Vol. 43, No. 3, 2018.
8) Leosphere M. Steger: Dual Scanning Lidar: Main Uncertainty Contributors, VAISALA webinar "Dual scanning lidar to increase accuracy and efficiency for offshore wind campaigns", 2021.
9) N. Vasiljevic, M. Courtney, A. Tegtmeier Pedersen: Uncertainty model for dual-Doppler retrievals of wind speed and wind direction. Atmos. Meas. Tech. Discuss., 2020.
10) E. Simon, M. Courtney: A Comparison of sector-scan and dual Doppler wind measurements at Høvsøre Test Station – one lidar or two? DTU Wind Energy. DTU Wind Energy E, Vol. 0112, 2016.
11) Susumu Shimada, Teruo Ohsawa, Ren Nakasato, Satoshi Nakamura, Yuko Takeyama, Tetsuya Kogaki, Masaki Furukawa: Investigation on wind resource assessment methods at a potential offshore wind farm site Part 1: Dual scanning LiDAR measurements, 40th Wind Energy Symposium, 2018.
12) Susumu Shimada, Tetsuya Kogaki, Mizuki Konagaya, Toshinari Mito, Takeshi Misaki, Ryuzo Araki, Yuko Ueda, Teruo Ohsawa: The Mutsu-Ogawara Scanning LiDAR experiment Part 2: Dual scanning LiDAR system validation, 43rd Wind Energy Symposium, 2021.
13) Keiichiro Watanabe, Susumu Takakuwa, Chikara Hemmi, Takeshi Ishihara: A study of offshore wind assessment using dual-Doppler scanning lidars, Journal of Wind Energy, JWEA, Vol. 45, No. 2, pp. 40-48, 2021.
14) Keiichiro Watanabe, Susumu Takakuwa, Chikara Hemmi, Takeshi Ishihara: Offshore wind assessment using dual scanning lidar and missing data complement using MCP method, 43rd Wind Energy Symposium, 2021.
15) Shizuka Ohhata, Ryuzo Araki, Susumu Shimada, Mizuki Konagaya, Teruo Ohsawa, Tetsuya Kogaki, Yuko Ueda: Mutsu-Ogawara scanning lidar field experiments Part 4. Measurement parameters and accuracy assessment in the dual-Doppler Lidar scanning mode, 43rd Wind Energy Symposium, 2021.
16) Gryning S.-E., and Floors R.: Carrier-to-Noise-Threshold Filtering on Off-Shore Wind Lidar Measurements. Sensors.19(3):592. DOI: 10.3390/s19030592, 2019.

17) Wataru Sasaki, Yukinari Fukumoto, Kaito Inomata, Michio Nittouji, Takeshi Ishihara: Validation of Dual-Doppler LiDAR wind assessment using the met-mast at Choshi offshore site, 44th Wind Energy Symposium, 2022.

18) Jun Tanemoto, Tsenwei Lin, Kazuya Takahashi, Koji Sumida, Tetsuji Shiroeda: Study on the correction of turbulence intensity values observed by dual scanning LiDAR, 44th Wind Energy Symposium, 2022.

19) Jay Prakash Goit, Atsushi Yamaguchi, Takeshi Ishihara: Performance Evaluation of Scanning Doppler Lidar and its Application to Wind Field Measurement, Journal of Wind Energy, JWEA, Vol. 42, No. 1, pp. 7-16, 2018.

20) Ryuzo ARAKI: Comparative measurements of wind between scanning Doppler LiDAR and meteorological mast on the west coast of Awaji Island, Journal of Wind Energy, JWEA, Vol. 43, No. 2, 2019.

21) Akiko Mano, Akiyo Ueno, Shunsuke Itozaki, Takeshi Ishihara: Accuracy verification of 3D scanning LIDAR and application to offshore wind measurement, 41st Wind Energy Symposium, 2019.

22) Akiko Mano, Akiyo Ueno, Shunsuke Itozaki, Takeshi Ishihara: Effects of data availability and sector size on the accuracy of 3D scanning LiDAR measurements, 42nd Wind Energy Symposium, 2020.

23) S. Shimada, J. P. Goit, T. Ohsawa, T. Kogaki, S. Nakamura: Coastal wind measurements using a single scanning LiDAR, Remote Sensing, 12, 1345, pp.1-24, 2020.

24) J.P. Goit, A. Yamaguchi, T. Ishihara: Measurement and Prediction of Wind Fields at an Offshore Site by Scanning Doppler LiDAR and WRF, Atmosphere, 11, 442, pp.1-20, 2020.

25) Kota Enoki, Takeshi Ishihara: Formulas for evaluation of coefficient of determination, slope and offset of wind speed and direction compensated by MCP method considering data availability of onsite measurement, 43rd Wind Energy Symposium, 2021.

26) Mattias Lange, Ulrich Focken, Takeshi Ishihara, Atsushi Yamaguchi, Kenji Shimada, joint translation: “Physical Approach to Short-Term Wind Power Prediction - Toward a Stable Supply of Power”, Ohmsha, 2012.

27) S. Shimada, T. Kogaki, M. Konagaya, T. Mito, R. Araki, Y. Ueda, T. Ohsawa: Validation of near-shore wind measurements using a dual scanning light detection and ranging system, Wind Energy, Vol25, pp1555-1572, 2022.

Annex A. Hard target adjustment

A.1 Cases when a hard target exists near an offshore measurement point

Figure A.1 shows the procedure for hard target adjustment in cases when a hard target exists in the vicinity of an offshore measurement point. When installing SL, perform adjustment so that the tilt angle and roll angle on the inclinometer inside the equipment become less than ±0.02°, to satisfy the survey accuracy.

Step	Procedure	Description
1	Survey the HT	a) Use the center of rotation of the head of the SL and the height of the beam irradiation as the origin. b) Survey the origin O and the position P of the HT. $P(\phi_t, \theta_t)$ ϕ_t : HT azimuth angle survey value θ_t : HT elevation angle survey value
2	Install the SL at the surveyed origin	Install the main body of the SL in accordance with the above-mentioned center of rotation of the head and beam irradiation height.
3	Level the SL mechanically	Adjust the lengths of the SL legs so that the tilt and roll angles on the inclinometer built into the SL become ±0.02° or less. *To minimize the effect of the head weight, point the head toward the zenith when performing the leveling work.
4	Create a CNR map for the HT and obtain the SL measurements	Create a CNR map for the HT and read the position of the HT. Here, the azimuth angle is the angle from the north of the main body of the SL device. $P_1(\phi_1, \theta_1)$ ϕ_1 : HT azimuth angle measurement value θ_1 : HT elevation angle survey value
5	Evaluate the elevation angle error	Evaluate the error from the elevation angle survey value and measured value. $\epsilon_1 = \theta_1(\phi_1) - \theta_t$ ϵ_1 : HT elevation angle error
6	Perform the set up for offshore observation	Perform the azimuth angle offset and elevation angle calibration, set the azimuth angle and elevation angle for the offshore observation point in FIX mode, and perform observation.

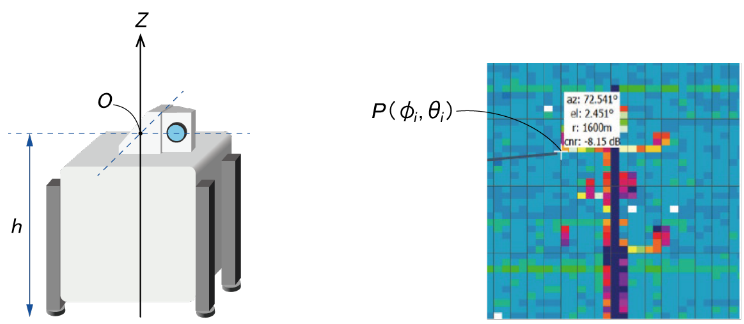


Figure A.1 Example of offshore hard target adjustment

A.2 In case of three hard targets

Figure A.2 shows the procedure for hard target adjustment in cases when there are three hard targets. It is desirable to have an angle of about 120° between the hard targets. When installing SL, perform adjustment so that the tilt angle and roll angle on the inclinometer inside the equipment become less than ±0.02°, to satisfy the survey accuracy.

1 Survey the HT

a) Use the center of rotation of the head of the SL and the height of the beam irradiation as the origin.

b) Survey the origin O and the position P of the HT.

$P(\phi_{ti}, \theta_{ti})$ ϕ_{ti} : Survey value of the azimuth angle of the *i*-th HT

θ_{ti} : Survey value of the elevation angle of the *i*-th HT

2 Install the SL at the surveyed origin

Install the main body of the SL in accordance with the above-mentioned center of rotation of the head and beam irradiation height.

*Mark a circle centered on the origin point on the frame during the installation and minimize the deviation of the origin when the main body is rotated.

3 Level the SL mechanically

Adjust the lengths of the SL legs so that the tilt and roll angles on the inclinometer built into the SL become ±0.02° or less.

*To minimize the effect of the head weight, point the head toward the zenith when performing the leveling work.

4 Create a CNR map for the HT and obtain the SL measurements

Create a CNR map for the HT and read the position of the HT.

Here, the azimuth angle is the angle from the north of the main body of the SL device.

$P_1(\phi_1, \theta_1)$, $P_2(\phi_2, \theta_2)$ ϕ_i : Measurement value of the azimuth angle of the *i*-th HT

$P_3(\phi_3, \theta_3)$ θ_i : Measurement value of the elevation angle of the *i*-th HT

5 Create the elevation angle error sine curve

Use the elevation angle errors of the three points and the least square method to create the elevation angle error curve by azimuth angle. The elevation angle error curve is expressed by the sine curve below.

$\epsilon_i = \theta_i(\phi_i) - \theta_{ti}$ ϵ_i : Elevation angle error of the *i*-th HT

$f_\epsilon(\phi) = \alpha \sin(\phi + \beta) + \gamma$ $f_\epsilon(\phi)$: Function of elevation angle error for the azimuth angle ϕ

α : Amplitude of elevation angle error

β : Phase of elevation angle error

γ : Offset of elevation angle error

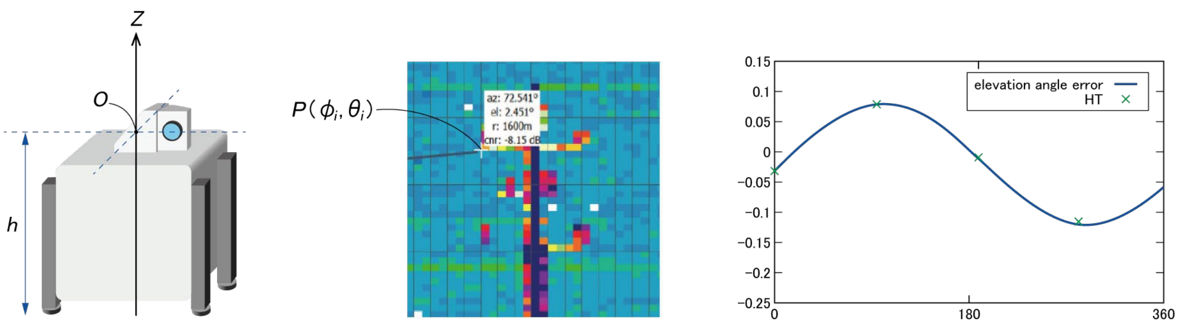


Figure A.2 In case of three hard targets

6 Verify the position accuracy at the peak of the elevation error sine curve

a) The azimuth angle ϕ_s during offshore observation is defined as the peak of the sine curve, where the change rate of the elevation angle error with respect to the azimuth angle is the smallest.

b) Point the azimuth angle at the time of offshore observation ϕ_s to the HT.
*In the FIX mode, set the azimuth angle ϕ_s and elevation angle θ_t and rotate the main body while conducting observation. When the HT is hit, it can be determined from the CNR value that the laser is irradiating the HT azimuth, so the legs are lowered and fixed there.

c) Perform (2) origin alignment and (3) horizontal alignment, and then (4) create a CNR map and read the position of the HT.

$P_5(\phi_5, \theta_5)$ ϕ_5 : HT azimuth angle measurement value
θ_5 : HT elevation angle measurement value

d) Check if the elevation angle error at azimuth angle ϕ_s matches the sine curve created in (6).

$$\Delta\epsilon(\phi_s)=(\theta_5(\phi_5)-\theta_t)-f_\epsilon(\phi_s)$$

$\Delta\epsilon(\phi_s)$: Bias with elevation angle error function at azimuth angle ϕ_s

7 Install the device at the offshore observation point with it pointing at the azimuth angle ϕ_s

Set the angle formed by the azimuth angle of the offshore observation point and the azimuth angle of the HT in the FIX mode in which the azimuth angle is the angle subtracted from the HT azimuth angle. Then, if the main body is rotated while observing, when the HT is hit, it can be determined from the CNR value that the laser is irradiating the HT azimuth, so the legs are lowered and fixed there.
Perform origin alignment and leveling in the same way as in steps (2) and (3).

$$\Delta\phi_{PQ}=\phi'_s-\phi_t$$

$$\phi'_s=\phi_s+\Delta\phi_{offset}$$

8 Perform the set up for offshore observation

Perform the azimuth angle offset and elevation angle calibration, set the azimuth angle and elevation angle for the offshore observation point in FIX mode, and perform observation.

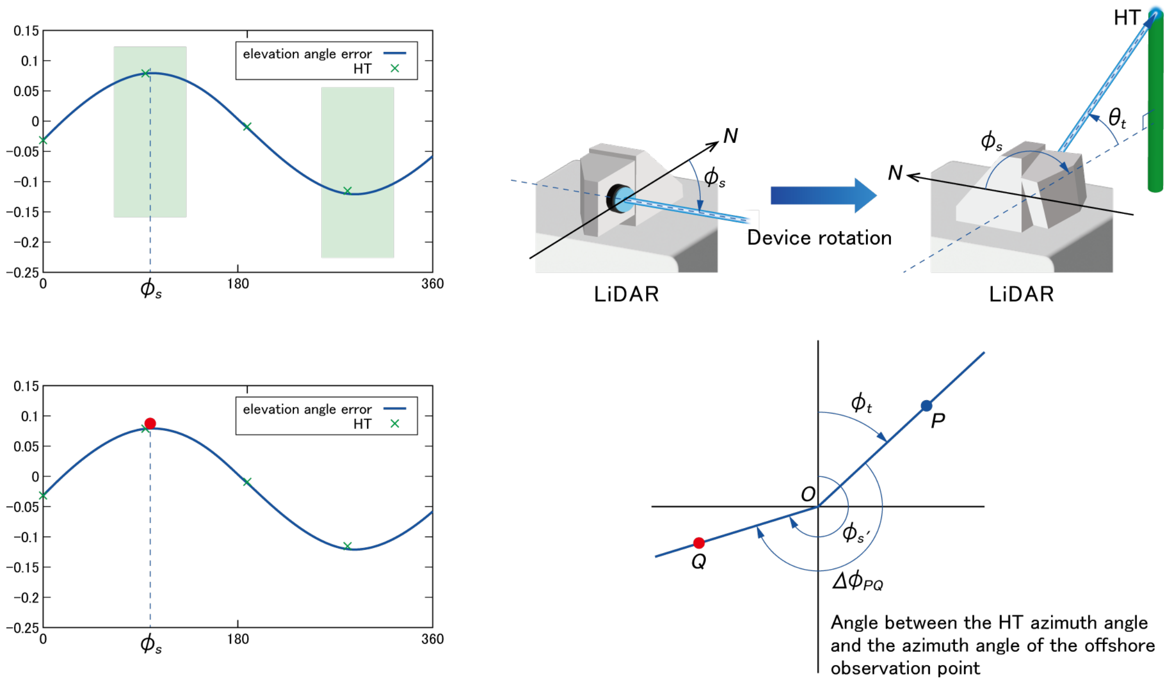
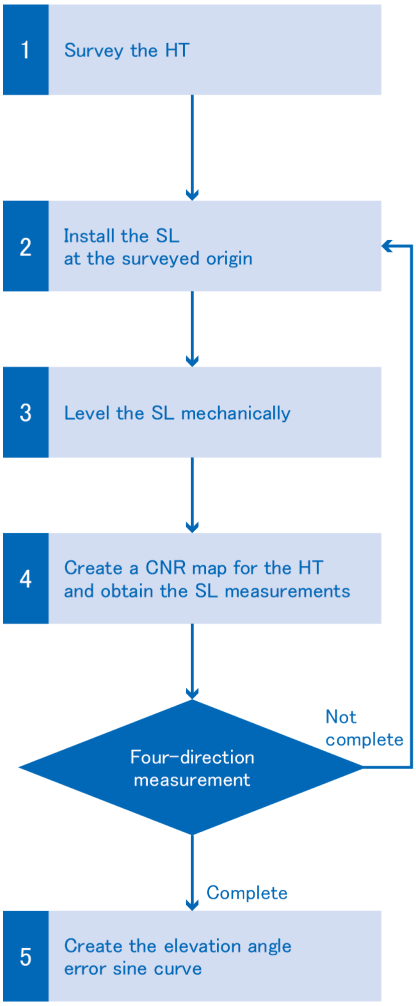


Figure A.2 In case of three hard targets (continued)

A.3 In case of two or fewer hard targets

Figure A.3 shows the procedure for hard target adjustment in cases when there are two or fewer hard targets. When installing SL, perform adjustment so that the tilt angle and roll angle on the inclinometer inside the equipment become less than ±0.02°, to satisfy the survey accuracy.



a) Use the center of rotation of the head of the SL and the height of the beam irradiation as the origin.

b) Survey the origin O and the position P of the HT.

$P(\phi_t, \theta_t)$ — ϕ_t : HT azimuth angle survey value; θ_t : HT elevation angle survey value

Install the main body of the SL in accordance with the above-mentioned center of rotation of the head and beam irradiation height.

*Mark a circle centered on the origin point on the frame during the installation and minimize the deviation of the origin when the main body is rotated.

Adjust the lengths of the SL legs so that the tilt and roll angles on the inclinometer built into the SL become ±0.02° or less.

*To minimize the effect of the head weight, point the head toward the zenith when performing the leveling work.

Create a CNR map for the HT and read the position of the HT.

Here, the azimuth angle is the angle from the north of the main body of the SL device.

$P_i(\phi_i, \theta_i)$ — ϕ_i : Measurement value of the azimuth angle of the *i*-th HT; θ_i : Measurement value of the elevation angle of the *i*-th HT

Rotate the main body of the SL by 90° and obtain a total of four azimuth angle and elevation angle measurement values by SL.

*For the 90° rotation, shorten the length of the legs so that the wheels attached to the bottom of the device are in contact with the ground and the device can be moved.

$P_1(\phi_1, \theta_1), P_2(\phi_2, \theta_2), P_3(\phi_3, \theta_3), P_4(\phi_4, \theta_4)$

Use the elevation angle errors of the four points and the least square method to create the elevation angle error curve by azimuth angle. The elevation angle error curve is expressed by the sine curve below.

$\epsilon_i = \theta_i(\phi_i) - \theta_{ti}$ — ϵ_i : Elevation angle error of the *i*-th HT

$f_\epsilon(\phi) = \alpha \sin(\phi + \beta) + \gamma$ — $f_\epsilon(\phi)$: Function of elevation angle error for the azimuth angle ϕ

α : Amplitude of elevation angle error

β : Phase of elevation angle error

γ : Offset of elevation angle error

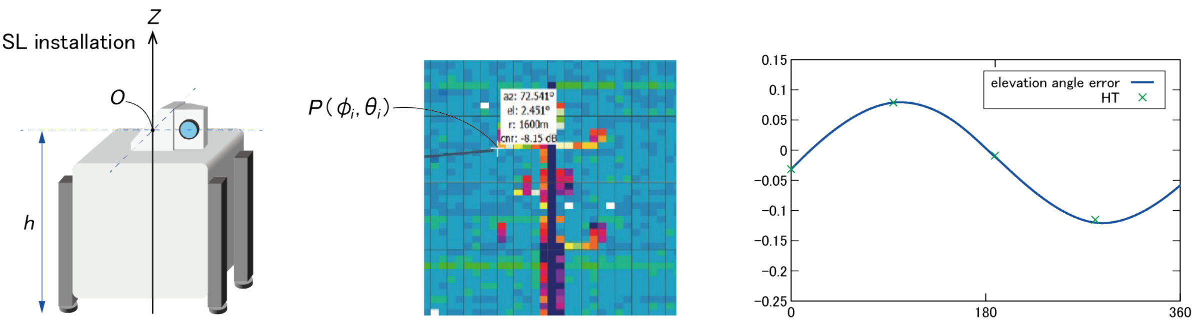


Figure A.3 In case of two or fewer hard targets

6 Verify the position accuracy at the peak of the elevation error sine curve

a) The azimuth angle ϕ_s during offshore observation is defined as the peak of the sine curve, where the change rate of the elevation angle error with respect to the azimuth angle is the smallest.

b) Point the azimuth angle at the time of offshore observation ϕ_s to the HT.
*In the FIX mode, set the azimuth angle ϕ_s and elevation angle θ_t and rotate the main body while conducting observation. When the HT is hit, it can be determined from the CNR value that the laser is irradiating the HT azimuth, so the legs are lowered and fixed there.

c) Perform (2) origin alignment and (3) horizontal alignment, and then (4) create a CNR map and read the position of the HT.

$P_5(\phi_5, \theta_5)$ ϕ_5 : HT azimuth angle measurement value
θ_5 : HT elevation angle measurement value

d) Check if the elevation angle error at azimuth angle ϕ_s matches the sine curve created in (6).

$$\Delta\epsilon(\phi_s)=(\theta_5(\phi_5)-\theta_t)-f_\epsilon(\phi_s)$$

$\Delta\epsilon(\phi_s)$: Bias with elevation angle error function at azimuth angle ϕ_s

7 Install the device at the offshore observation point with it pointing at the azimuth angle ϕ_s

Set the angle formed by the azimuth angle of the offshore observation point and the azimuth angle of the HT in the FIX mode in which the azimuth angle is the angle subtracted from the HT azimuth angle. Then, if the main body is rotated while observing, when the HT is hit, it can be determined from the CNR value that the laser is irradiating the HT azimuth, so the legs are lowered and fixed there.

Perform origin alignment and leveling in the same way as in steps (2) and (3).

$$\Delta\phi_{PQ}=\phi'_s-\phi_t$$
$$\phi'_s=\phi_s+\Delta\phi_{offset}$$

8 Perform the set up for offshore observation

Perform the azimuth angle offset and elevation angle calibration, set the azimuth angle and elevation angle for the offshore observation point in FIX mode, and perform observation.

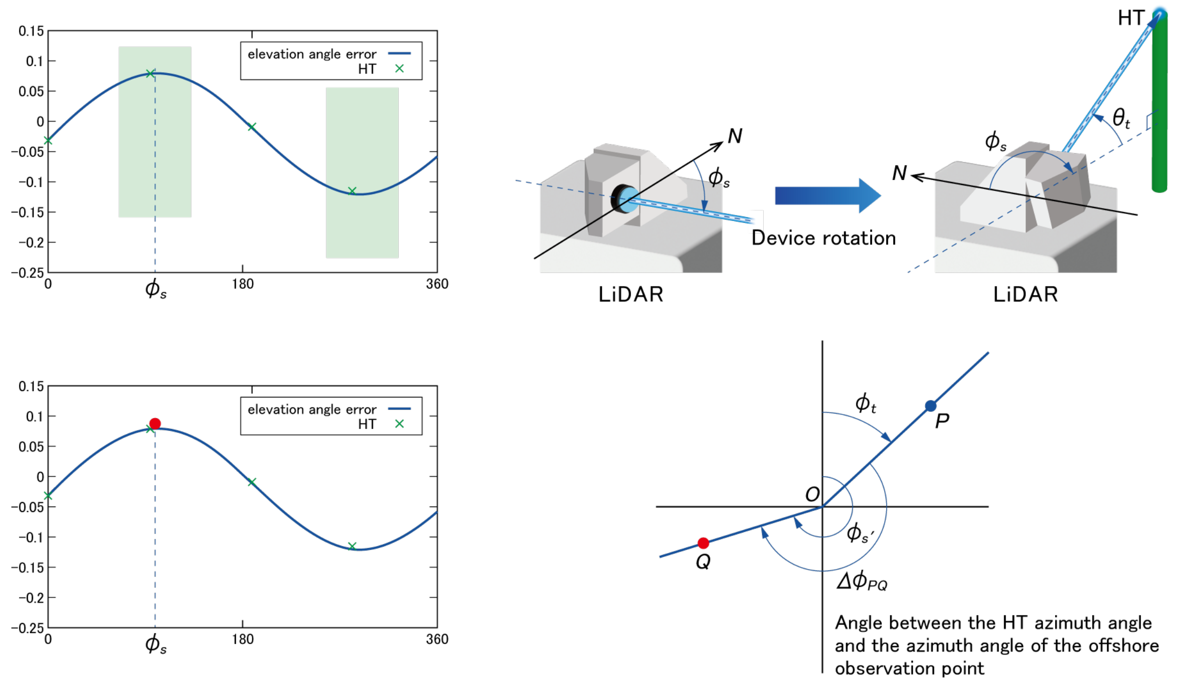


Figure A.3 In case of two or fewer hard targets (continued)

Annex B. Pre-deployment verification of accuracy

B.1 Pre-deployment verification of accuracy

The pre-deployment verification of accuracy for DSL and SSL is performed based on regression analysis using the measurement data from meteorological mast cup anemometers and wind vanes installed in accordance with the requirements described in Chapter 3. The results of the correlation analysis of wind speed and wind direction are shown in a scatter plot.

Remove the abnormal values, flow distortion due to topography, and the effects of structures to perform the verification using the reliable data.

For the number of data required for the pre-deployment verification of accuracy, the number of data remaining after the filtering in which the abnormal values and others are removed must satisfy the acceptance criteria shown in Table B.1.

Table B.1 Number of data required for accuracy verification

Evaluated item	Wind speed bin width	Acceptance criteria for number of data
2 m/s - 12 m/s	1 m/s	≥ 40
12 m/s - 16 m/s	2 m/s	≥ 40
> 16 m/s (if use possible)	2 m/s	≥ 40

The accuracy verification period should be set with consideration of the fact that the number of data will be reduced by the weather conditions during the accuracy verification period and the filtering.

B.2 Accuracy KPIs and acceptance criteria

B.2.1 Wind speed and wind direction

See 8.3.1.

If the error in the wind speed or wind direction measured by the RSD is less than or equal to the minimum in Table 8.2, the measured value can be used as having an accuracy equivalent to that of a cup anemometer or a wind vane.

B.2.2 Wind speed standard deviation

See 8.3.2.

If the error in the standard deviation of the wind speed measured by the RSD is 5% or less, the measured value can be used as having an accuracy equivalent to that of a cup anemometer. For DSL, accuracy below this error has been reported in previous studies[12] and was also confirmed in this project.

Annex C. Data acquisition rate check

C.3 Data acquisition rate check

Prior to conducting site measurements, conduct preliminary verification at the offshore measurement points to ensure that sufficient data acquisition rates can be obtained. When checking the data acquisition rate, the same settings as in the accuracy verification should be used.

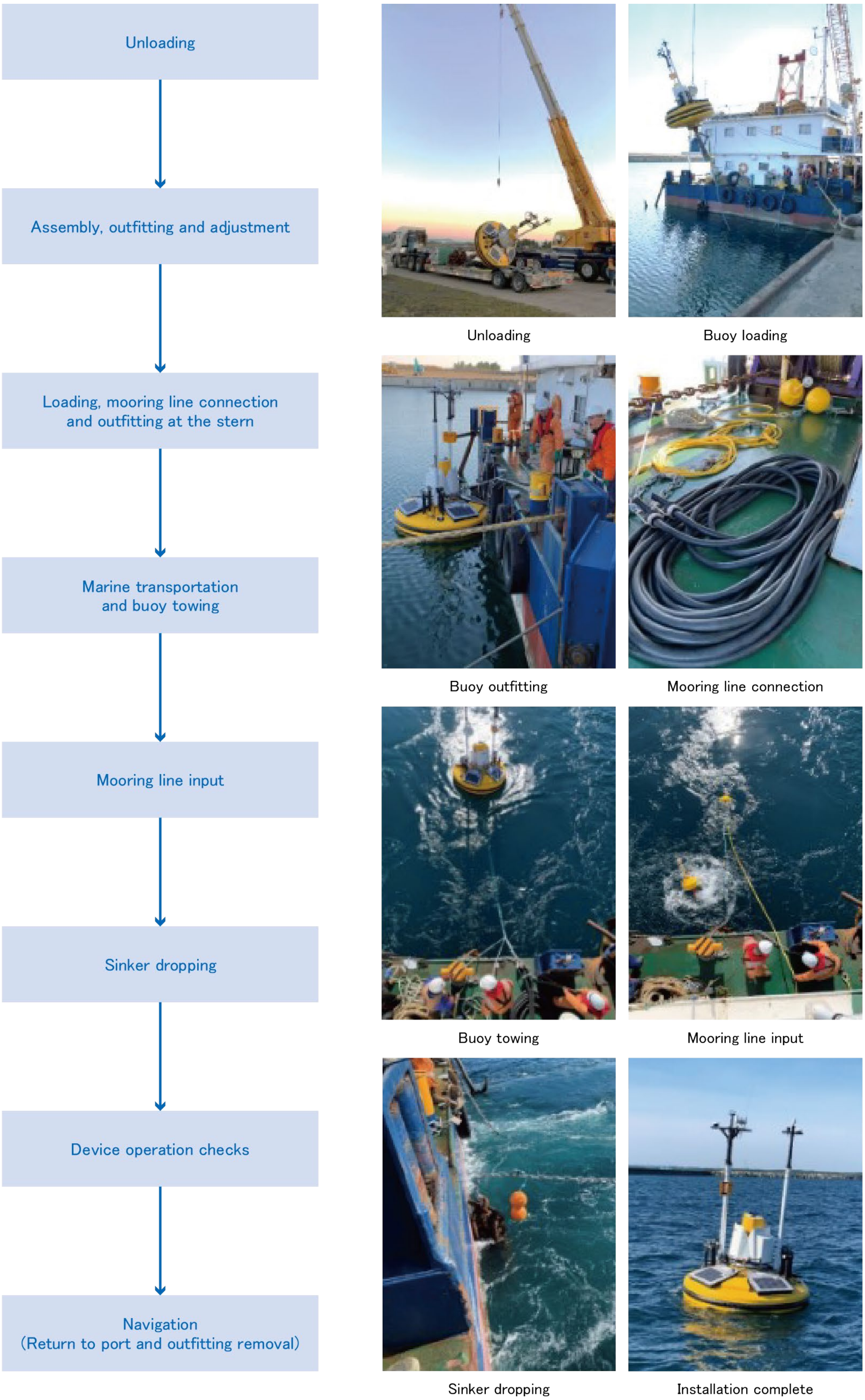
The data acquisition rate at the measurement point is affected by the SL device performance (laser output, etc.), the measurement distance, the measurement settings (range gate, accumulation time, time intervals used in the switching between each measurement height, focus), and the weather conditions (dense fog, heavy snow, snowstorms, heavy rain, etc.).

It is not easy to change the measurement settings after starting site measurements, so it is desirable to check the data acquisition rate beforehand and formulate a careful measurement plan so that a sufficient data acquisition rate can be obtained throughout the year.

It is desirable that a data acquisition rate of 60% or more is obtained during the period of the preliminary verification for the measurement distance of the offshore measurement point where year-long measurement will be carried out. It should be noted that as weather conditions vary throughout the year, it is not guaranteed that the data acquisition rates identified here will be representative values for a year at the planned point.

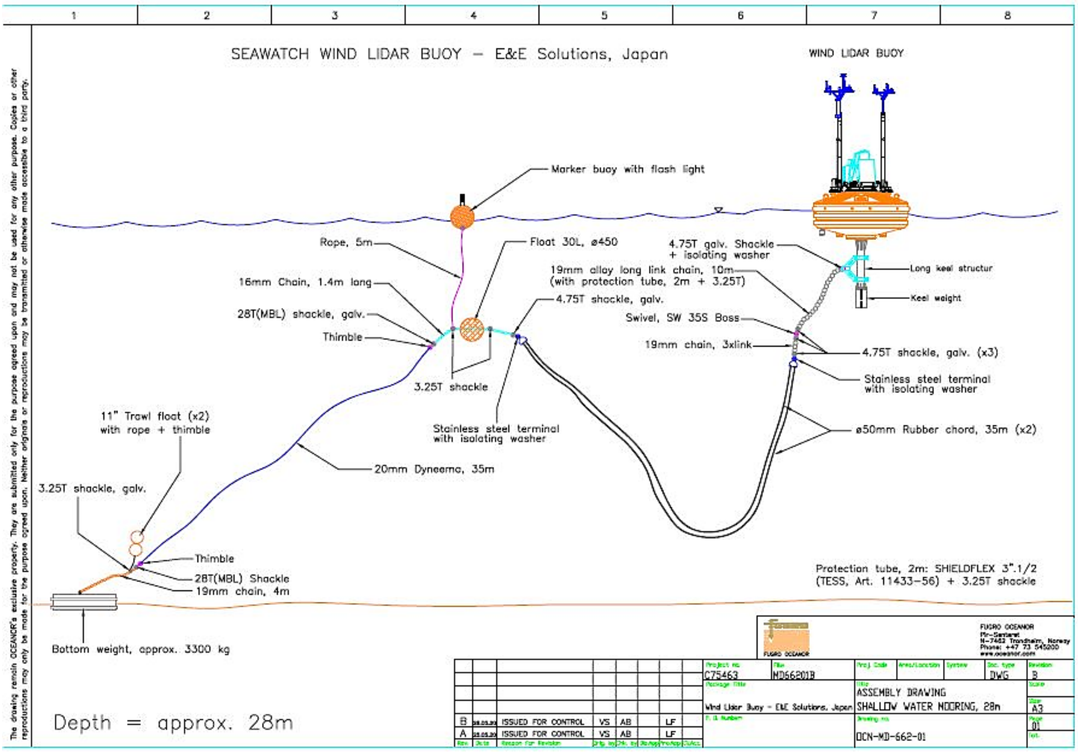
Annex D. Example FLS installation work

Figures D.1 to D.3 show the flow of installation work and mooring diagrams for three models as examples of the installation work for each FLS.



(a) Flow of installation work

Figure D.1 SeaWatch installation case example and mooring diagram



(b) Mooring diagram

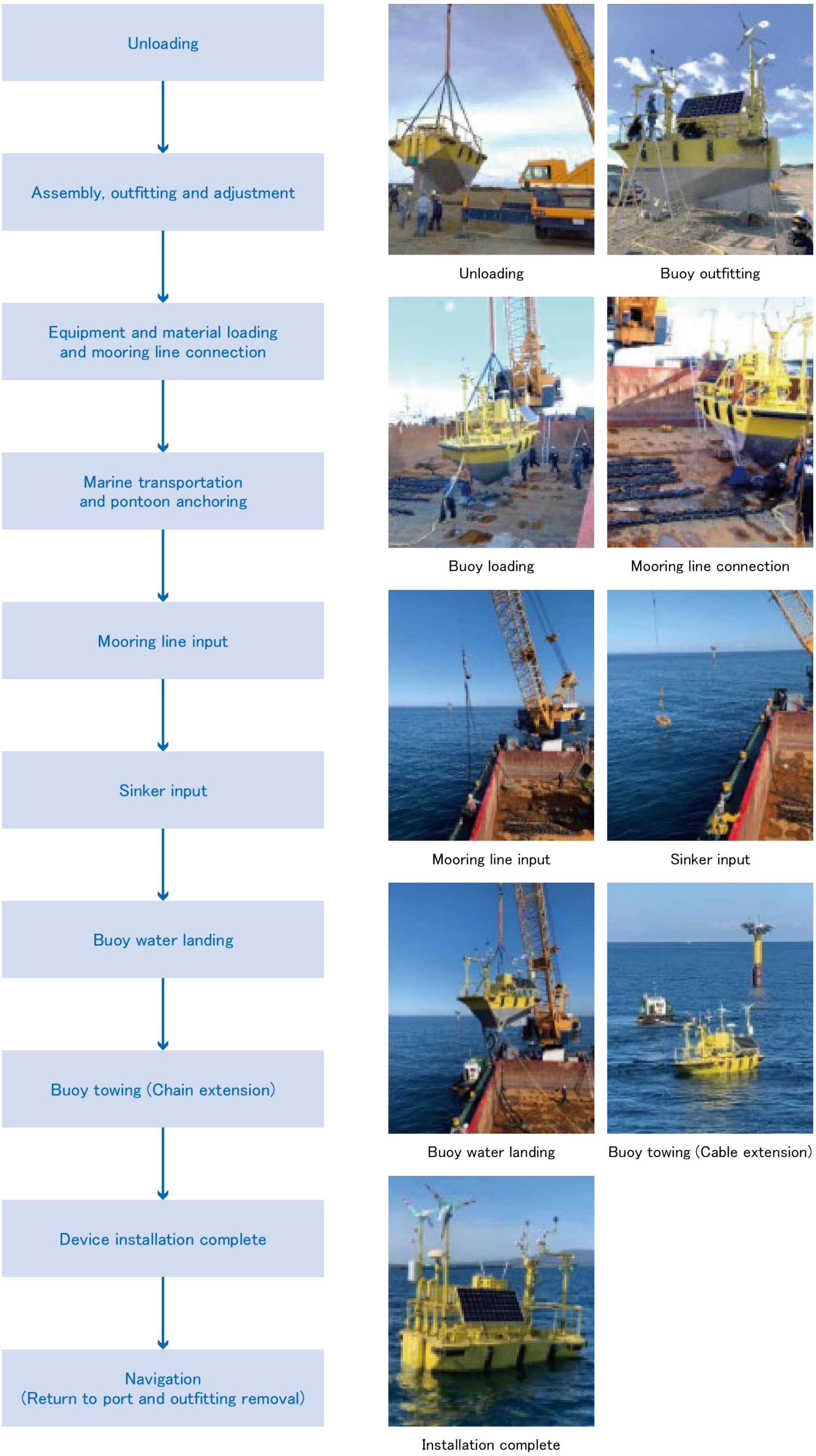
(c) Floating body dimensions

Item	Contents
Type	Disk shaped
Dimensions	Diameter 2.8 m, total height 7.2 m
Draft	4 m
Weight	Approx. 2.2 tons

(d) Mooring specifications

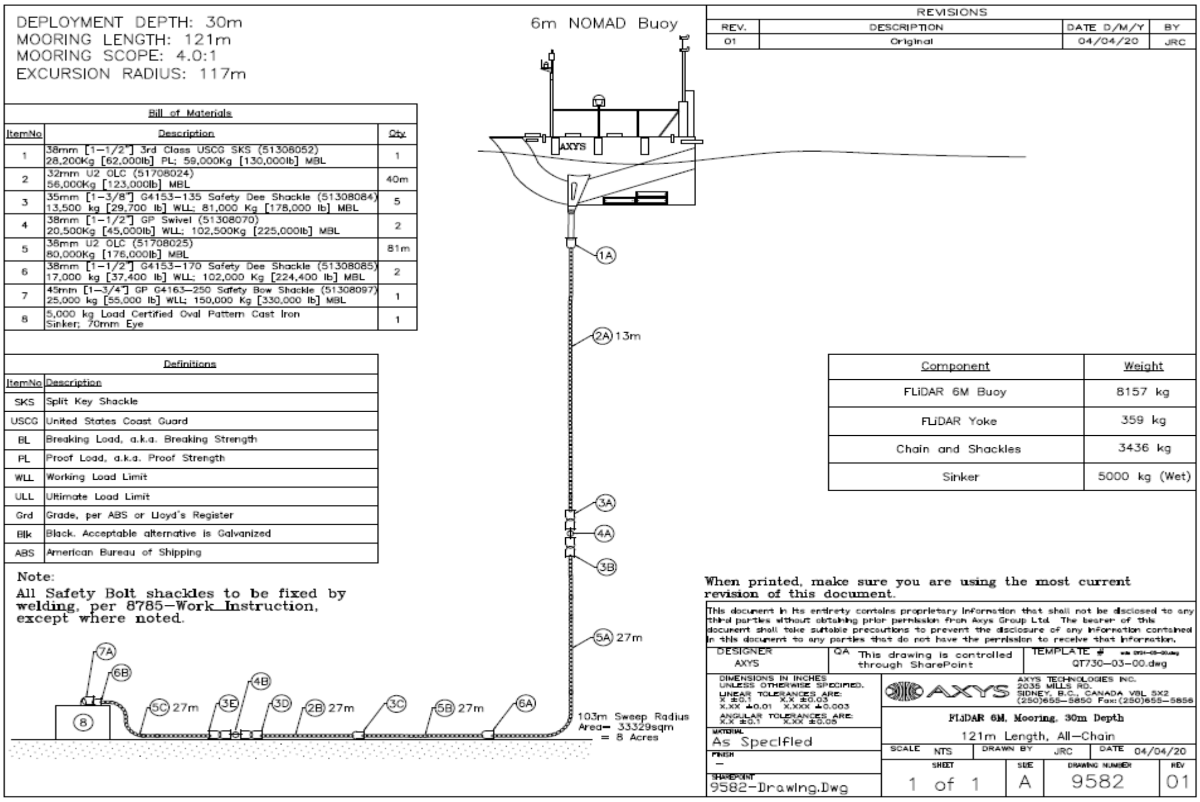
Item	Contents
Type	Single point mooring
Dimensions	Total length: 85.4 m (Upper chain 10 m + Rubber cord 35 m + Intermediate float + Synthetic fiber rope 35 m + Bottom chain 4 m)
Sinker	3.3-ton chain

Figure D.1 SeaWatch installation case example and mooring diagram (continued)



(a) Flow of installation work

Figure D.2 WindSentinel installation case example and mooring diagram



(b) Mooring diagram

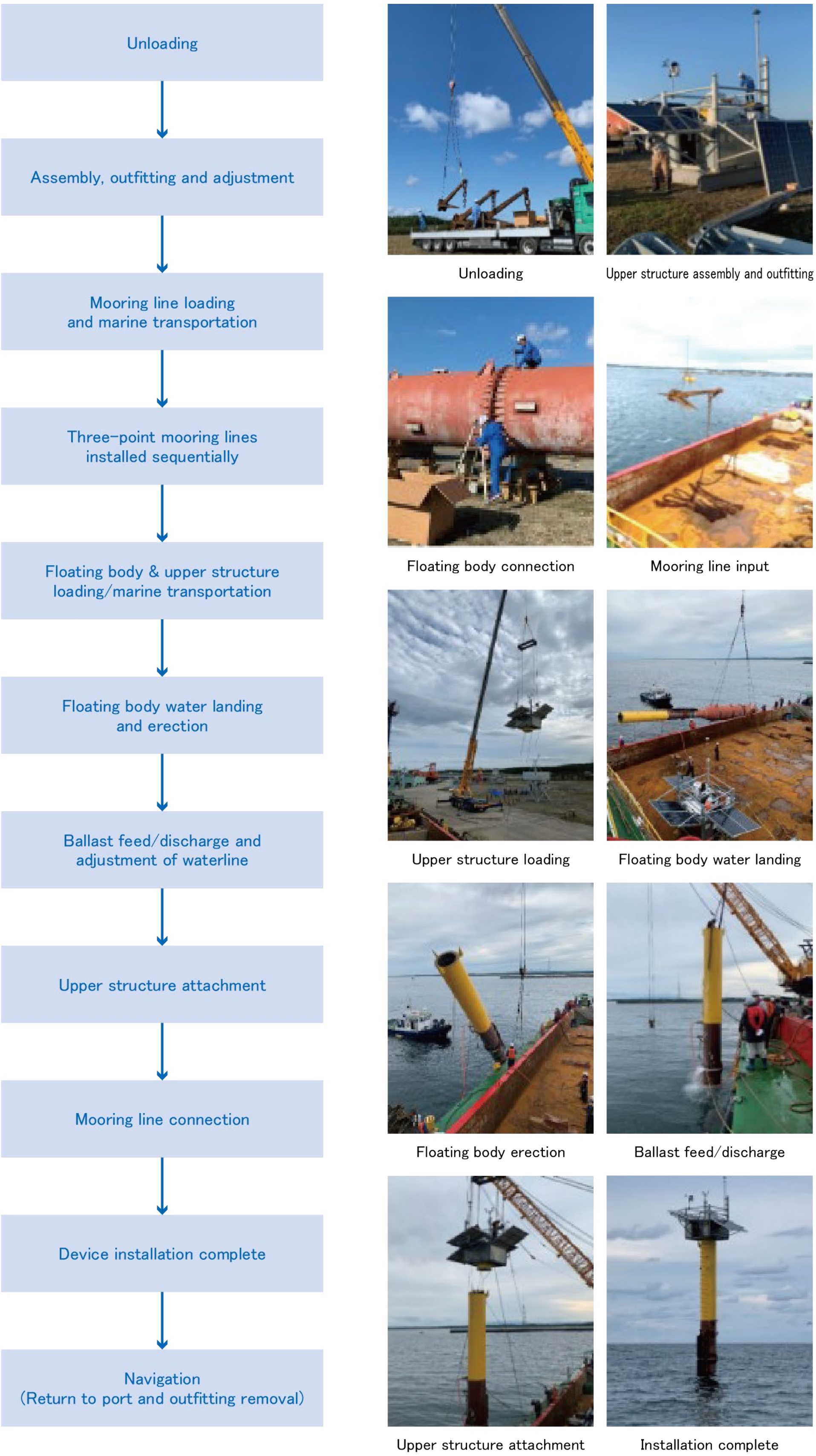
(c) Floating body dimensions

Item	Contents
Type	Boat shaped
Dimensions	Length 6 m x Width 3.1 m x Height 9 m
Draft	4 m
Weight	Approx. 9 tons

(d) Mooring specifications

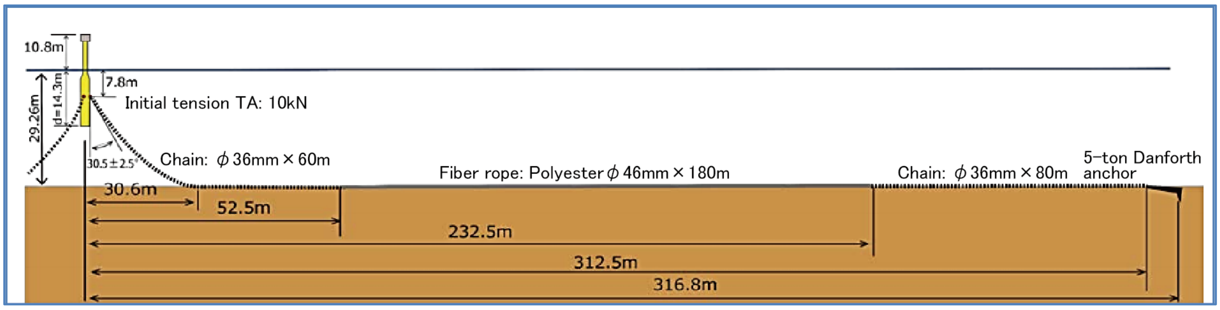
Item	Contents
Type	Single point mooring
Dimensions	Total length: 121 m (38 mm open link chain)
Sinker	5-ton cast iron construction

Figure D.2 WindSentinel installation case example and mooring diagram (continued)



(a) Flow of installation work

Figure D.3 MIA installation case example and mooring diagram



(b) Mooring diagram

(c) Floating body dimensions

Item	Contents
Type	Spar type
Dimensions	Diameter 1.0 m/2.15 m x Length 25 m
Draft	4 m
Weight	Approx. 46 tons

(d) Mooring specifications

Item	Contents
Type	Three-point mooring
Dimensions	Total length: 320 m x 3 (Chain 60 m + Synthetic fiber rope 180 m + Chain 80 m)
Anchor	5-ton Danforth anchor x 3

Figure D.3 MIA installation case example and mooring diagram (continued)

New Energy and Industrial Technology Development Organization