Assessment of offshore wind climate in coastal areas of Japan using single scanning Doppler LiDAR

A. Mano RENOVA Inc.
A. Ueno RENOVA Inc.
**S. Itozaki RENOVA Inc.**
T. Ishihara The University of Tokyo

RENOVA

東京大学
THE UNIVERSITY OF TOKYO

- In Japan, offshore wind farms are located at coastal area
- Wind conditions affected by the terrain need to be assessed

⑫Sea area offshore the Gan-u and Minamishiribeshi regions, Hokkaido Pref.

⑬Sea area offshore Hiyama, Hokkaido Pref.

⑨Mutsu Bay, Aomori Pref.

⑤Sea of Japan offshore Aomori Pref. (northern side of the Pref.)

⑥Sea of Japan offshore Aomori Pref.(southern side of the Pref.)

⑦Sea area offshore Happo Town and Noshiro City, Akita Pref.

②Sea area offshore Noshiro City・Mitane Town・Oga City, Akita Pref.

⑩Sea area offshore Katagami City and Akita City, Akita Pref.

③Sea area offshore Yurihonjo City（North・South), Akita Pref.

⑭Sea area offshore Yuza Town, Yamagata Pref.

⑪Sea area offshore Murakami City and Tainai City, Niigata Pref.

④Sea area offshore Choshi City, Chiba Pref.

⑧Sea area offshore Eno Island, Saikai City, Nagasaki Pref.

①Sea area offshore Goto City, Nagasaki Pref.

RENOVA

東京大学
THE UNIVERSITY OF TOKYO

■ Carbon Trust and RES offshore measurement campaign in the Dublin Bay and reported the data availability and measurement range. The impact of weather conditions were not discussed.
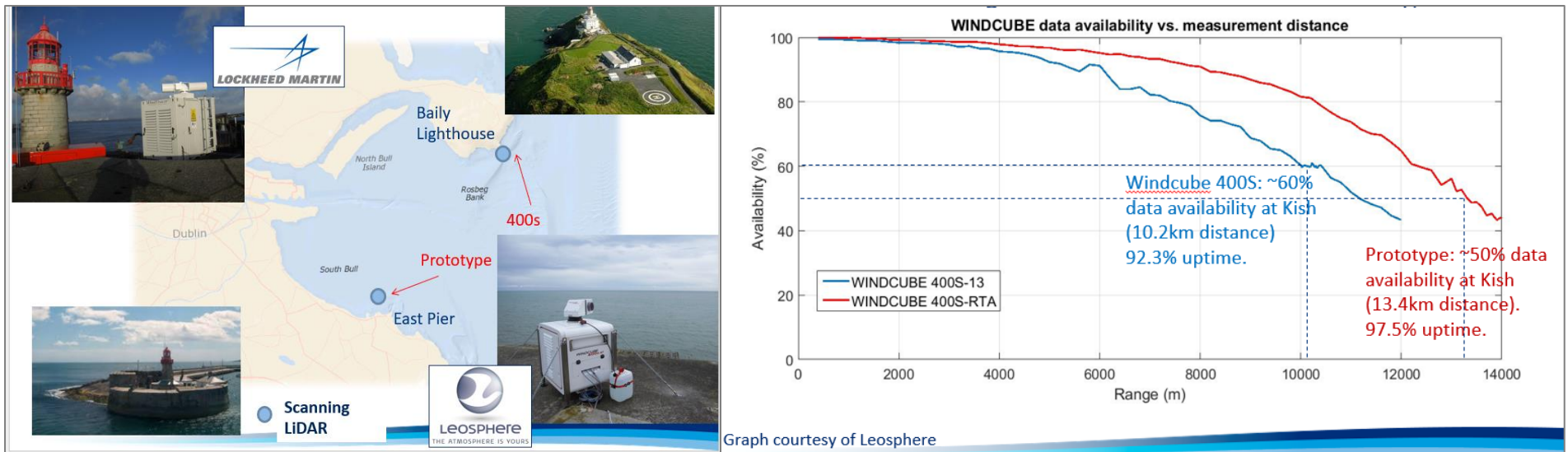

https://windeurope.org/summit2016/conference/allfiles/204_WindEurope2016presentation.pptx

Japan has four seasons with different climates, such as rainy summer and snowy winter. 1 year measurement is necessary to clarify effect of precipitation on the data availability.

Challenge 2 : Data filtering criteria to meet accuracy and post-processed data availability requirements

Measurement point

3°

Scanning Lidar

45°

Sector scan
(View from above)
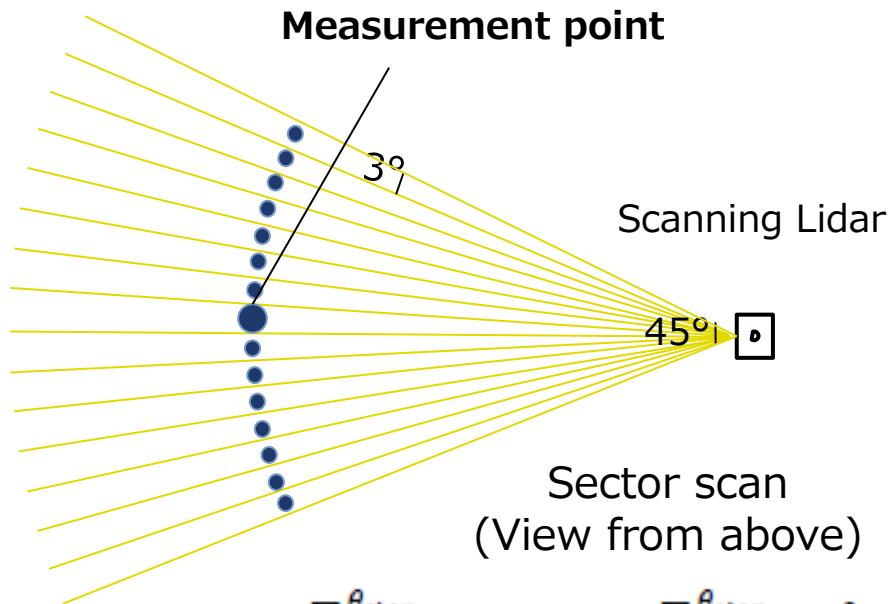
■ Sector scan reconstruction methods by using least square fitting are proposed by Simon and Courtney (2016). They discussed effects of scan sector size on accuracy of measurement data.

		Period
Missing	Invalid	[Overall/Monthly] Post-processed Data Availability
Missing		[Overall/Monthly] System Availability

$$\overline{u} = \frac{(\sum_{\theta_{start}}^{\theta_{stop}} (\hat{u}_r * \cos\theta) * \sum_{\theta_{start}}^{\theta_{stop}} (\sin^2\theta)) - (\sum_{\theta_{start}}^{\theta_{stop}} (\hat{u}_r * \sin\theta) * \sum_{\theta_{start}}^{\theta_{stop}} (\cos\theta * \sin\theta))}{((\sum_{\theta_{start}}^{\theta_{stop}} \cos^2\theta) * \sum_{\theta_{start}}^{\theta_{stop}} \sin^2\theta)) - (\sum_{\theta_{start}}^{\theta_{stop}} (\cos\theta * \sin\theta))^2)}$$

$$\overline{v} = \frac{(\sum_{\theta_{start}}^{\theta_{stop}} (\hat{u}_r * \sin\theta) * \sum_{\theta_{start}}^{\theta_{stop}} (\cos^2\theta)) - (\sum_{\theta_{start}}^{\theta_{stop}} (\hat{u}_r * \cos\theta) * \sum_{\theta_{start}}^{\theta_{stop}} (\cos\theta * \sin\theta))}{((\sum_{\theta_{start}}^{\theta_{stop}} \cos^2\theta) * \sum_{\theta_{start}}^{\theta_{stop}} \sin^2\theta)) - (\sum_{\theta_{start}}^{\theta_{stop}} (\cos\theta * \sin\theta))^2)}$$

Criteria needs to be discussed to satisfy both data availability and accuracy

RENOVA

東京大学 THE UNIVERSITY OF TOKYO

- Wagner, R. (2014) conducted the scanning lidar measurement campaign at different heights, at an onshore site.
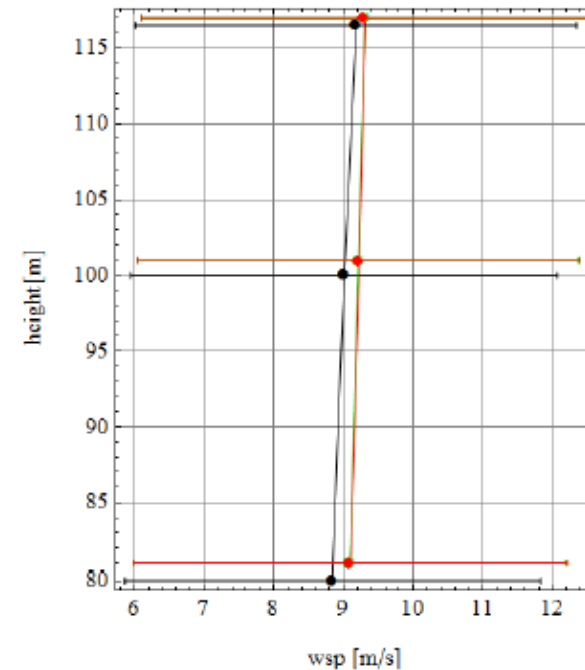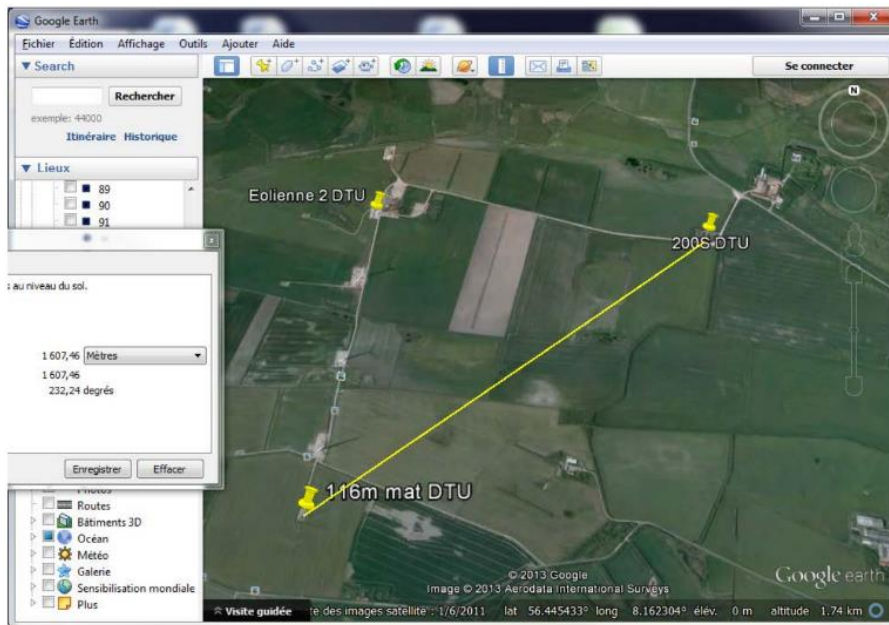
A large wind shear is expected the offshore site in Japan due to the terrain nearby and should be investigated in detail.

Objective

- ■ Investigate the variation of data availability with measurement range and precipitation.

- ■ Propose criteria for data filtering to meet both accuracy and post-processed data availability requirements.

- ■ Analyze the vertical profile of offshore wind to clarify the influences from the terrain nearby and atmospheric stability.
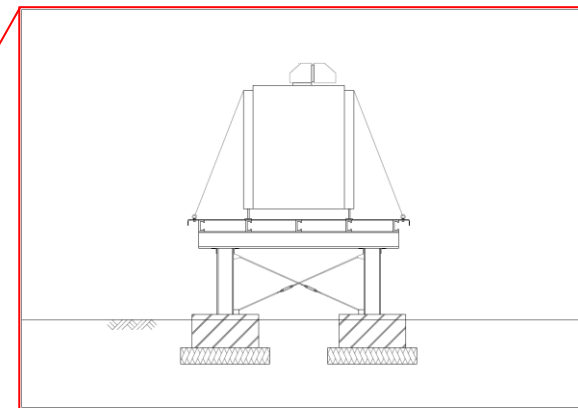
- Windcube 200S was used and 150 days's measurement were performed, including rain fall of 1345 hours and Snow fall of 35 hours
- Data filtering are based on CNR, Mean Error and σ_{Vr}

Offshore virtual tower

1750m

Scanning lidar

0   500   1000m
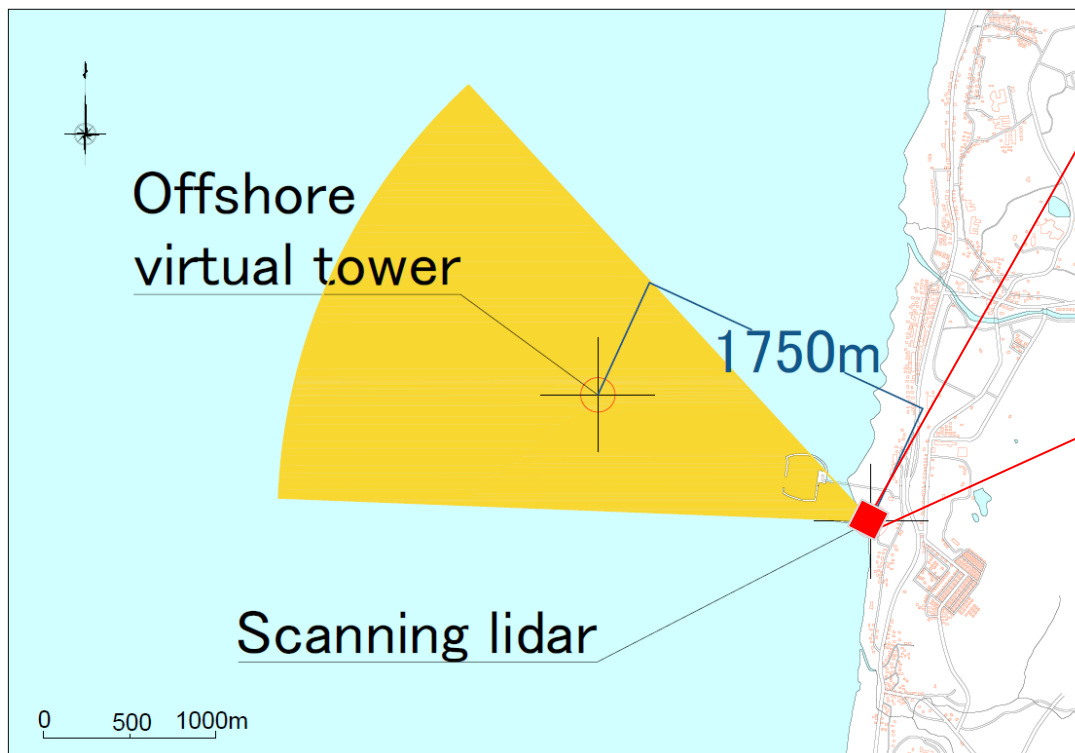
Location of the scanning Lidar

Side view of the Lidar mount

| CNR | : signal-to-noise ratio |
| Mean Error | : average error between the received Doppler spectrum and the spectrum reconstructed by instrument processing |
| σ_{Vr} | : variance reflecting wind speed fluctuations during the measurement |

RENOVA

東京大学
THE UNIVERSITY OF TOKYO

■ The data availability for all weather condition for all weather condition is also investigated.
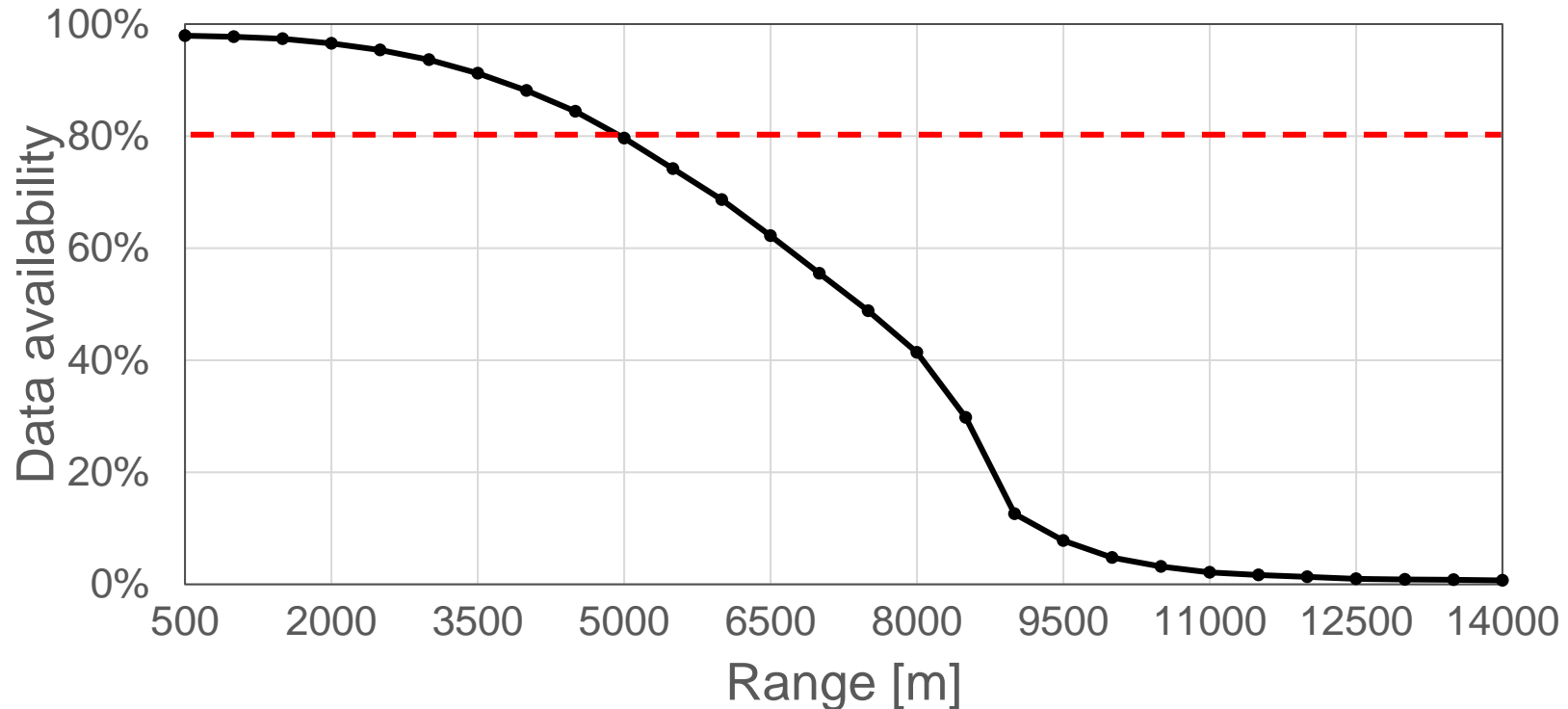
Data availability is higher than 80% if the range is less than 4.5 km

RENOVA 東京大学 THE UNIVERSITY OF TOKYO

Effect of snow fall on data availability
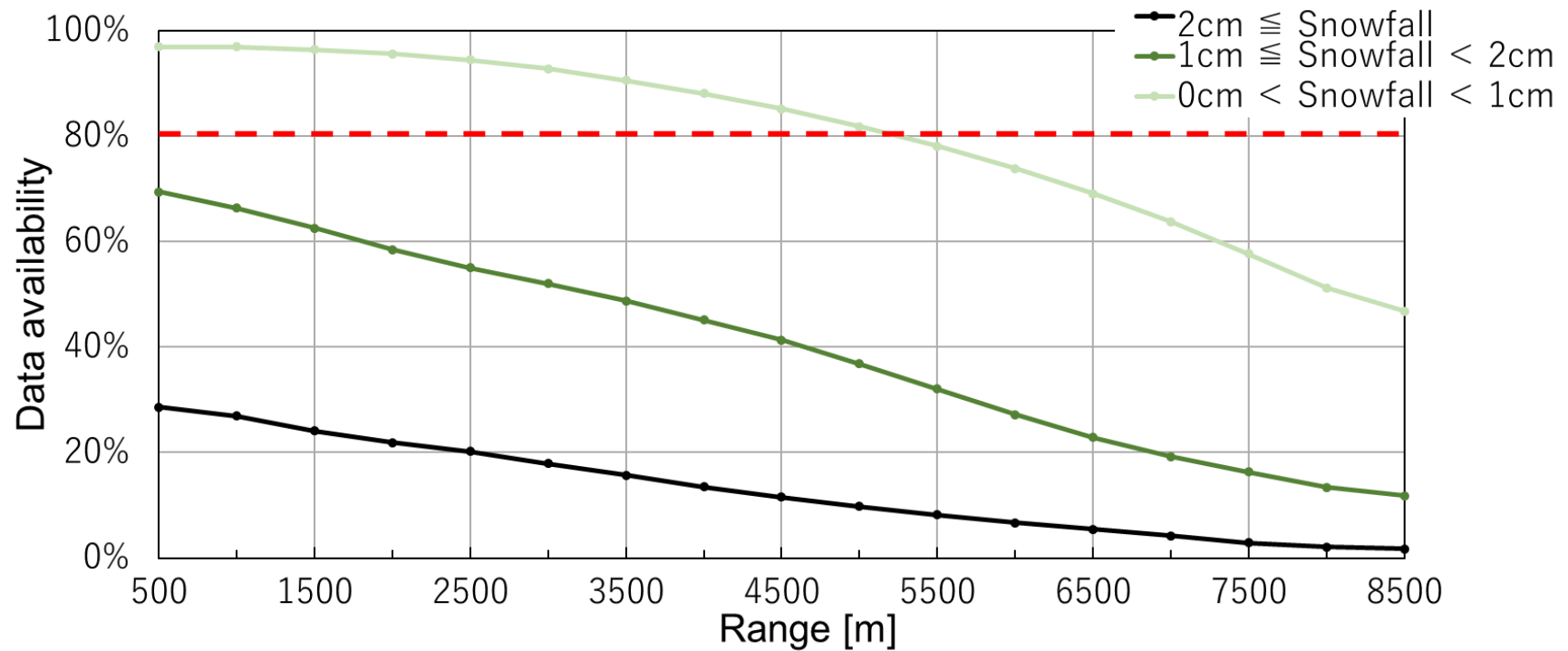
Data availability is higher than 80% if the range is less than 5km and snowfall is less than 1cm/h.

Effect of rainfall on data availability
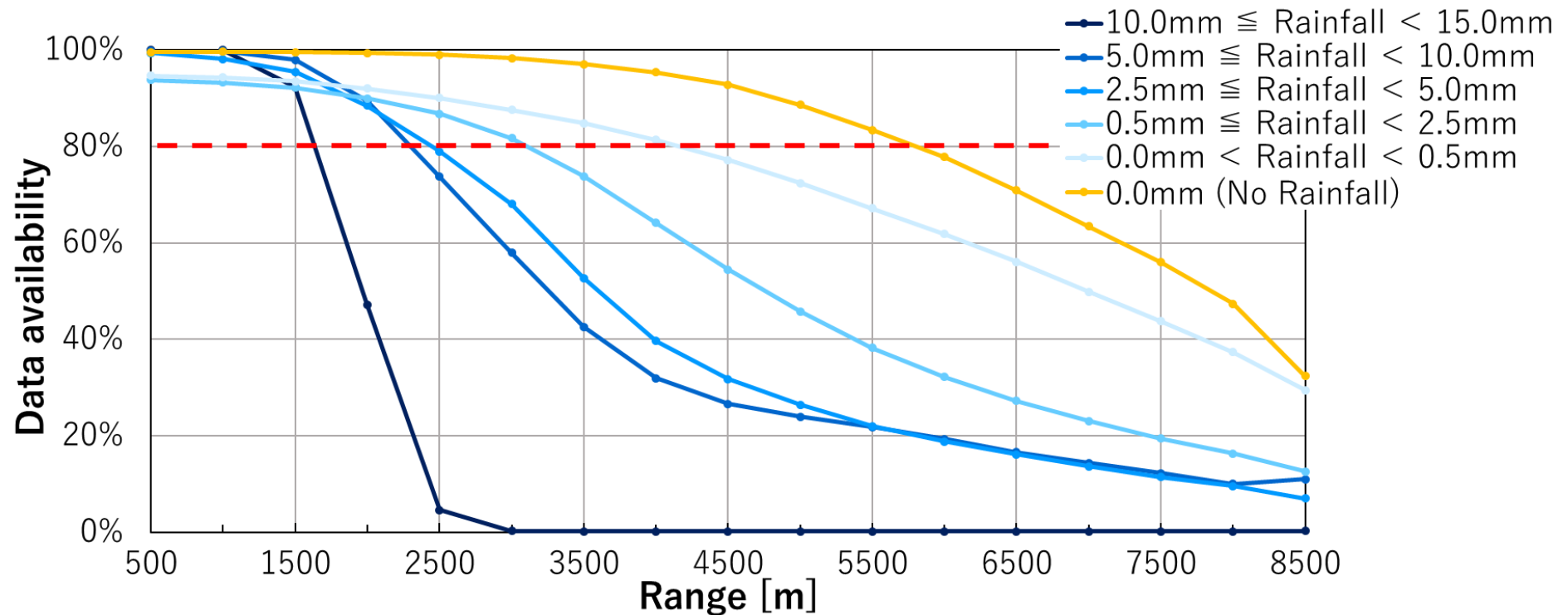
Data availability is higher than 80% if the range is less than 2km and rainfall is less than 10mm/h.
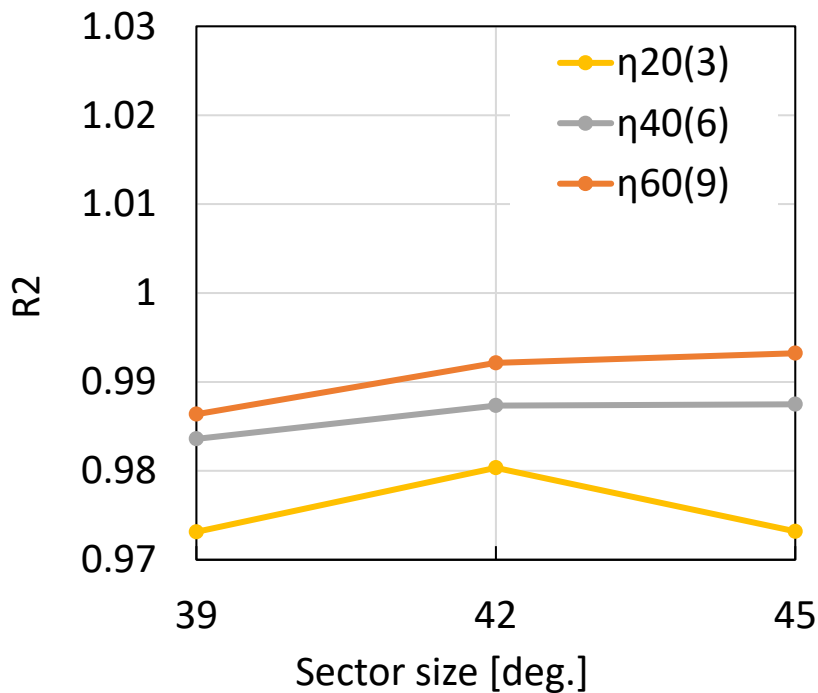
Possible measurement range with high data availability must be considered around **2km.**

■ The proposed criteria is validated using onshore met mast. Only wind direction perpendicular to the coastline is used.

Proposed criteria was used.

1. Minimum sector size > **39 deg.**
2. Minimum amount of data within one scan is **3**.
3. Data availability higher than **10%**.
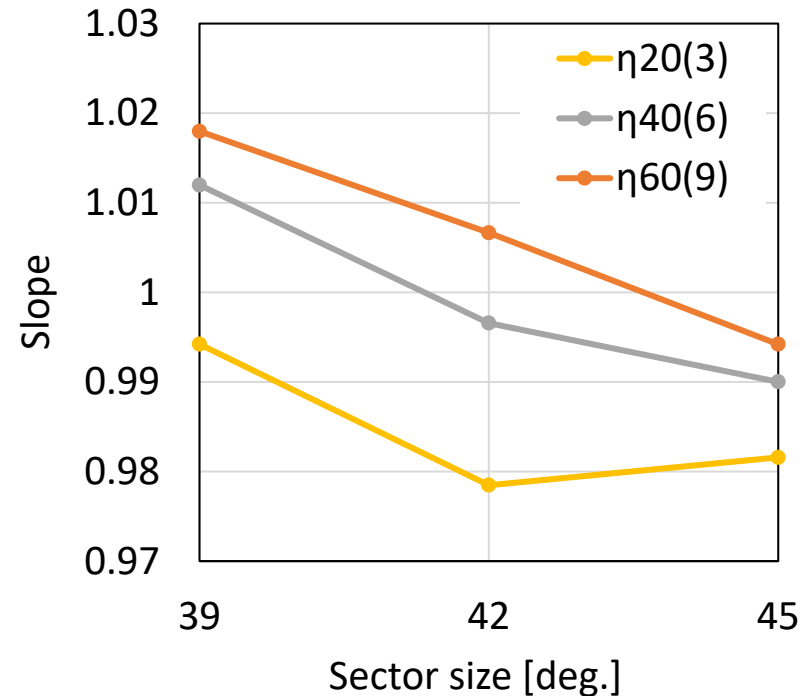
Sector size : sector covered by valid data

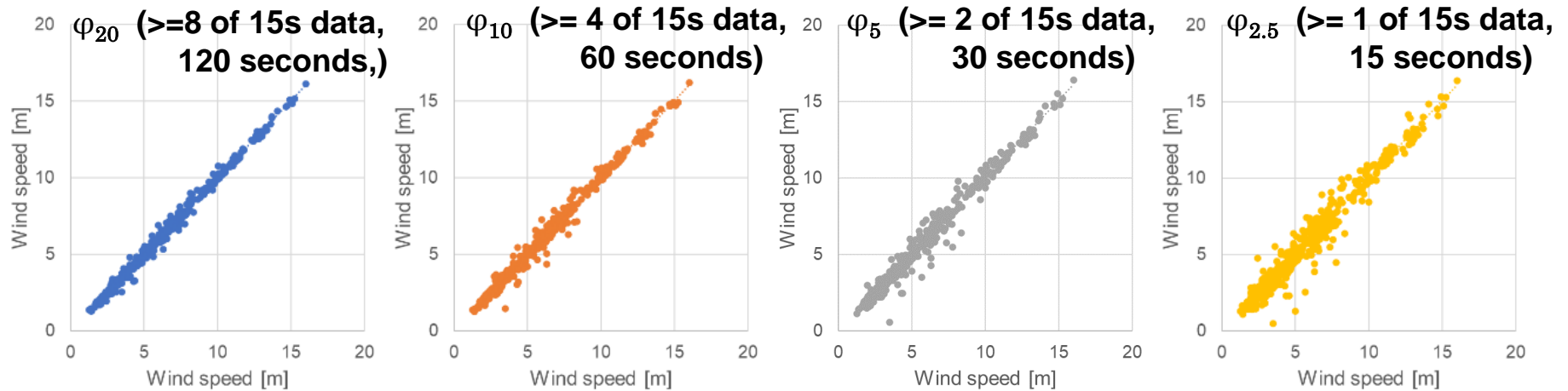$$\eta_x = \frac{Number\ of\ valid\ data}{Total\ number\ of\ data} \times 100$$

Total number of data **= 15 of 1s data**
15 seconds

■ **Accuracy depends on sector size**, no matter how many data points are there.

Minimum sector size > **39 deg.** and Minimum amount of data within one scan is **3** for using least-square fitting method.

REN⬡VA

東京大学
THE UNIVERSITY OF TOKYO

Effect of data number on the accuracy of 10min mean wind speed

■ The effect of number of 15s averaged wind speed on 10 minutes mean wind speed. φ_{10} means 10% of 10minutes (4 of 15s data).

φ_{20} (>=8 of 15s data, 120 seconds,)

φ_{10} (>= 4 of 15s data, 60 seconds)

φ_5 (>= 2 of 15s data, 30 seconds)

$\varphi_{2.5}$ (>= 1 of 15s data, 15 seconds)

$$\varphi_x = \frac{Number\ of\ valid\ data}{Total\ number\ of\ data} \times 100$$

Total number of data = **40 of 15s data, (600 seconds)**

Data availability higher than **10%**.

|	R^2	RMSE
φ_{80}	1.000	0.054
φ_{60}	0.999	0.110
φ_{40}	0.995	0.219
φ_{20}	0.995	0.236
φ_{10}	0.989	0.339
φ_5	0.979	0.464
$\varphi_{2.5}$	0.959	0.663

Correlation between φ_{100} and each φ_x for 10-minute averaged wind speed

R2, Slope and Offset are corresponding to the best practice of the KPI proposed by the Carbon Trust.
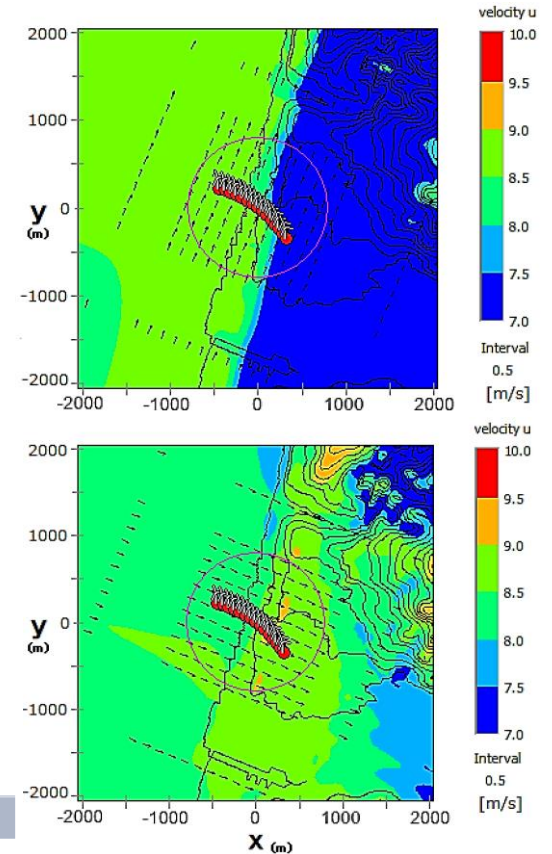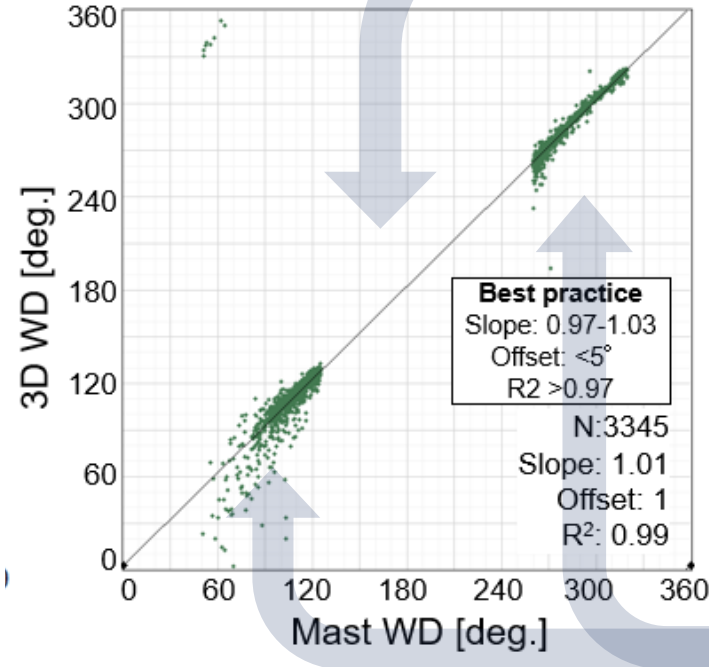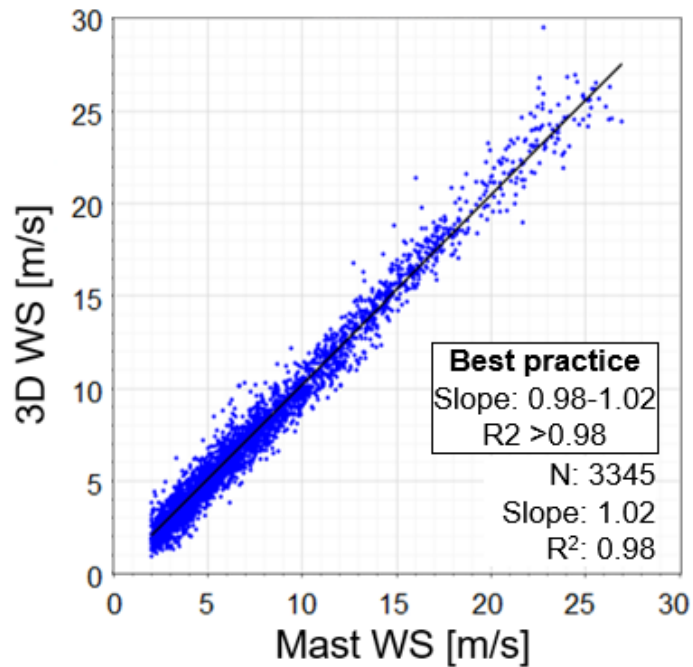
the 10-minute mean wind speed and wind direction measured by the single lidar measurements and the met mast.

1 year measurement at offshore virtual tower

- One year wind measured was performed at three different heights and the proposed filtering criteria are applied.
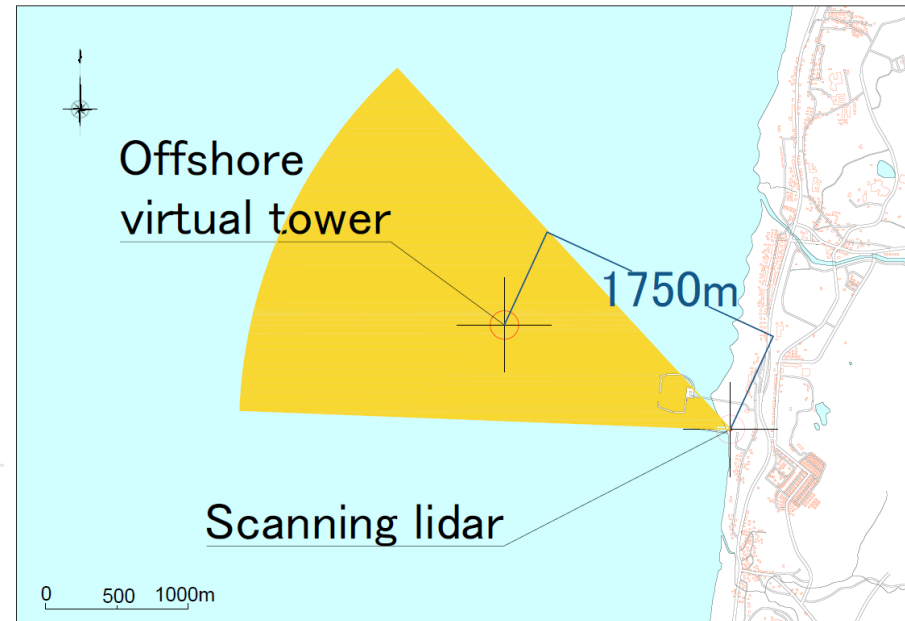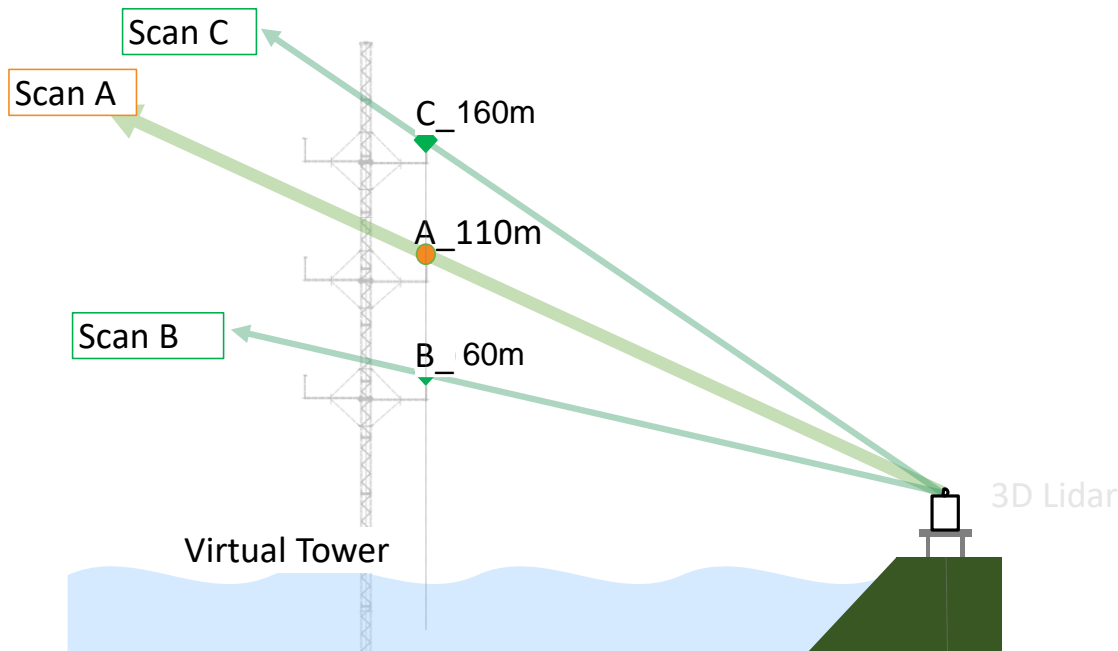

The overall data availability of 10 minutes average wind speed were 96.5%, 96.3% and 96.0% at 160m, 110m and 60m respectively, as they correspond to Stage 3 of the KPI proposed by the Carbon Trust.

Effect of wind direction on wind shear
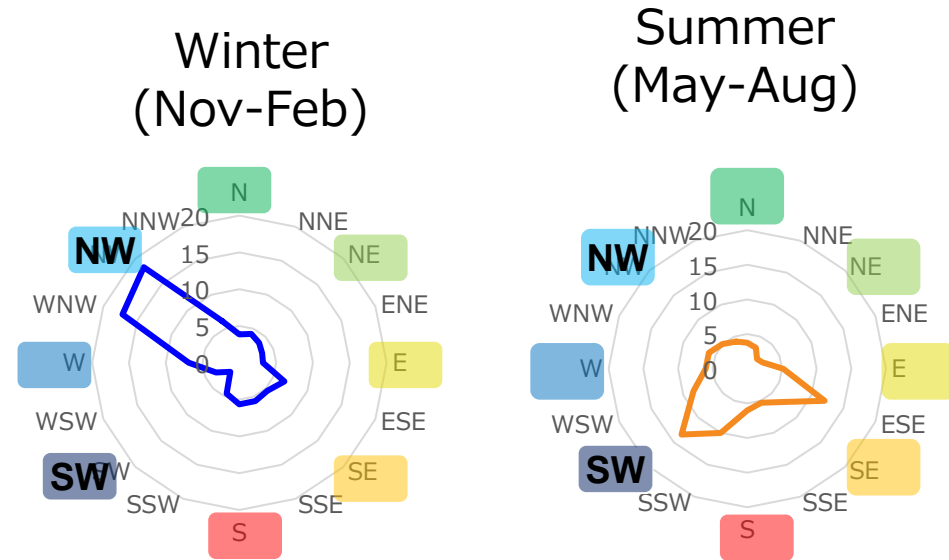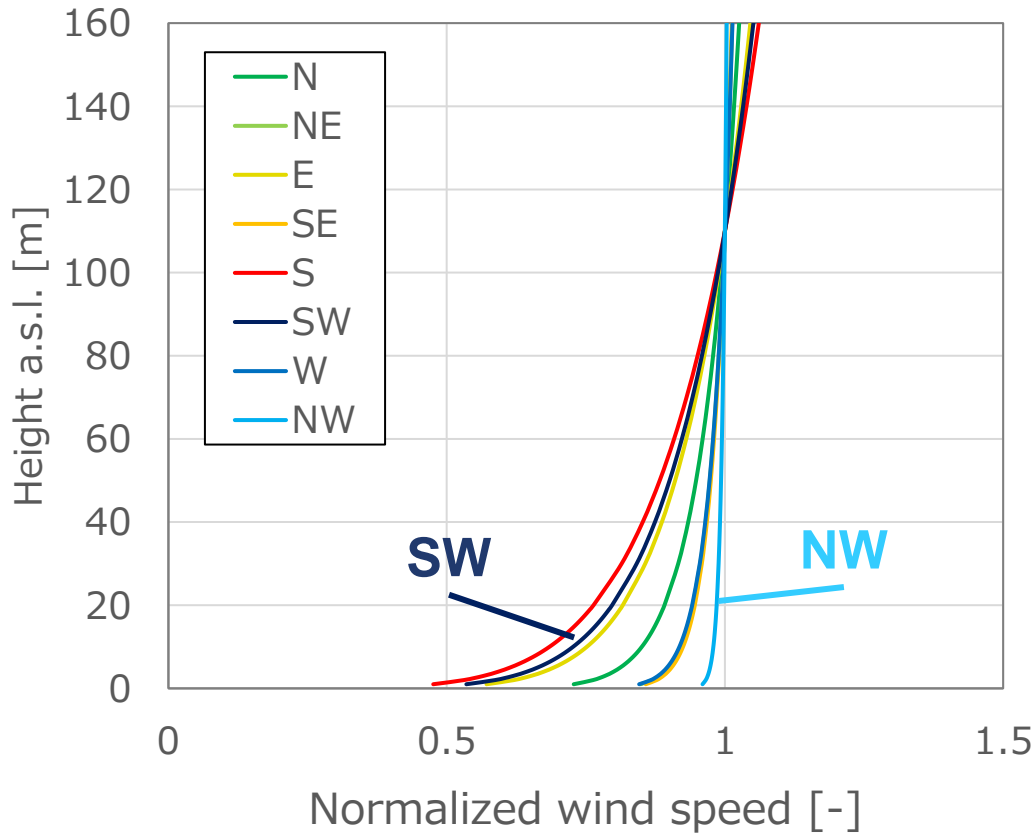
SW wind and NW winds are from offshore, but the vertical profiles are different, caused by the seasonal difference of stability.

Horizontal distribution of mean wind speed
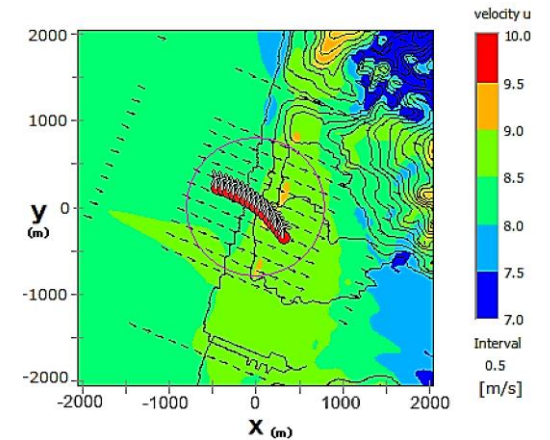
Wind speeds are weaker offshore in the SE direction, considered to be effect of the change in cross-sectional area due to mountains.

Horizontal distribution of mean wind speed at 110m height

Horizontal distribution of mean wind speed in SE
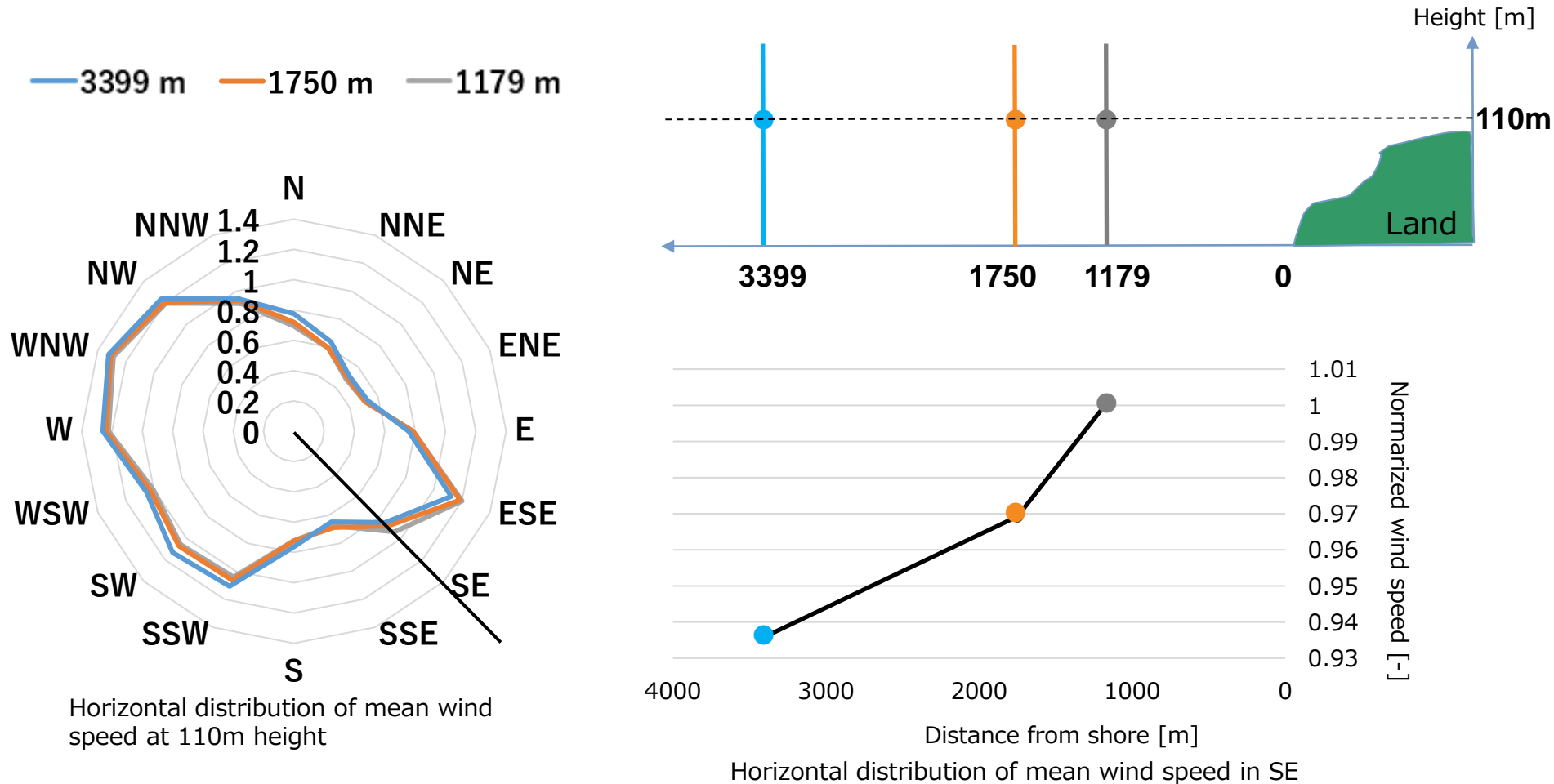
1) Although precipitation and snowfall have significant impacts on the data availability of the scanning Lidar, the annual overall data availability is satisfied.

2) A minimum sector size of 39 degrees and a minimum data acquisition rate of 10% are proposed as filtering criterion to measure 10 minutes mean wind speed and wind direction.

3) The post-processed data availability of 1-year of offshore wind measurement at three different heights satisfies the Stage 3 requirements of the KPI proposed by the Carbon Trust. It Is found that the vertical shear is affected by the atmospheric stability and the onshore terrain.

KPI	Definition	Acceptance Criteria	
		Best Practice	**Minimum Stage 2, only**
X_{mws}	Mean Wind Speed –Slope	0.98 – 1.02	0.97 – 1.03
R^2_{mws}	Mean Wind Speed – Coefficient of Determination	>0.98	>0.97
M_{mwd}	Mean Wind Direction –Slope	0.97 – 1.03	0.95 – 1.05
OFF_{mwd}	Mean Wind Direction –Offset	< 5°	< 10°
R^2_{mwd}	Mean Wind Direction – Coefficient of Determination	> 0.97	> 0.95

KPI	Definition	Acceptance Criteria	
		Stage 3	**Stage 2**
OSA_{CA}	Overall System Availability – Campaign Average	≥97%	≥95%
$OPDA_{CA}$	Overall Post-processed Data Availability	≥90%	≥85%
MSA_{1M}	Monthly System Availability – 1 Month Average	≥95%	≥90%
$MPDA_{1M}$	Monthly Post-processed Data Availability – 1 Month Average	≥85%	≥80%

The Carbon Trust, "OWA Roadmap for the Commercial Acceptance of Floating LiDAR Technology, Version 2.0", 2018