Investigation of wind properties at Mutsu Bay and Tsugaru Strait Japan

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Abstract. Present investigation was conducted to confirm the wind properties at Mutsu Bay and Tsugaru Strait by measurement. The wind distribution along the pathway of ferry ship was investigated. Wind speed and wind direction were measured on one of the four ships operated between Aomori Harbour and Hakodate Harbour during 2018. This paper describes the wind properties measured by ferry anemometer.

1. Introduction

In recent years, offshore wind power generation has been put into practical use especially in Europe as power generation costs have been reduced, and various capital investments are underway. In Japan, the offshore wind resource can be estimated using the “NeoWins”¹ wind map published by NEDO in 2017.

As Tsugaru Strait is said to be excellent in wind energy generation, the authors analysed data observed by anemometer installed on the ferry. Comparison with meteorological data of lighthouse was made to estimate offshore wind conditions.

This study was conducted in the Ministry of the Environment’s “Zoning Introduction Possibility Study Model Project Related to Wind Power Generation”, and the data are the results of observations during 2018.

2. Surrounding Topography and Wind data at Lighthouses

The Tsugaru Strait between Honshu and Hokkaido in Northern Japan connects the Sea of Japan and the Pacific Ocean. Study on wind properties at this area was conducted.

2.1. Features of surrounding terrain

The maximum depth of the Tsugaru Strait is 450m, and the Tsugaru warm current flows from the Sea of Japan to the Pacific Ocean. There is a 1000m class mountain in the north and south of the strait, and the east-west wind is dominant. Mutsu Bay, located on the south side of the Tsugaru Strait, is a closed sea area surrounded by the Tsugaru Peninsula on the west side and the Shimokita Peninsula on the east side. The width in the east-west direction and the north-south direction is about 40 km. The maximum depth of water is about 70m, and the average is about 40-45m. The maximum elevation of the Tsugaru Peninsula is about 700m, and the maximum elevation of the Shimokita Peninsula is about 900m.
2.2. Observation at the lighthouses

In the coastal area of the target area, the Japan Coast Guard conducts wind observations at the lighthouse. This time, in order to investigate the wind conditions on the ocean, we referred to the average wind direction (16 directions) and wind speed data every 30 minutes at the lighthouse. Table 1 shows the altitude, latitude/longitude and the annual average wind speed in 2018 of the referred lighthouses, and LH② has the highest annual average wind speed.

Table 1. Elevation, location and annual mean wind speed in 2018 of lighthouses

| Symbol | Name                  | Elevation of light above Sea | Latitude     | Longitude     | Annual mean wind speed |
|--------|-----------------------|------------------------------|--------------|---------------|------------------------|
| LH①   | Matsumae              | 25m                          | 41°25'07.52"N | 140°05'19.04"E | 5.0 m/s                |
| LH②   | Tappi                 | 119m                         | 41°15'30.54"N | 140°20'32.61"E | 10.4 m/s               |
| LH③   | Mustu-Ohshima         | 42m                          | 41°00'58.16"N | 140°52'18.70"E | 7.5 m/s                |
| LH④   | Ohma                  | 36m                          | 41°33'16.99"N | 140°54'41.83"E | 8.7 m/s                |
| LH⑤   | Esan                  | 44m                          | 41°48'54.81"N | 141°11'00.24"E | 6.3 m/s                |
| LH⑥   | Shiriya               | 47m                          | 41°25'49.32"N | 141°27'43.50"E | 6.9 m/s                |

Fig. 1 shows the wind direction frequency distribution at the position of these lighthouses, and the prevailing wind direction at each lighthouse seems to be distorted due to the topography. The most windy lighthouse LH② is located at the tip of the cape that stretches over the Strait as shown in Fig. 2.

![Figure 1](image-url)

**Figure 1.** Wind rose of lighthouses and ferry trajectory (Jan. 2018)
Fig. 3 compares the monthly average wind speed of LH in 2018 with that in the 20 years from 1995 to 2014, which is referred to by NeoWins. The shape of the monthly mean wind speed change in 2018 is like that of the 1995-2014 monthly mean wind speed, but the absolute value of the former is higher than the absolute value of the latter.

Fig. 4. Ferry hull with wind anemometer
In order to store the data, a data logger (ANEOS WU61T) is added on the 'Blue Happiness' of them, and the data observed by anemometer and the position information output from GPS are recorded every 1 minute. The output of anemometer is corrected to the Earth coordinate system by cancelling the ship's speed obtained from GPS, and it is considered to be an average wind speed of 10 minutes average, 1 minute average, and momentary (approximately 0.25 to 0.5 seconds from previous literature). As described in Reference 5), the hull may influence the wind direction and anemometer. However, up to section 3, the raw observation results are described, and in section 4, the evaluation is performed by taking these effects into account.

Figures 5 and 6 show data of LH② from January 9-11, 2018 and July 6-8, 2018, when the wind direction in the winter and summer was stable and strong in the west and east respectively. Wind direction and wind speed (a) at (LH②), wind direction and wind speed at the ferry (b), The change in latitude (c) of the ferry position during navigation with time.

Looking at the changes in wind direction in Figs. 5 (a) and 5 (b), from the afternoon of January 9, the wind direction is almost stable from the west, and the wind speed at LH② is from 18:00 to 20:00 on January 9. Wind speed shows a maximum of 29m/s.

The shaded time period in the figure indicates that the ferry is anchored at Aomori Port or Hakodate Port. The wind speed on the ferry anchored at the port is significantly lower than the wind speed at route, and the position of the ferry is considered to be important for wind speed evaluation. The voyage scheduled to depart from 22:25 Aomori Port on January 9 was cancelled due to strong wind, and the ship was anchored at Aomori Port. Therefore, the observation results on the ferry route might underestimate the wind speed when it is simply time averaged. On the other hand, from July 6th shown in Fig. 6, the wind from east has blown, wind speed fluctuations observed during ferry navigation appear to be periodic and different between Fig. 5 and Fig. 6.

![Figure 5](image_url)

Figure 5. Time history data for January 9-11, 2018
3.1. Monthly average wind speed

In order to evaluate the distribution of wind speed according to the location of the ferry, the route was divided into sectors at intervals of 0.1-degree latitude (F① to F⑪ in Fig. 1), and the wind characteristics were evaluated for each sector4). Fig. 7 shows the changes in the monthly average wind speed between F③ and F⑦. The wind tends to increase in winter and weaken in summer. F⑤ has a large fluctuation range of monthly average wind speed.
The distribution of monthly average wind speed in the latitude direction in January, April, July, October and annual average are shown in Fig. 8. The average monthly wind speed in Sector F① and F⑪ corresponding to Aomori Port and Hakodate Port in January is as low as 5m/s, but the wind speed is 9m/s in Mutsu Bay and over 10m/s in Tsugaru Strait. The monthly average wind speed of F⑤ to F⑥ exceeds 12m/s. In July, the monthly average wind speed generally decreased significantly in sectors F④ to F⑦.

![Figure 8. Changes of the distribution in the latitude direction of monthly average wind speed](image)

### 3.2. Wind direction frequency

Table 2 compares the wind direction frequency distribution for winter and summer at latitude sectors F③ to F⑦.

In January 2018, the wind blowing from the west is dominant. In July, the frequency of winds from the east increases, and F⑤ has a wider range of wind directions than F③ and F⑦, with no remarkable prevailing wind direction.

In this season, the wind speed was reduced, and the wind direction was widely distributed because it was downwind of the mountainous terrain east of F⑤.
Table 2. Monthly wind direction frequency distribution at each point

| Point     | F③ 41° 00'N — 41° 06'N | F⑤ 41° 12'N — 41° 18'N | F⑦ 41° 24'N — 41° 30'N |
|-----------|-------------------------|-------------------------|-------------------------|
| January, 2018 | ![Image]                | ![Image]                | ![Image]                |
| July, 2018   | ![Image]                | ![Image]                | ![Image]                |

4. Data Correction and Uncertainty

Various corrections and uncertainties need to be considered to estimate the average annual wind data at 100m above sea level from the data observed by ferry in 2018.

4.1. Data correction

4.1.1. Observed year correction
When comparing with the wind speed of NeoWins, the monthly average wind speed during 2018 tends to be higher than the average value of 1995-2014 that was evaluated by NeoWins. Then, the ratio of monthly average values was used to adjust to the year of evaluation at NeoWins.

4.1.2. Altitude correction
The altitude correction was made to the altitude of 100 m using the following formula for the wind speed observed at the draft of 27.3 m at the ferry.

\[ U_{100} = U_{27.3} \times \left( \frac{100}{27.3} \right)^{0.1} = U_{27.3} \times 1.14 \] (1)

Note that the power index of 0.1 is an assumed value assuming the sea,

4.1.3. Hull shape correction
The effect of the hull\(^6\) on the measured wind speed at the anemometer was examined by wind tunnel experiments. The model was 1/200 on scale and in a uniform flow, and accelerated wind speed of 12% was obtained at the wind anemometer position.

4.2. Uncertainty
The average wind speed for 10 minutes on a ferry traveling at a speed of 20 knots might differ from the normal 10-minutes average wind speed because it is the average of time of 10 minutes and
distance of 6 km. In addition, it is necessary to keep in mind that uncertainty of the observed wind speed occurs about ± 15% because the ferry passes through the place of interest four times a day at a specific time. 4)

5. Summary and future issues

To understand the wind characteristics in Mutsu Bay and Tsugaru Strait, observations at Tsugaru Strait Ferry was conducted in 2018. Then, the following findings were obtained.

(1) Compared with 1995-2014, which was evaluated by NeoWins, the wind speed at LH 2 is higher during 2018, and consideration is necessary for comparing absolute values with NeoWins.

(2) The planned route of the Tsugaru Strait Ferry connects the 1° latitude direction linearly, but the actual operating route spreads about 0.3° in the longitudinal direction due to the strong wind and high waves.

(3) Wind speed along the route of Ferry was investigated, and statistical characteristics of wind direction and wind speed of each sector are evaluated. The fluctuation of monthly average wind speed depends on the location, and it seems to be due to the surrounding topography and wind direction.

The authors hope that the results of this research will be used to verify NeoWins with actual measurements and open new offshore wind areas. Then, observations should be made at fixed locations on the ocean, considering the height of the wind turbine. Furthermore, study on the turbulent characteristics and extreme wind speed is also necessary.

6. References

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