Experimental study on effects of buoy motion on offshore wind speed measurement

Hiroto Ichikawa[1)*], Teruo Ohsawa[1)], Kengo Wakabayashi[1)]
Hiroshi Asou[2)], Shintaro Hashimoto[2)], Shigenori Komori[2)]
Satoshi Nakamura[3)]

1) Graduate school of Maritime Sciences, Kobe University, Japan (* presenting author)

2) Zeni Lite Buoy Co., Ltd.

3) Port and Airport Research Institute, Japan.

1) * Graduate School of Maritime Science, Kobe university, 5-1-1 Fukaeminami, Higashinada, Kobe, Hyogo, 658-0022, Japan; E-mail: 158w301w@stu.kobe-u.ac.jp

Abstract

This study is undertaken to understand the effects of buoy motion on wind speed measurement by using a buoy-motion simulator. A method for motion correction is proposed and the effect is evaluated. The following conclusions are obtained in this study. 1) A 10-min averaged wind speed measured with an oscillating anemometer is almost the same as that obtained from a fixed anemometer, even without motion correction. 2) In the randomly oscillated case, the 10-min averaged wind speed largely differs from the fixed-anemometer-measured wind speed, though it can be properly corrected with motion correction. 3) As an averaging time is shorter, the effectiveness of motion correction can be clearly confirmed. This means that the motion correction technique must be applied for a raw instantaneous (4 Hz) wind speed, which can be used for turbulence analysis. 4) The motion correction for a shorter averaging time can fail, if an anemometer fluctuates relatively faster to its sampling cycle.

Key word: buoy measurement, motion correction, coastal water, wind resource assessment

1. Introduction

Compared to onshore, wind speed measurements are much fewer offshore, especially in coastal waters, where satellite observation is not available. In Japan, most of the offshore wind speed measurements are obtained from buoys. However, a frequently asked question is whether the buoy measured wind speed is really accurate or not. In fact, there are few studies which directly answer this question. Thus, this study is undertaken to understand the effects of buoy motion on wind speed measurement. A method for motion correction is proposed and the effect is also evaluated.

2. Data and method

The experiment was conducted at the pier of the Hazaki Oceanographical Research Station (Figure 1) in Ibaraki Prefecture, Japan, from 28th to 30th September, 2015. At the head of the 427-meters-long bier, a buoy-motion simulator, which can oscillate a sonic anemometer like an inverted pendulum, was installed. Using this buoy-motion simulator, five experiments with different oscillations were performed, and the measured wind speeds were compared to those measured with a fixed sonic anemometer, installed next to the simulator (Figure 2). Then, a motion correction technique was applied to the wind speeds measured with the oscillated anemometer and the performance was evaluated. The motion correction can be simply written as follows.

$$V_{\text{corrected}} = \boldsymbol{R} \cdot V_{\text{measured}} + V_{\text{anemometer}} \quad (1)$$

where, $V_{\text{corrected}}$ is a corrected wind speed, $\boldsymbol{R}$ is a rotation matrix to convert the anemometer fixed coordinates to the Earth fixed coordinates, V_{measured} is a measured wind speed, and $V_{\text{anemometer}}$ is a speed of the sonic anemometer in the Earth fixed coordinate. Changing the cycle, amplitude and constant slope of the oscillation, five experimental cases shown in Table 1 were conducted.

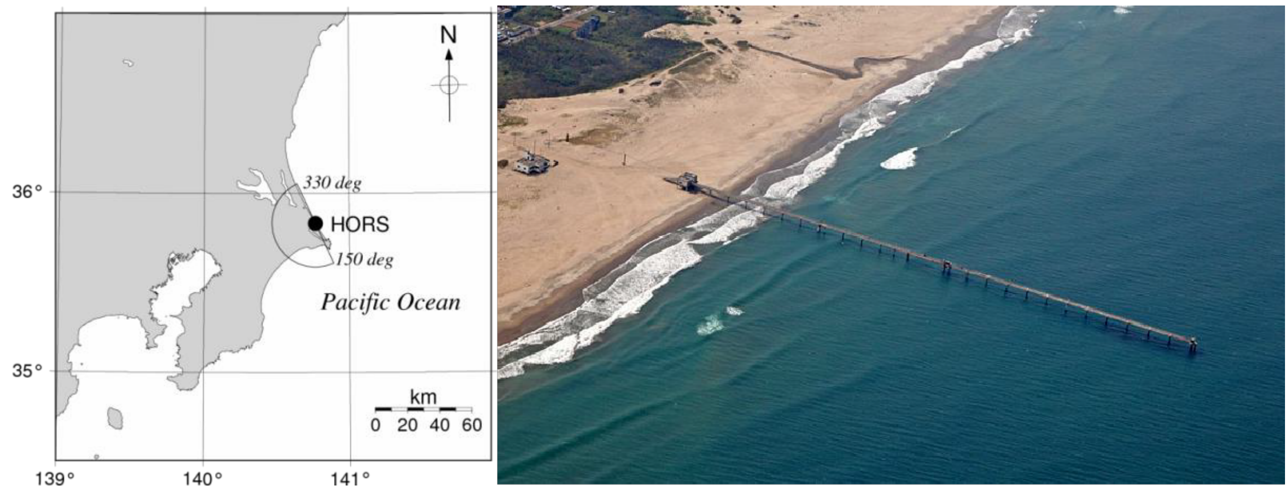

Figure 1: Location and bird's-eye view of the Hazaki Oceanographical Research Station.

Figure 2: Oscillated anemometer on the buoy-motion simulator and fixed anemometer.

Table 1: Experiment cases.

Case name	Cycle	Half amplitude	Constant slope	Samples
Case 1	4 sec.	12 deg.	0 deg.	10
Case 2	4 sec.	12 deg.	5 deg.	10
Case 3	8 sec.	12 deg.	5 deg.	50
Case 4	12 sec.	12 deg.	5 deg.	9
Case 5	random	random	0 deg.	3

3. Results

Results of all of the experiment cases are summarized in Tables 2 and 3, which show three statistics (bias, root- mean-square-error (RMSE) and correlation coefficient (CC)) on the accuracy of the oscillated-anemometer-measured wind speed against the fixed-anemometer-measured wind speed. Tables 2 and 3 show those before and after motion correction, respectively.

Firstly, 10-min wind speeds are compared. Regardless of motion correction, the oscillated-anemometer-measured wind speeds have nearly-zero bias and RMSE and nearly-one CC, except Case 5. This means that there are no large differences in 10-min average wind speed between the oscillated and the fixed anemometers. In addition, comparing the averaged statistics for all cases between Tables 2 and 3, the three statistics all indicate that the corrected wind speeds are more accurate than those before motion correction, though the differences are very small. Figure 3 shows a representative scatter diagram (for Case 3) comparing wind speeds before and after motion correction. It is found that most of the samples are distributed on or around the straight line of 1 : 1 with or without motion correction. This feature can be also seen in other cases.

Secondly, 2-min average, 10-sec average and raw (4 Hz) wind speeds are compared. In Table 2, it is found that as an averaging time is shorter, RMSE and CC become higher and lower, respectively, indicating the accuracy gets lower. Although the same tendency can be seen in Table 3, it is found that the accuracy is higher compared to before motion correction shown in Table 2. In particular, the effectiveness of motion correction can be clearly seen in 4Hz raw wind speed. However, Case 5 is exceptional, because RMSE decreases by making motion correction. In this case, the anemometer was fluctuated manually, and sometimes it moved very fast compared to the sampling interval of the anemometer. This causes an error in estimating the speed of the anemometer, leading to an error in corrected wind speed.

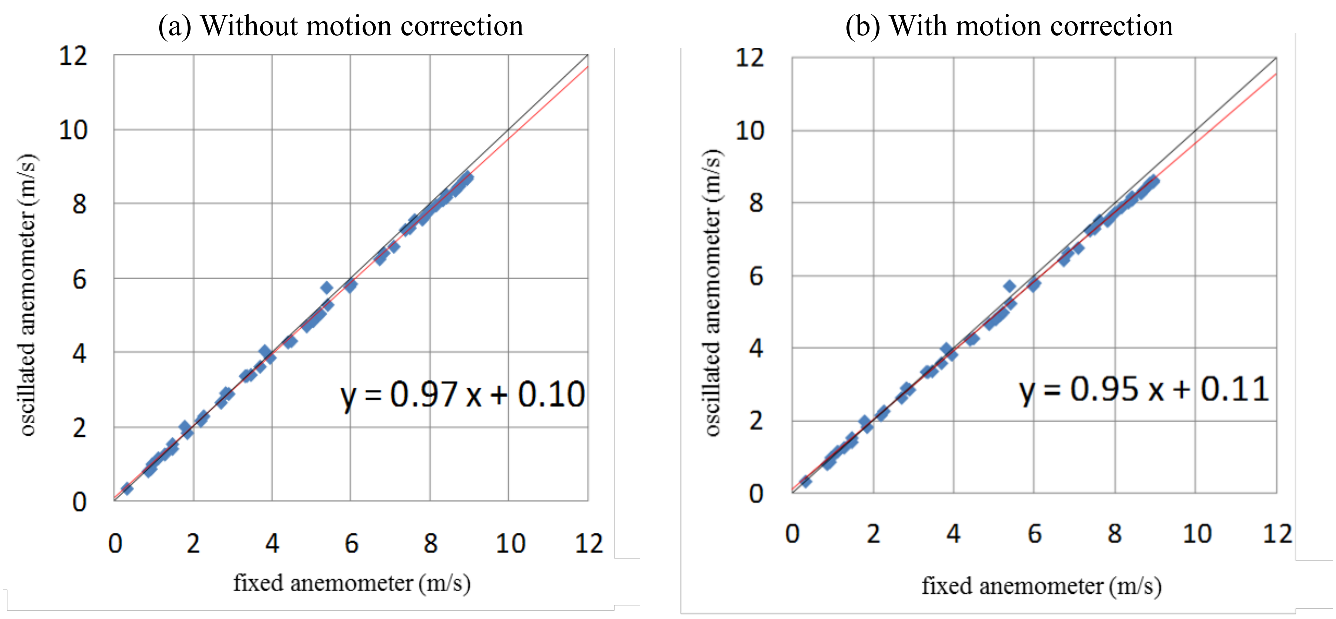

Figure 3: 10-min average wind speeds measured with fixed-anemometer versus oscillated-anemometer. (a) with and (b) without motion correction anemometer.

Table 2: Statistics on accuracy of oscillated-anemometer-measured wind speed against fixed-anemometer-measured wind speed.

Bias(m/s)	Averaging time			Raw(4Hz)	Average
	10-min	2-min	10-sec		
Case1	0.081	0.081	0.080	0.101	0.086
Case2	0.015	0.014	0.014	0.041	0.021
Case3	-0.104	-0.113	-0.110	-0.100	-0.107
Case4	0.079	0.077	0.075	0.078	0.077
Case5	-0.301	-0.284	-0.277	0.108	-0.189
Average	-0.046	-0.045	-0.043	0.046	-0.022

RMSE(m/s)	Averaging time			Raw(4Hz)	Average
	10-min	2-min	10-sec		
Case1	0.024	0.029	0.069	0.478	0.150
Case2	0.039	0.043	0.086	0.469	0.159
Case3	0.038	0.043	0.099	0.387	0.142
Case4	0.022	0.028	0.070	0.210	0.083
Case5	0.161	0.150	0.214	1.235	0.440
Average	0.057	0.059	0.108	0.556	0.195

Corr.Coef.	Averaging time			Raw(4Hz)	Average
	10-min	2-min	10-sec		
Case1	0.997	0.996	0.989	0.923	0.976
Case2	0.994	0.993	0.987	0.935	0.977
Case3	0.999	0.999	0.995	0.976	0.992
Case4	0.995	0.994	0.983	0.947	0.980
Case5	0.981	0.985	0.968	0.719	0.913
Average	0.993	0.993	0.985	0.900	0.968

Table 3: Statistics on accuracy of motion-corrected wind speed against fixed anemometer-measured wind speed.

Bias(m/s)	Averaging time			Raw(4Hz)	Average
	10-min	2-min	10-sec		
Case1	0.093	0.093	0.092	0.100	0.094
Case2	0.036	0.036	0.036	0.047	0.039
Case3	-0.069	-0.069	-0.067	-0.064	-0.067
Case4	0.112	0.110	0.109	0.107	0.109
Case5	-0.057	-0.059	-0.059	-0.015	-0.048
Average	0.023	0.022	0.022	0.035	0.025

RMSE(m/s)	Averaging time			Raw(4Hz)	Average
	10-min	2-min	10-sec		
Case1	0.026	0.031	0.071	0.325	0.113
Case2	0.040	0.044	0.083	0.328	0.124
Case3	0.024	0.028	0.083	0.293	0.107
Case4	0.026	0.032	0.073	0.194	0.081
Case5	0.043	0.047	0.090	1.460	0.410
Average	0.032	0.036	0.080	0.520	0.167

Corr.Coef.	Averaging time			Raw(4Hz)	Average
	10-min	2-min	10-sec		
Case1	0.997	0.996	0.989	0.946	0.982
Case2	0.994	0.993	0.988	0.953	0.982
Case3	0.999	0.999	0.995	0.982	0.994
Case4	0.996	0.994	0.984	0.953	0.982
Case5	0.990	0.990	0.980	0.746	0.926
Average	0.995	0.995	0.987	0.916	0.973

4. Conclusions

Main results obtained in this study are summarized as follows.

1) A 10-min averaged wind speed measured with an oscillating anemometer is almost the same as that obtained from a fixed anemometer, even without motion correction.
2) Only for Case 5, randomly oscillated, the 10-min averaged wind speed largely differs from the fixed-anemometer-measured wind speed, though it can be properly corrected with motion correction.
3) As an averaging time is shorter, the effectiveness of motion correction can be clearly found. The motion correction technique must be applied for a raw instantaneous (4 Hz) wind speed, which can be used for turbulence analysis.
4) The motion correction for a shorter averaging time can fail if an anemometer fluctuates relatively faster compared to its sampling cycle (Case 5).

A 10-min averaged wind speed is found to be a robust parameter against buoy motion, and it can be practically used even without motion correction, depending on wind and sea conditions. For instantaneous wind speed, the motion correction applied is confirmed to work effectively and this is necessary for turbulent intensity calculation. Based on the results, the authors plan to develop a hub-height wind speed estimation method by combining a buoy-measured wind speed with a vertical profile from numerical simulation.

Acknowledgement

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