ANALYSIS AND FORECASTING OF WINDS AND WAVES FOR A FLOATING TYPE WIND TURBINE

Hajime Mase[1], Tomohiro Yasuda[1], Nobuhito Mori[1],
Tracey H.A. Tom[2], Ai Ikemoto[2] and Tomoaki Utsunomiya[3]

The floating type wind turbine demonstration project has been promoted in Japan. In 2012, a 1:2 scale model was installed off Kabashima Island in Nagasaki Prefecture. And a year later, a full scale model was installed. For the design of the wind turbine's floating body, winds, waves and other parameters were analyzed. For the construction and daily management, a prediction system was developed and the predictions and observations of winds and waves were compared and the agreement between them was good.

Keywords: floating type wind turbine; design parameters; winds and waves forecasting; forecasting system

INTRODUCTION

Since we are facing global warming, it is important to utilize renewable energy sources, such as wind, solar, geothermal, biomass and so on. Wind energy is easy to use, among various kinds of natural renewable energies, and has been used for many years. Higher wind speeds are available offshore compared to those on land. Although the offshore wind power is expensive to utilize, offshore floating wind turbine technology is being developed and actually operated: 1) Italy: small wind turbine (2007), 2MW wind turbine (2012); 2) Norway: 2.3MW wind turbine (2009); 3) Portugal: 2MW wind turbine (2011); 4) Japan: 100kW (2012), 2MW wind turbine in Nagasaki (2013) and in Fukushima (2013).

The floating type wind turbine demonstration project has been promoted in Japan. A 1:2 scale model (100KW) was installed off Kabashima Island in Nagasaki Prefecture (2012), a full scale model of 2MW was installed after removing the 1:2 scale model (2013) and another full scale model of 2MW was installed offshore in Fukushima Prefecture (2013).

As for the design of floating body of the wind turbine off Kabashima Island, external forces such as winds and waves were evaluated using various re-analysis and prediction data including NCEP wind data, JMA meteorological GPV data and NEDO data. The design parameters were wave characteristics of the maximum and mean wave heights, 2D wave height-period and wave height-wind distributions, and wave energy spectrum. Tides and currents were also evaluated. For the construction and daily management, a prediction system was developed, and the predictions and observations of winds and waves were compared and the agreement was good.

EVALUATION OF WINDS AND WAVES FOR DESIGN CONDITIONS OF FLOATING BODY

Demonstration Site

Figure 1 shows the demonstration site off Kabashima Island, Nagasaki Prefecture, Japan, where a 1:2 scale model was installed in 2012 and a year later a full scale model was installed (GOTO-FOWT, 2013). Near the floating body, a wave buoy has been set. In Kabashima Island a 15 m-height wind observation tower was built and a 40 m-height wind observation tower was installed later. Figure 2(a) shows a photo of the 1:2 scale model while Figure 2(b) shows the full scale model. The 1:2 scale model was 71 m in length (41 m height from the sea surface) having a 100KW turbine with 11 m length blades, and the opening ceremony was held on 29/8/2012. The full scale model is 172 m long (96 m high above the sea surface) having a 2MW turbine with 40 m long blades, and the opening ceremony on 28/10/2013. Detailed explanations of the evaluation of external forces are seen in Mase et al. (2009, 2010, 2011, 2012a, 2012b).

Evaluation of Wind Speed

Five kinds of data were used for the determination of extreme and mean values of wind speed. The data were as follows:

[1] Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan
[2] Surflegend, Inc., 3-1-1 Nishi-kaigan, Tsujido, Fujisawa, Kanagawa 251-0046, Japan
[3] Dept. of Ocean Energy Resources, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan

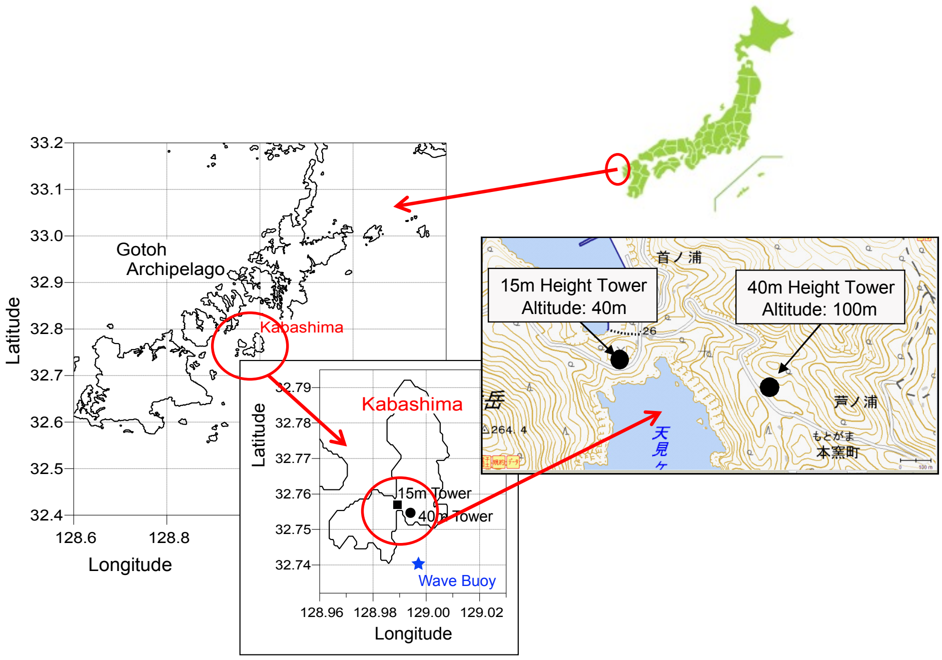

Figure 1. Map of the demonstration site of floating type wind turbine.

(a) (b)

Figure 2. Photos of (a) a 1:2 scale model installed in 2012 and (b) a full scale model in 2013.

1) observed data from the Fukue Meteorological Office near the demonstration site to determine both the extreme value and mean value;
2) wind condition map by NEDO (New Energy and Industrial Technology Development Organization) to determine both the extreme value and mean value;
3) hourly analysis GPV data by JMA (Japan Meteorological Agency) to determine the mean value;
4) NCEP/NCAR re-analysis data to determine both the extreme value and mean value;
5) Japanese Building Standards Act to determine the extreme value.

The data of Fukue Meteorological Office was 1975~2010 from which wind speeds of 1, 50 and 100 years return periods from the annual maximum wind speed data were obtained as 19.72 m, 50.73 m and 46.06 m, respectively, by considering the bias between the Fukue Meteorological Office and the site in offshore (correction factor = 1.18, obtained from the ratio of annual averaged wind speed at site to that at the office). The wind speed at 60 m height was estimated by power law (coefficient 0.14 for annual averaged wind speed and 0.11 for extreme wind speed).

The wind speed obtained from the wind condition map by NEDO might become smaller since the annual averaged and extreme wind estimations are for data on land but not offshore, and the data contain the effects of topography and surface roughness. Annual averaged and 50 years return period wind speeds are 6.9 m/s and 47.0 m/s from the data.

Hourly analysis GPV (HAGPV) wind data is provided by JMA (Japan Meteorological Agency) every hour and is a numerical analysis of the horizontal wind and temperature fields surrounding Japan. The data grid covers an area between latitude of 22.4 to 47.6 degrees and longitude of 120 to 150 degrees with a spatial resolution of 0.05 by 0.0625 degrees. From the HAGPV, the modal value of the frequency distribution was obtained as 4.5 m/s and the averaged value as 6.36 m/s at 10 m height (that is, 8.17 m/s at 60 m height).

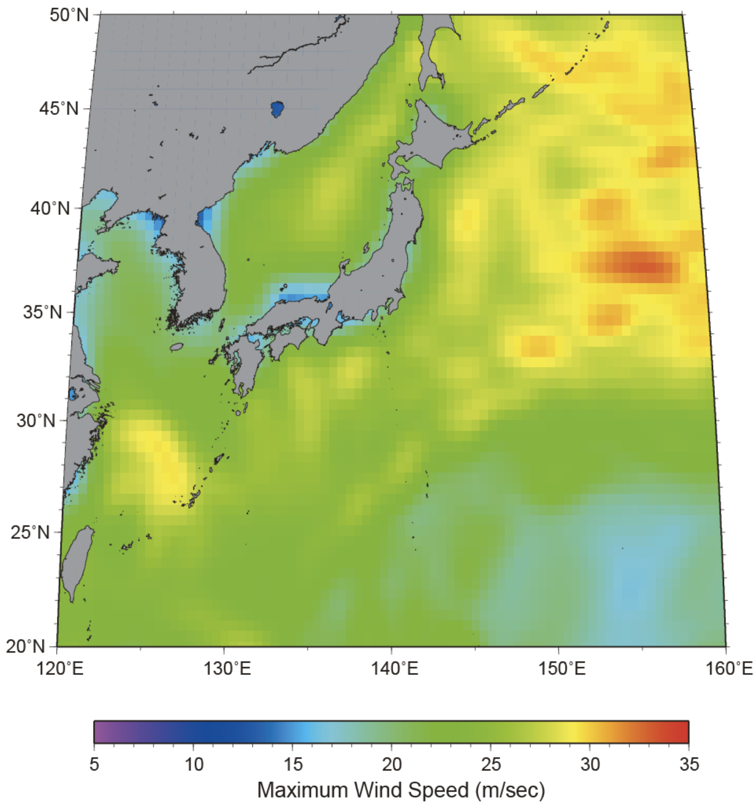

Figure 3. Spatial distribution of wind speed of 50 year return period

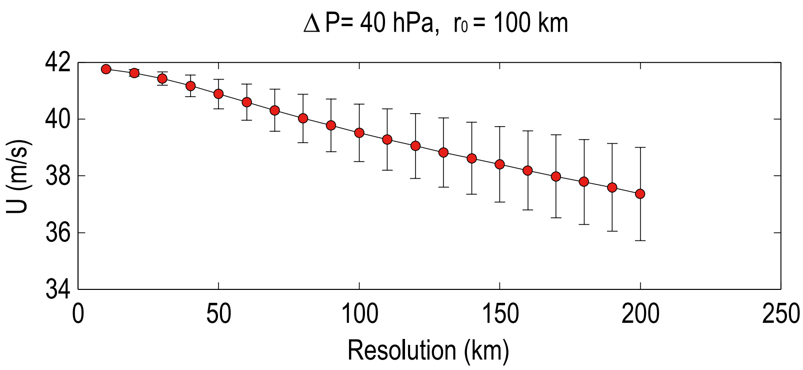

Figure 4. Effect of spatial resolution on maximum wind speed

NCEP/NCAR re-analysis data used here was 54 years data during 1948~2001. The wind speed of the 50 year return period is shown in Fig. 3. A data point nearest to the demonstration site was selected and the data was corrected by considering the spatial resolution of the grid. Figure 4 examines the effect of spatial resolution on the estimation of maximum wind speed. A hundred typhoons with a radius of 100 km and pressure depression of 40 hPa were artificially simulated. The spatial resolutions were changed from 10 km to 200 km, and the wind speeds obtained at the site were plotted by the mean values and the standard variations. By using the result of Figure 6, the NCEP/NCAR wind data was modified. For example for the grid of 200 km, the maximum wind speed was underestimated by 12%. Thus, the corrected wind speeds of annual, 50 year and 100 year return periods are 8.85 m/s, 51.85 m/s, and 54.56 m/s, respectively.

The Japanese Building Standards Act and The AIJ Recommendations for Loads on Buildings (1993 Edition) by Architectural Institute of Japan decides the extreme value at Fukue City according to the rule: 53.1 m/s at 60 m height for the 50 year return period and 57.0 m/s at 60 m height for the 100 year return period.

In summary, from the obtained data from five types of data are as follows:

1) For annual data, the value of 6.9 m/s from NEDO was modified by IEC61400-1 (Class 3), for safety consideration, as 7.5 m/s.
2) As for the extreme values of 50 year and 100 year return period, wind speeds are 53.1 m/s and 57.0 m/s, respectively, from the Japanese Building Standards Act.

Evaluation of Waves

A design wave was estimated as follows:

1) Offshore waves were predicted by WAM using NCEP/NCAR wind data;
2) Effect of land due to spatial resolution around the demonstration site as well as the offshore point of output was checked. If there are any wave observation stations, the relation of wave heights between the observations and predictions is examined. If there are no wave observation stations, the relation between wave heights predicted by WAM and by wave prediction model with finer spatial resolution wave model (SWAN) considering the effect of land was examined.
3) The modified wave predicted values considering the relation between wave heights at the offshore location and the demonstration site were used to get design waves.

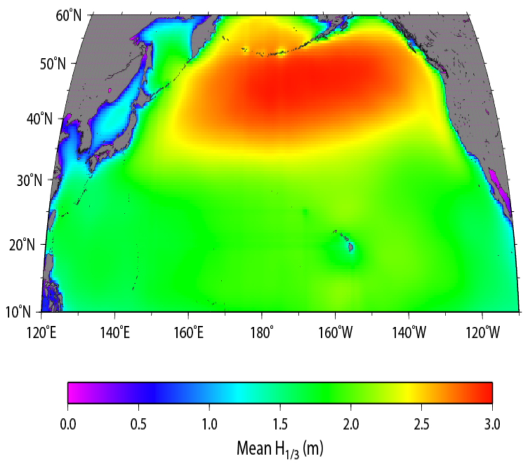

Figure 5. Spatial distribution of annual averaged significant wave height.

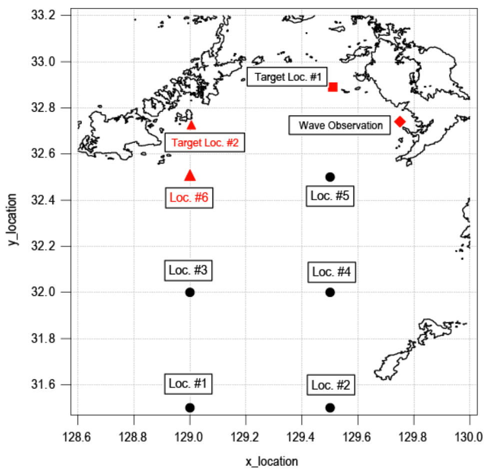

Figure 6. Locations of outputs of offshore wave predictions (Loc. #1~#6) and the demonstration site (Target Loc #2) and the first candidate of demonstration site (Target Loc. #1).

Figure 5 shows the spatial distribution of annual averaged significant wave height in the North Pacific Ocean. Figure 6 shows the locations of offshore wave predictions (shown by Loc. #1~#6) and the final demonstration site (Target Loc. #2) and the first candidate location (Target #1). If the demonstration site was Target Loc. #1, there is a wave observation station, shown as 'wave

Observation', and the relation between wave heights at Loc. #5 and at 'Wave Observation' location was examined. However, the actual demonstration site was determined at Target Loc. #2, the relation between wave heights at Target Loc. #1 and Offshore Loc. #6 was examined with a finer mesh calculation.

Figure 7 shows an example of the relation between wave heights at offshore location (Loc. #6) and the demonstration site (Target Loc. #2). By using such relations, wave heights were modified and the probabilistic wave height of 50 year and 100 year wave heights were determined.

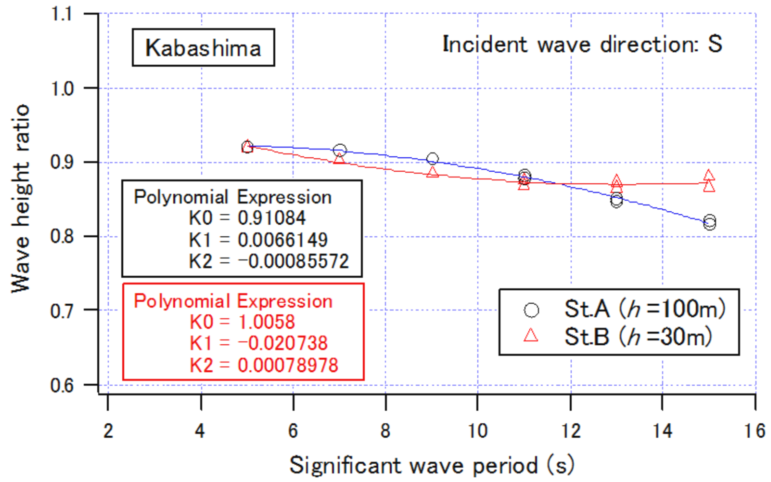

Figure 7. Relation between wave heights at the demonstration site (water depth of 100 m denoted as St. A of Target #2) and offshore (Loc. #6).

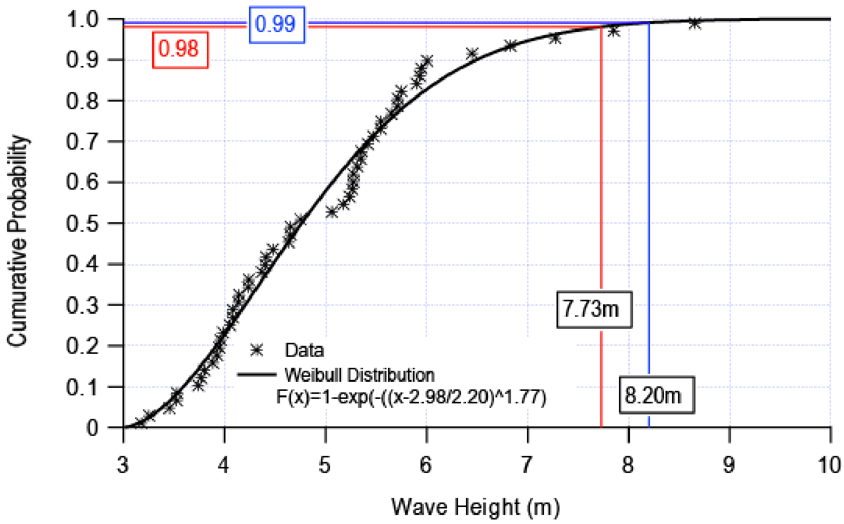

Figure 8. Fitting of Weibull distribution for the determination of probabilistic wave heights.

Figure 8 shows how to determine the probabilistic wave heights. The 50 year and 100 year return period wave heights are 7.73 m and 8.20 m, respectively, from Fig. 8. Figure 9 shows the relationship between the significant wave heights and periods predicted at locations Loc. #1 ~Loc. #6. The wave periods corresponding to the wave heights 7.73 m and 8.20 m are 14.0 s and 14.3, respectively. However, after the construction of the 1:2 scale model, a large Typhoon #1216 (SANBA) passed close to the demonstration site and exceeded the above design values. Then, the wave height and period used for the design of floating body were determined as 12.1 m and 16.1 s with a margin.

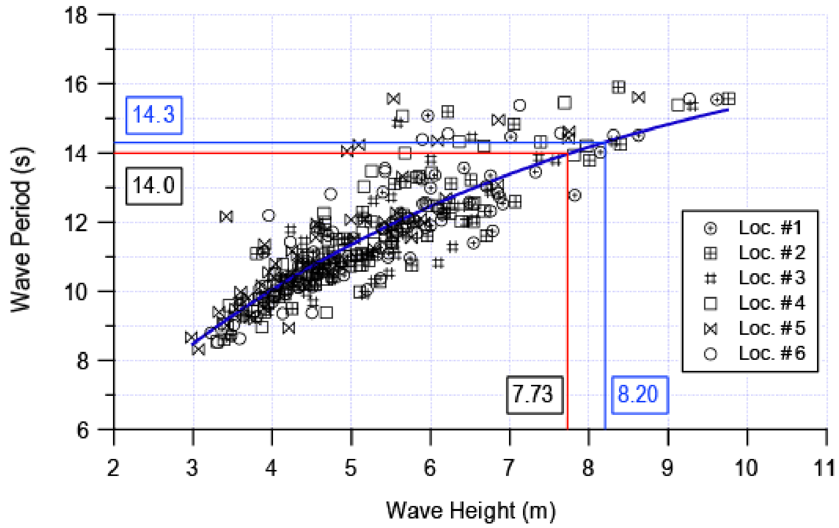

Figure 9. Relation between significant wave heights and periods.

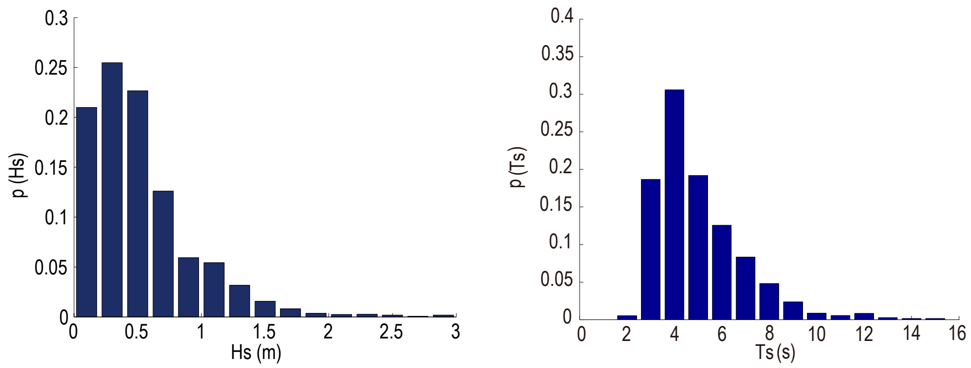

Figure 10. Daily distribution of significant wave heights and periods.

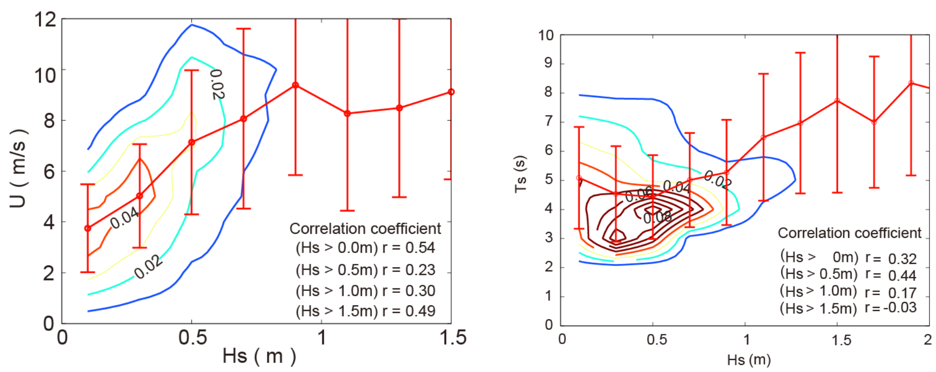

Figure 11. 2D distributions: (a) significant wave heights and wind speeds; (b) significant wave heights and periods.

Figure 10 shows the daily distribution of significant wave heights and period obtained from wave predictions using HAGPV wind data; from which it is seen that wave heights are less than 2 m, peak wave period is 4 s.

Figure 11 shows combined distributions of significant wave heights, periods and wind speeds; these data are used to calculate the floating body motions due to waves and winds. It is seen that the correlation coefficient is 0.49 above 1.5 m wave height and the correlation between wave height and period is not seen above 1.5 m wave height.

Evaluation of Tide, Tidal Current and Wind-induced Current

For the determination of tide, the data near the site was used. The storm surge height of 0.675 m was estimated from the existing largest pressure depression 45 hPa (0.015 m/1 hPa for safety). The design highest high water level was estimated as 3.51 m. The maximum of tidal current is 1.09 knots bellow 5 m from the surface, and 0.96 knots bellow 50 m from the surface. The wind-induced current are 1, 50, 100 year return period current velocities are 0.21 m/s, 0.40 m/s, 0.43 m/s (determined from DNV-OS-J101).

DAILY WIND AND WAVE PREDICTION SYSTEM

Required information of wind and wave are:

1) 1 week prediction information to make Operation and Maintenance Plan (OMP);
2) 3 days prediction information, more detailed than 1 week prediction as used for OMP;
3) 1 day prediction information for related persons to know wind and wave information before they go out for work;
4) 2 hour real-time prediction for related persons to know the real time situation.
5) interactive web information to display animations for a desirable region, graph, text data delivered at a certain time.

Figures 12 and 13 show the schematic view of wind and wave prediction system. The detailed prediction flow can be seen Mase et al. (2012b)

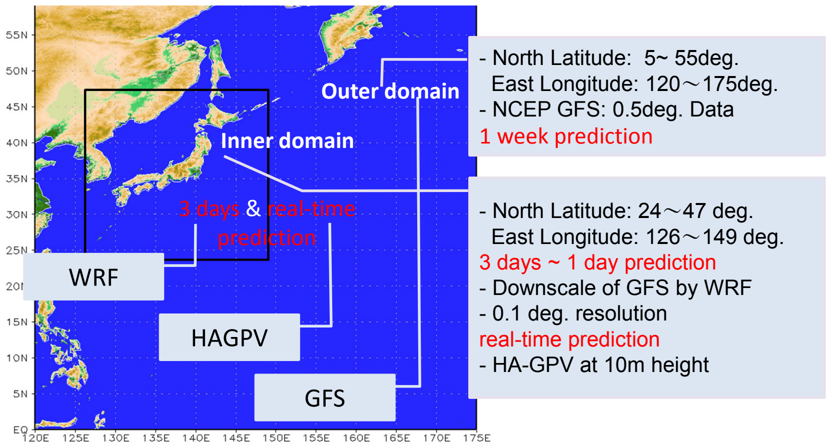

Figure 12. Schematic view of wind prediction system.

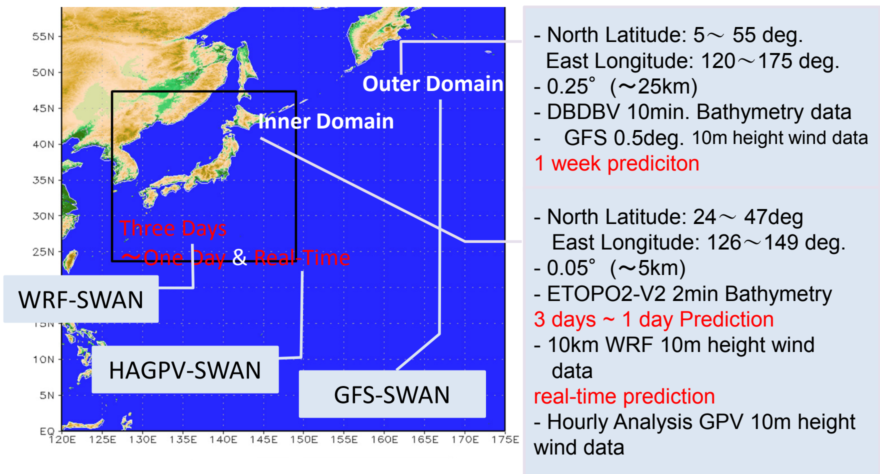

Figure 13. Schematic view of wave prediction system.

COMPARISON BETWEEN PREDICTIONS AND OBSERVATIONS OF WINDS AND WAVES AT THE DEMONSTRATION SITE

Figures 14 and 15 shows the comparison between observations and real-time predictions of significant wave heights and periods from April to July, 2011. It is seen that both values agree well except swell condition.

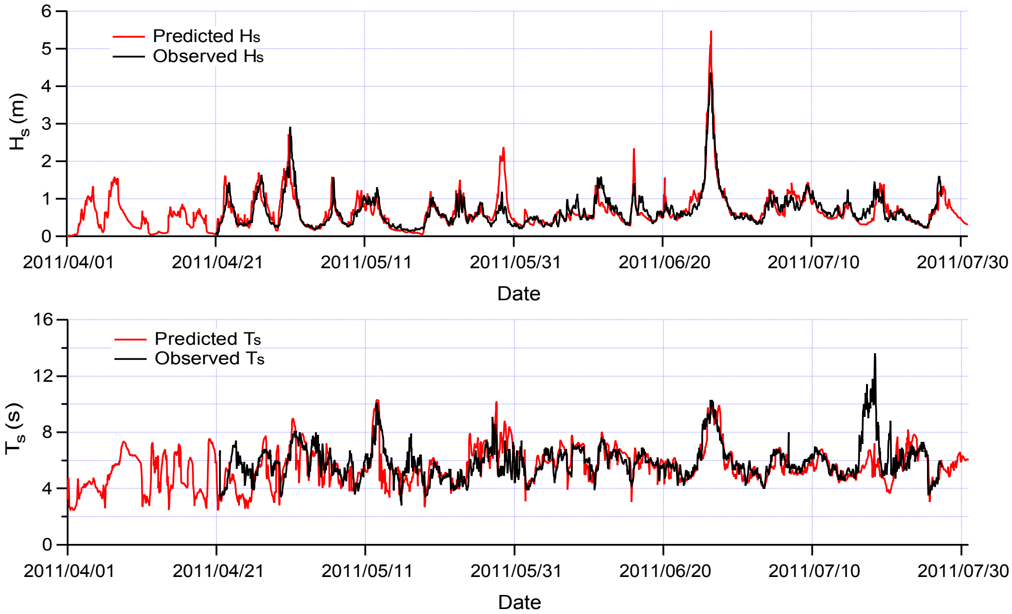

Figure 14. Comparison between observed and predicted wave heights (upper figure) and periods (lower figure) by a real-time prediction system for 4 months.

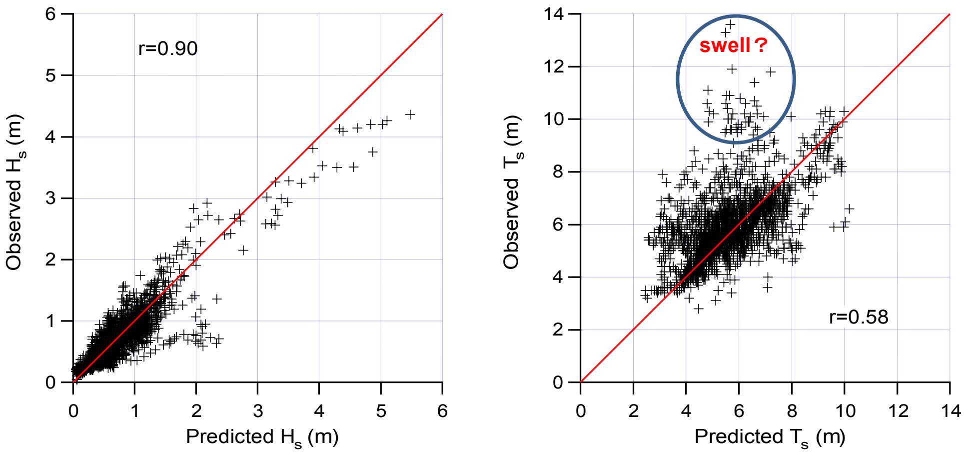

Figure 15. Direct comparison between observed and predicted wave heights and periods.

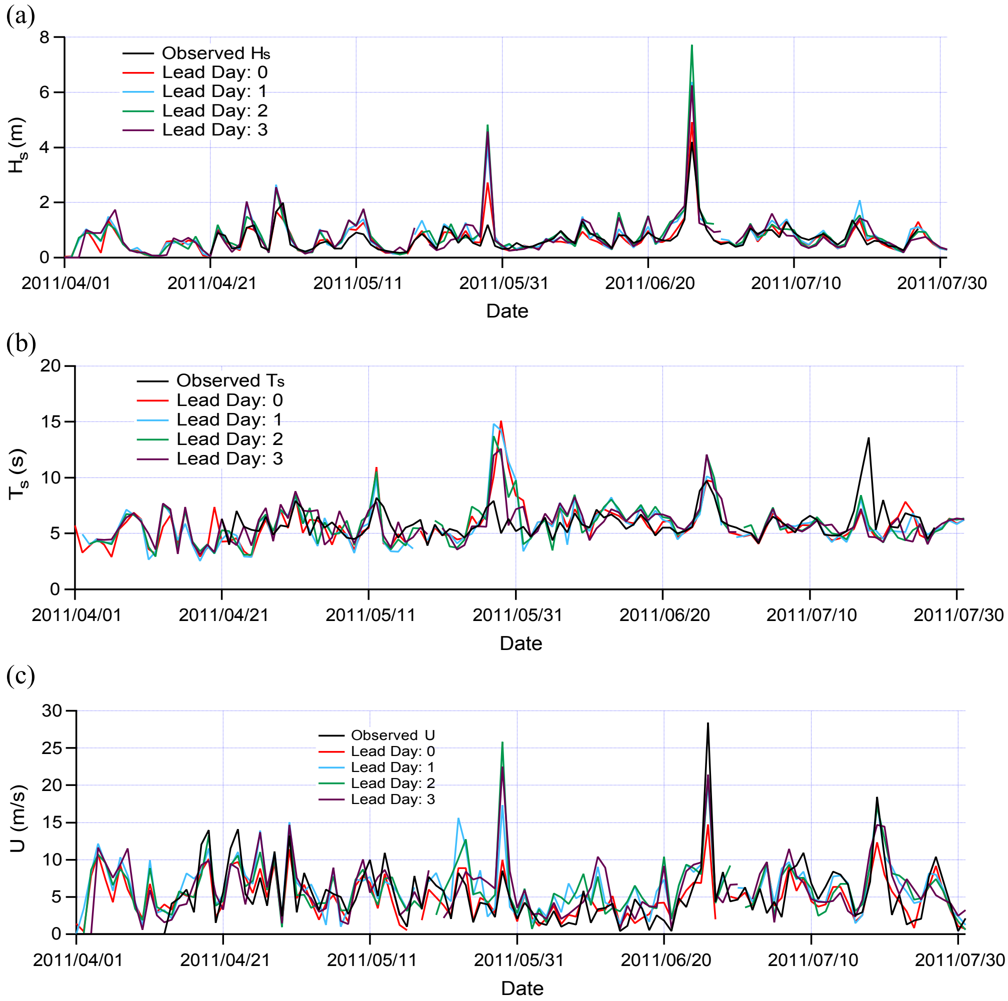

Figure 16. Comparison between observed and predicted wave heights and periods for different lead time: (a) significant wave heights; (b) significant wave periods; (c) wind speeds.

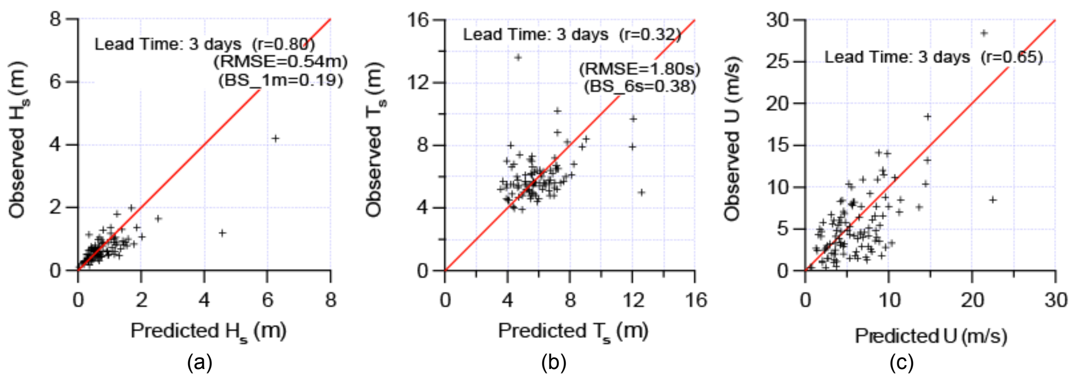

Figure 17. Direct comparison between observed and predicted wave heights and periods for 3 days lead time: (a) significant wave heights; (b) significant wave periods; (c) wind speeds.

Figure 16 shows the results of comparison between observations and predictions at 0:00 of each day for different lead times, and direct comparison is shown in Fig. 17. The correlation coefficient for the wave period is rather small; however, agreements between the wave heights and wind speeds are fairly good.

INFORMATION SYSTEM

Here the system is introduced briefly. Figure 18 shows the initial display of the prediction system including animations of wave height, period and wind, from which we can select a site and lead time by clicking a mouse or input of latitude and longitude. When the site is selected, the time series of wave height, period and wind speed are displayed as shown by Fig. 19.

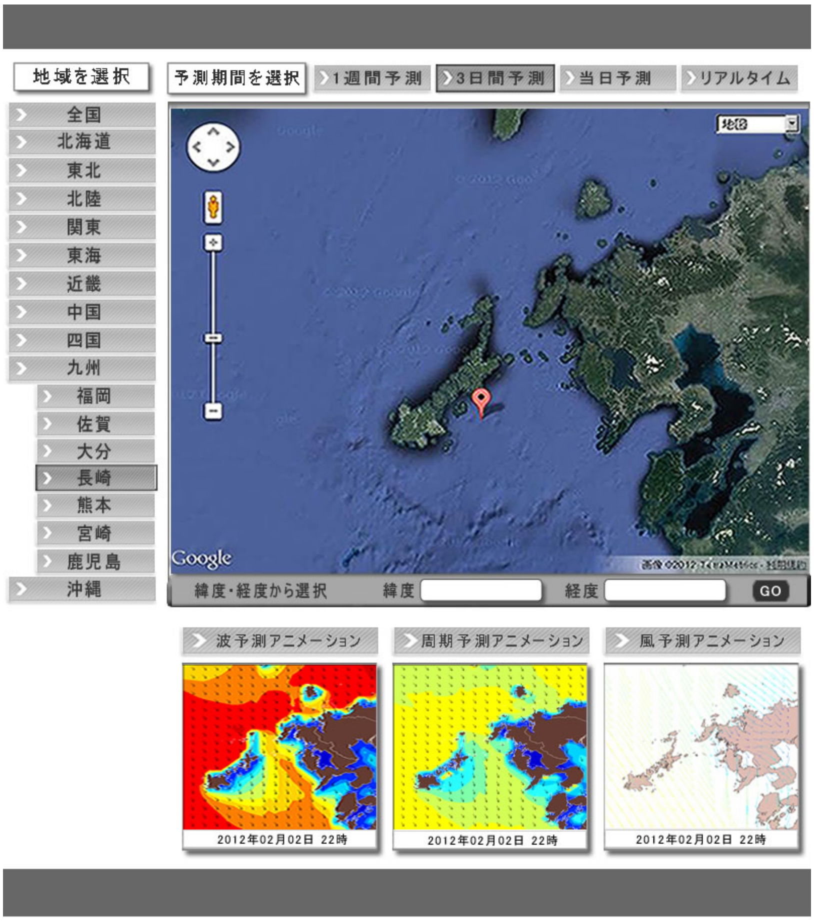

Figure 18. Display of information system.

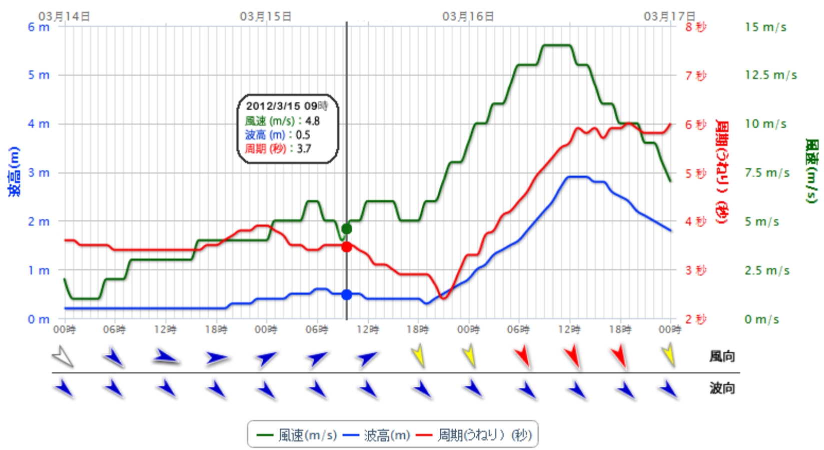

Figure 19. Time series of wave height (blue), period (red) and wind speed (green).

CONCLUSIONS

This paper summarized recent studies of estimating external forces acting on floating body of wind turbine, as one of studies of 'Floating Offshore Wind Turbine Demonstration Project' carried by Ministry of the Environment, Japan.

A 1:2 scale model (100KW) was installed off Kabashima Island in Nagasaki Prefecture in 2012, and a full scale model of 2MW was installed after removing the 1:2 scale model in 2013. As for the design of floating body of the wind turbine, external forces such as winds and waves were evaluated using various re-analysis and prediction data including NCEP wind data, JMA meteorological GPV data and NEDO data since no data available beforehand. The design parameters were wave characteristics of the maximum and mean wave heights, 2D wave height-period and wave height-wind distributions, and wave energy spectrum. Tides and currents were also evaluated. For the construction and daily management, a prediction system was developed, and the predictions and observations of wind and wave were compared and showed good correspondence.

Acknowledgments, Appendices, Footnotes and the Bibliography

A part of this study was supported by the Grant-in-Aid of Ministry of Education, Culture, Sports, Sciebnce and Technology (MEXT), and Floating Offshore Wind Turbine Demonstration Project by Ministry of the Environment, Japan.

REFERENCES

Architectural Institute of Japan. 1993. AIJ Recommendations for Loads on Buildings, Maruzen Co., Ltd.GOTO-FOWT. 2013. The first grid-connected floating offshore wind turbine in Japan, http://goto-fowt.go.jp/english/.

IEC61400. 2006. Wind turbines, communications for monitoring and control of wind power plants – overall description of principles and models, Part 25-1, International Electrotechnical Commission.

Mase, H., N. Mori, T. Yasuda, J. Sakunaka and T. Utsunomiya. 2009. Assessment of coastal design wave utilizing North Pacific wave analysis data, Jour. of JSCE, Ser. B2 (Coastal Eng.), Vol.65, pp.146–150 (in Japanese).

Mase, H., A. Konno, N. Mori, T. Yasuda and S. Dong. 2010. Wave and wind analyses at a site of floating type wind farm, Jour. of JSCE, Ser. B2 (Coastal Eng.), Vol. 66, No.1, pp.386–390 (in Japanese).

Mase, H., N. Mori, S. Nakajo, T. Yasuda, S. Dong and A. Ikemoto. 2011. Evaluation of design wind and wave for floating type wind farm using meteorological re-analysis and prediction data, Jour. of JSCE, Ser. B2 (Coastal Eng.), Vol.67, No.2, pp.I_1226–I_1230 (in Japanese).

Mase, H., T. Yasuda, T.H. Tom, N. Mori and S. Nakajo. 2012a. Observation and prediction of winds and waves at floating type wind farm, Jour. of JSCE, Ser. B2 (Coastal Eng.), Vol.68, No.2, pp.I_1451–I_1455 (in Japanese).

Mase, H., T. Yasuda, A. Ikemoto, T.H. Tom and N. Mori. 2012b. Development of interactive web system providing offshore wind and wave information, Observation and prediction of winds and waves at floating type wind farm, Jour. of JSCE, Ser. B3 (Ocean Eng.), Vol.68, No.2, pp.I_1204–I_1208 (in Japanese).