An Assessment of the External Condition for Offshore Wind Energy Using a Mesoscale Simulation and a Typhoon Simulation

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Introduction

In IEC61400-1, MCP method and Gumbel analysis is proposed to estimate the extreme wind speed. However, the wind climate in Japan is the mixed wind climate and depends not only seasonal wind but also typhoon.

In this study, in order to investigate the effect of seasonal wind and typhoon on the wind climate in Japan, an assessment of the external condition for offshore wind energy was carried out using a mesoscale meteorological model and a typhoon simulation at Choshi Meteorological Station and verified by measurement data.

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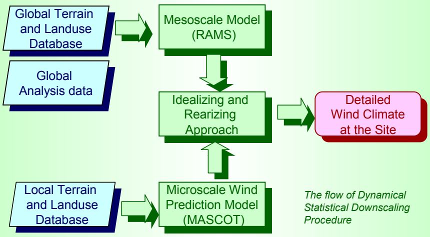
Mesoscale Simulation

In this study, a Dynamical Statistical Downscaling procedure (Yamaguchi et al., 2003) was used in order to estimate the non-typhoon wind climate and verified using the measured wind speed at Choshi Meteorological Station.

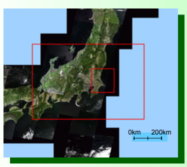


The flow of Dynamical Statistical Downscaling Procedure

Mesoscale Model

As a mesoscale meteorological model, RAMS (Regional Atmospheric Modeling System) was used.

- ECMWF Analysis data was used as the boundary and initial condition.
- Two level nested grids were used, with the horizontal resolution of 8km and 2km.
- The simulation was carried out for one year (2000).

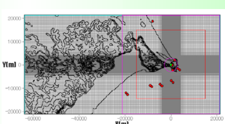


The computational domain of the mesoscale model

Microscale Model

A non-linear model MASCOT (Microclimate Analysis System for COmplex Terrain) was used to estimate the effect of local terrain on wind climate.

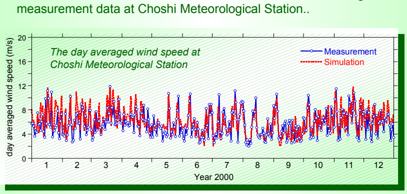
- MASCOT is based on non-linear Navier-Stokes equations and used to calculate the speed-up and the change of the wind direction by local terrain.



The computational domain and the grid of the microscale model

Verification

The mesocale and the microscale simulation was verified using the measurement data at Choshi Meteorological Station..



$$0.85 \le \frac{\overline{U}_y}{\overline{U}_x} = \frac{\sum u_{yi}}{\sum u_{xi}} = 1.066 \le 1.15 \qquad \rho = \frac{\sum u_{xi}u_{yi}}{\sqrt{\sum u_{xi}^2}\sqrt{\sum u_{yi}^2}} = 0.893 \ge 0.8$$

$$0.85 \le \frac{\dfrac{\sqrt{\sum u_{yi}^2}}{\overline{U}_y}}{\dfrac{\sqrt{\sum u_{xi}^2}}{\overline{U}_x}} = 0.976 \le 1.15$$

- NEDO criteria for wind climate assessment is satisfied

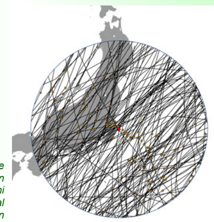
Typhoon Simulation

In order to obtain the wind speed during the typhoon period, typhoon simulation was carried out by using the method proposed by Ishihara et al. (2005).

First, Based on the past typhoon data, the probability distribution of typhoon parameters at the target site are estimated.

Typhoon parameter	Model function	Model parameter
Central pressure depth	Mixed distribution $F_M(x) = a \times \frac{1}{\sqrt{2\pi}\sigma_{\ln x}} \exp\left[-\frac{1}{2}\left(\frac{\ln x - \mu_{\ln x}}{\sigma_{\ln x}}\right)^2\right] + (1-a) \times \frac{k}{C}\left(\frac{x}{C}\right)^{k-1} \exp\left[-\left(\frac{x}{C}\right)^k\right]$	μ=1.58, σ=0.114, k=4.22, c=43.7, a=1.00
Radius of maximum wind speed		μ=2.10, σ=0.246, k=1.91, c=163, a=0.502
Translation Speed		μ=1.58, σ=0.114, k=4.22, c=43.7, a=1.00
Translation Direction	Normal distribution $F_S(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]$	μ=144 s=26.0
Minimum distance	Quadratic function $d_{min} = z(x^2 - x) + 1000x - 500$	-500<d_{min}<500 0<x<1.0 z=390
Number of typhoon per year	Poisson's distribution $\frac{\lambda^x \exp(-\lambda)}{x!}$	λ=2.77

Then, typhoons are generated for 10,000 based on the estimated typhoon parameters.



The path of the generated typhoon around Choshi Meteorological Station

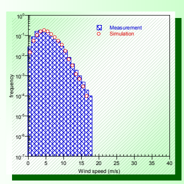
Finally, surface wind speed was estimated by using the result of microscale model considering the local terrain.

Frequency distribution of wind speed

The contribution of seasonal wind and typhoon on the frequency distribution of wind speed is investigated by comparing the simulated and measured wind speed data.

Seasonal wind

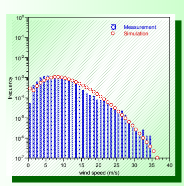
From the meteorological simulation, the frequency distribution of wind speed for non-typhoon season was estimated.



The frequency distribution of wind speed by seasonal wind at Choshi Meteorological Station

Typhoon

From the typhoon simulation, the frequency distribution of wind speed for typhoon season was estimated.



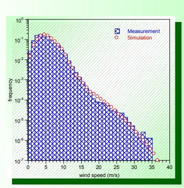
The frequency distribution of wind speed by typhoon at Choshi Meteorological Station

The combination

The total frequency distribution was calculated.

$$f_{total} = af_{typhoon} + (1-a)f_{non\text{-}typhoon}$$

a is the ratio of the typhoon and is 0.0127 in this case.



The combined frequency distribution of wind speed at Choshi Meteorological Station

50 year return period extreme wind speed

In order to obtain the extreme wind speed of 50 year return period, the extreme wind speed by seasonal wind and typhoon are estimated separately and combined.

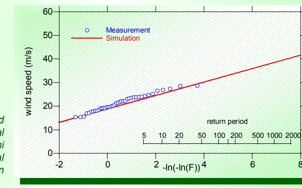
Seasonal wind

The extreme wind speed of 50 year return period by seasonal wind was calculated by the method proposed by Gomes and Vickery (1977), in which the extreme wind speed can be expressed as a function of the Weibull parameters of the frequency distribution.

$$U_s = U_1 + (1/a)\ln R$$

$$U_1 = c(\ln N)^{1/k}\left[1 + \left(\frac{k-1}{k^2}\right)\frac{\ln(\ln N)}{\ln N}\right] \qquad 1/a = \frac{c}{k}(\ln N)^{1/k-1}\left[1 + \frac{k-1}{k\ln N} - \left(\frac{k-1}{k}\right)^2\frac{\ln(\ln N)}{\ln N}\right]$$

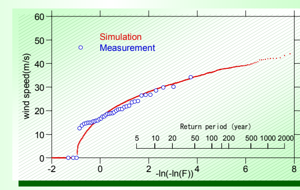
$$N = 2\pi v_u \beta_u (k\sigma_u / c)$$



The extreme wind speed by seasonal wind at Choshi Meteorological Station

Typhoon

The extreme wind speed of 50 year return period by typhoon was estimated by the results of 10,000 years typhoon simulation.

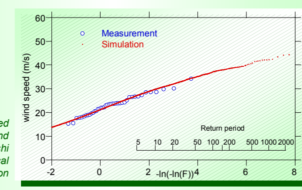


The extreme wind speed by typhoon at Choshi Meteorological Station

The combination

The total extreme wind speed of 50 year return period was calculated so that the following equation is satisfied.

$$F_{total}(U) = 1 - \left[1 - F_{typhoon}(U)\right]\left[1 - F_{non\text{-}typhoon}(U)\right]$$



The combined extreme wind speed at Choshi Meteorological Station

Conclusion

The external conditions for offshore wind energy in Japan was investigated by using mesoscal simulation and the typhoon simulation. Following results were obtained.

- The frequency distribution of wind speed is dominated by both seasonal wind and typhoon which means that for the fatigue design of wind turbine in Japan, typhoon has to be considered.
- The extreme wind speed is dominated by typhoon for 50 years return period and typhoon simulation has to be carried out to obtain the design extreme wind speed.

References

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