The design wind seed and air density in mixed climate region

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Introduction

In IEC61400-1[1], the extreme wind speed with the recurrence period of 1 year (V_1) is specified as 0.8 times of the wind speed with the recurrence period of 50 years (V_{ref}). However, in the mixed climate region, V_{ref} is usually caused by tropical cyclones, while V_1 is usually caused by the extratropical cyclone and the difference between the V_{ref} and V_1 can be larger, resulting the overestimation of V_1. During tropical cyclones, the air temperature is usually higher, and the air pressure is lower than standard value, which implies the air density during tropical cyclones is lower than the standard value specified in IEC61400-1. This study focuses on an offshore site in Japan where tropical cyclones are the major causes of the extreme wind speed and the relationship between V_1 and V_{ref} is investigated. A method for estimating air density during tropical cyclones is proposed and validated using measurement data at an offshore wind demonstration site in Choshi, Japan.

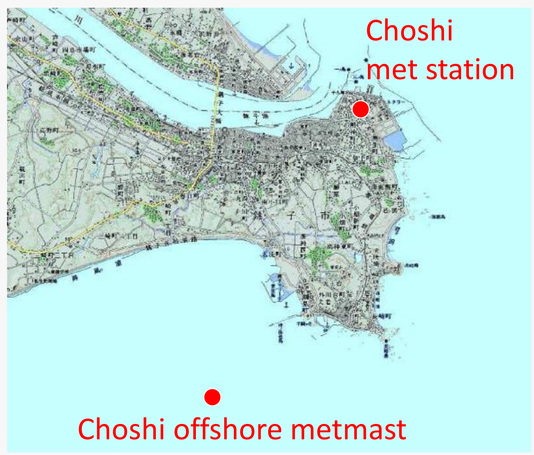
Measurement data

Measurement data at an offshore metmast and nearby met station located in Choshi, Japan are used in this study.

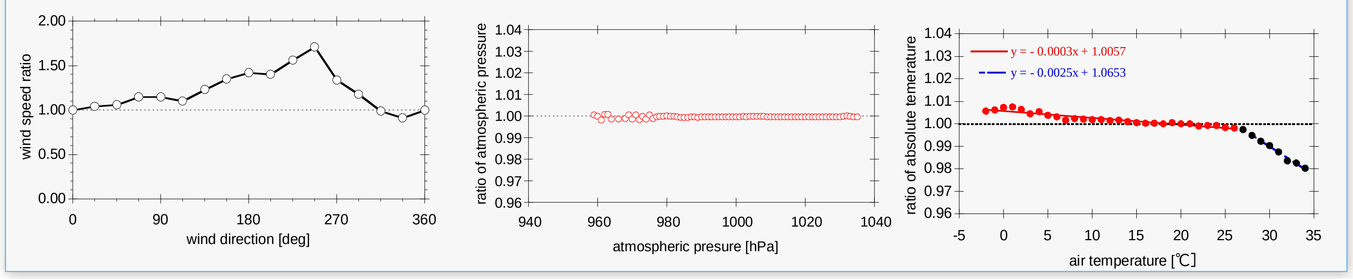
Bin averaged value of the ratio of wind speed, atmospheric pressure and absolute temperature are plotted as functions of wind direction, atmospheric pressure and temperature at the met station.

These ratio are used to extrapolate the long-term measurement data at the met station to the offshore site.

Offshore metmast and met station



Bin averaged value of the ratio of wind speed, atmospheric pressure and absolute temperature



The design wind speed V_1 and V_{ref}

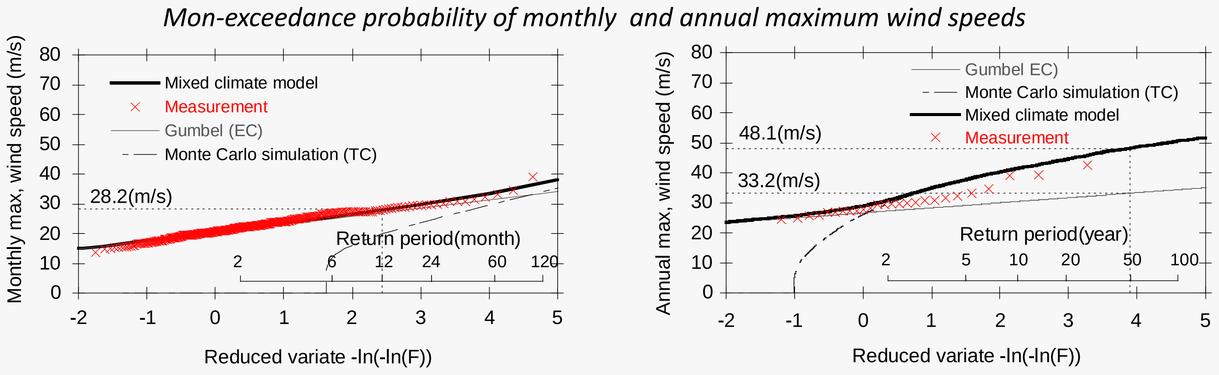
The non-exceedance probability of monthly maximum wind speed and annual maximum wind speed at the offshore site are estimated to predict V_1 and V_{ref}.

For extratropical cyclones (EC), Gumbel fitting with Measure-Predict-Correlate (MCP) method is used based on the long-term measurement data at the met station and the wind speed ratio between the two sites.

For tropical cyclones (TC), Monte Carlo simulation [2] at the offshore site is used.

Mixed climate non-exceedance probability was calculated by multiplying the non-exceedance probability of TC and EC.

Mon-exceedance probability of monthly and annual maximum wind speeds



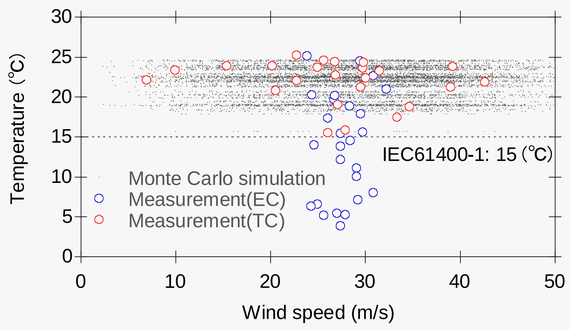
- The proposed model for mixed climate shows good agreement with measurement for both monthly maximum and annual maximum.
- V_1 is estimated to be 28.2m/s from monthly maximum and V_{ref} is estimated to be 48.1m/s from annual maximum.
- V_1 is much smaller than 0.8 V_{ref}, which is specified in IEC61400-1 and is estimated as 48.1m/s x 0.8 = 38.5m/s.
- V_1 is caused by extratropical cyclone, and thus closer to the 80% of the extreme wind speed with the recurrence period of 50 years caused by extratropical cyclone, which is estimated as 33.2m/s x 0.8 = 26.6m/s.

The air density during tropical cyclones

Monte Carlo simulation of tropical cyclones including the model of air temperature and atmospheric pressure are performed to investigate the characteristic of air density during tropical cyclones.

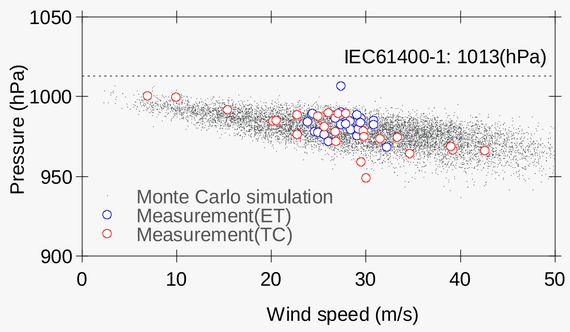
- Temperature is based on monthly averaged value.
- Atmospheric pressure is directly from pressure field model included in the Monte Carlo simulation of tropical cyclones.
- The effect of humidity is not considered.
- The air density is calculated for each synthetically generated tropical cyclones.

Air temperature as function of wind speed



- The simulated air temperatures show similar tendency as measurement during tropical cyclones.
- The air temperatures during tropical cyclones are usually higher than the standard value assumed in IEC61400-1 and those during extratropical cyclones.

Air pressure as function of wind speed



- The simulated air pressures show similar tendency as measurement during tropical cyclones.
- The air pressure decrease as wind speed increase. During tropical cyclones, air pressure is usually lower than the standard value assumed in IEC61400-1.

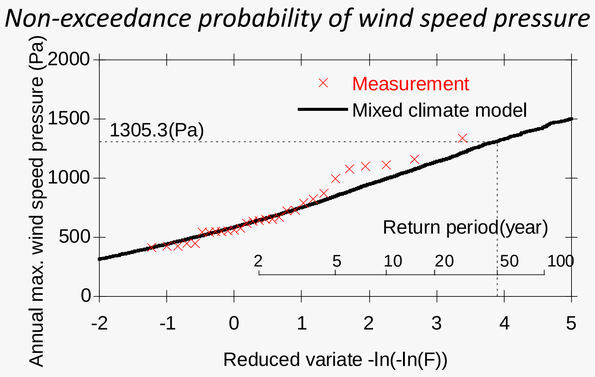
The non-exceedance probability of wind speed pressure is estimated for calculating the annual maximum air pressure with the recurrence period of 50 years (q_{50}).

- The air pressure, q_{50}, is estimated to be 1305.3Pa.
- The air density, ρ_{50}, corresponds to V_{ref} is inversely calculated as

$$\rho_{50} = \frac{2q_{50}}{V_{\mathrm{ref}}^2} = 1.143\mathrm{kg/m^3}$$

which is 6.7% lower than the standard value in IEC61400-1.

Non-exceedance probability of wind speed pressure



Conclusions

In this study, Monte Carlo simulation of tropical cyclone and wind speed extrapolation from nearby met station are carried out to investigate the characteristic of extreme wind speed and corresponding air density. Following conclusion are obtained.

1. The value of V_1 at Choshi offshore metmast is 28.2m/s and caused by extratropical cyclones, while V_{ref} is 48.1m/s and caused by tropical cyclones. The value of V_1 is much smaller than $0.8V_{\mathrm{ref}}$ because the causes of two values are different. The value of V_1 can be estimated as 0.8 times of the extreme wind speed with the recurrence period of 50 years only considering the extratropical cyclones as the cause.
2. The wind speed pressure with the recurrence period 50 years is calculated and the air density for the extreme wind speed is inversely calculated. The calculated air density at Choshi offshore metmast is 1,143kg/m^3, which is smaller than the standard value of 1.225kg/m3 specified in IEC61400-1.

References

1) IEC 61400-1, 2019. Wind Turbines – Part 1: Design Requirements.

2) T. Ishihara, A. Yamaguchi, Prediction of the extreme wind speed in the mixed climate region by using Monte Carlo simulation and Measure-Correlate-Predict method. *Wind Energy*, 18(1), 171-186, 2015.

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