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A Numerical Study of Wind Wave and Swell by Using Wave Prediction Models and Combined Wind Fields

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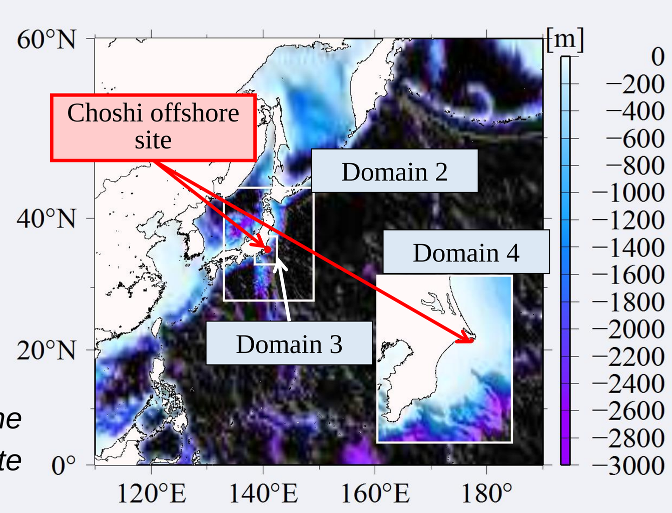
Introduction

Wave predictions are necessary for the design of offshore wind turbine. The waters around Japan, large swells are caused by waves propagated over Pacific ocean. Furthermore, not only large swells but also wind waves are induced by tropical cyclones.

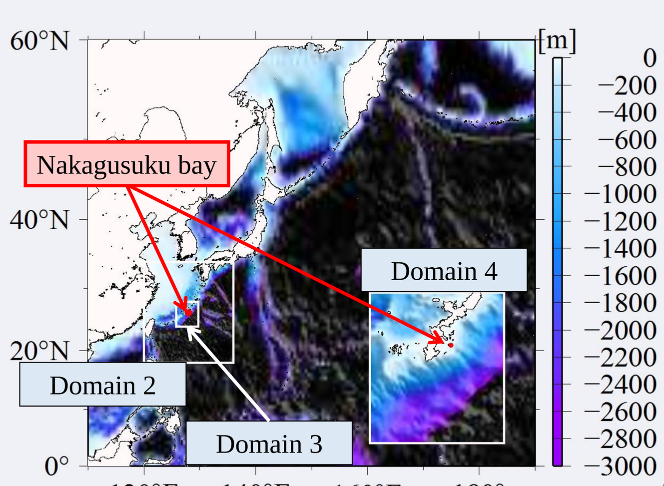
In the conventional studies, different wave models and wind fields for wave simulations have been proposed[1][2][3]. In this study, at first, the conventional wave models, SWAN and WAVEWATCH III (WW3), are validated. Then, tropical cyclone induced waves are predicted by using wind field obtained from mesoscale model, typhoon model and combined wind field. Prediction methods for both wind wave and swell are discussed through those numerical studies.

Wave simulation

SWAN and WW3 are validated at Choshi offshore wind energy test site, which can be obtained observations of wave spectra.



Domains for the Chosih offshore site



Domains for the Nakagusuku bay

Validations of wind fields are conducted by using observed waves at NOWPHAS Nakagusuku bay, which are frequently attacked by strong tropical cyclones.

Configuration of the wave models

	Domain1	Domain2	Domain3	Domain4
Spin-up	More than 10 days from the time peak wave height observed			
Horizontal resolutions	0.5° × 0.5°	0.2°×0.2°	0.05°	0.02°
Bathymetry	ETOPO2		ETOPO1	
Sea surface boundary	Mesoscale model			
	NNRP (2.5°)	WRF (18km)	WRF (6km)	WRF (2km)
	Typhoon model or Combined wind field			
Lateral boundary	Open	Nest down (2-way nesting)		
Spectrum resolutions	36 directions and 36 frequencies (0.0345~0.97Hz)			
Source terms	S_{lin}: Cavaleri and Malanotte-Rizzoli (1981) S_{nl}: Hasselmann et al. (1985) S_{bot}: Hasselmann et al. (1973) S_{db}: Bettjes and Janssen (1987) $S_{in}+S_{ds}$ for SWAN: Komen et al. (1984) $S_{in}+S_{ds}$ for WW3: Tolman and Chalikov (1996)			

Wave height H_S and period T_S are predicted as follows:

$$H_S = 4\sqrt{m_0} \qquad T_S = m_{-1}/m_0 \qquad m_n = \iint f^n E(f,\theta)\,df\,d\theta$$

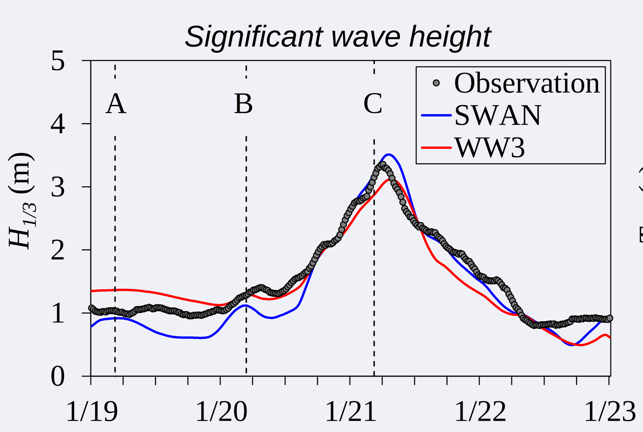
where $E(f, \theta)$ is energy spectrum for frequency f and direction θ. Significant wave height $H_{1/3}$ and period $T_{1/3}$ are observed at both sites and following formula are used in this study for the comparison:

$$H_{1/3} \approx 0.956 H_S \qquad T_{1/3} \approx T_S$$

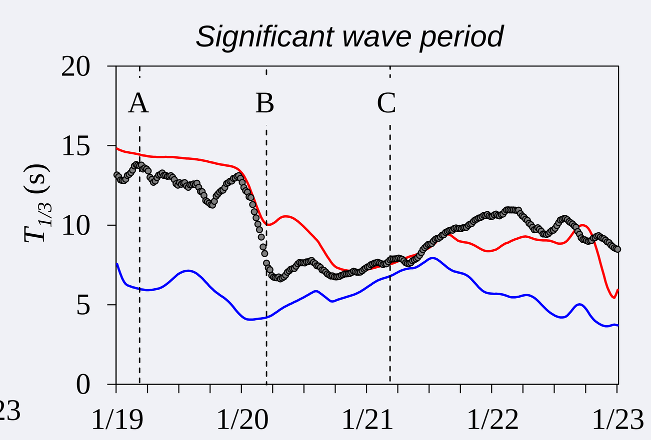
Validation of the wave models

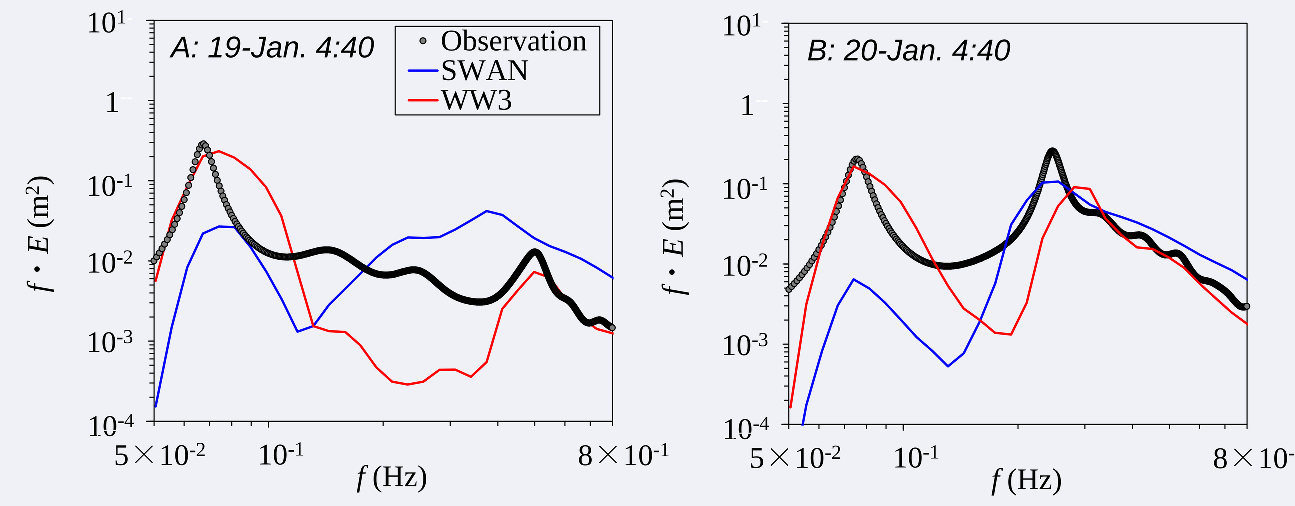
Predicted wave heights by SWAN show good agreement with observations. However, wave periods are underestimated. On the other hand, both wave height and period can be predicted accurately by using WW3.

Significant wave height

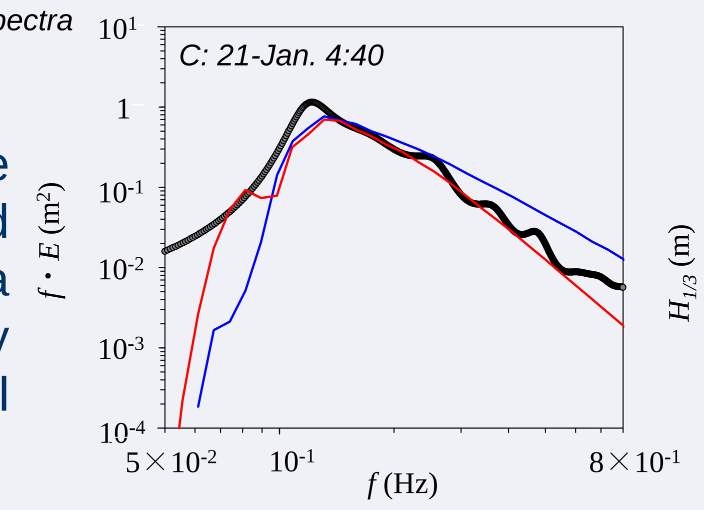


Significant wave period





Observed and predicted wave spectra



At the time of A (in the timeseries fig.), observed wave spectrum has a peak at the low frequency region, so called swell state.

Two peaks wave spectrum is obtained at the time B, and decreasing $T_{1/3}$ with increase of wind wave. Finally, at the time of C, wind wave is well developed and high wave height is observed.

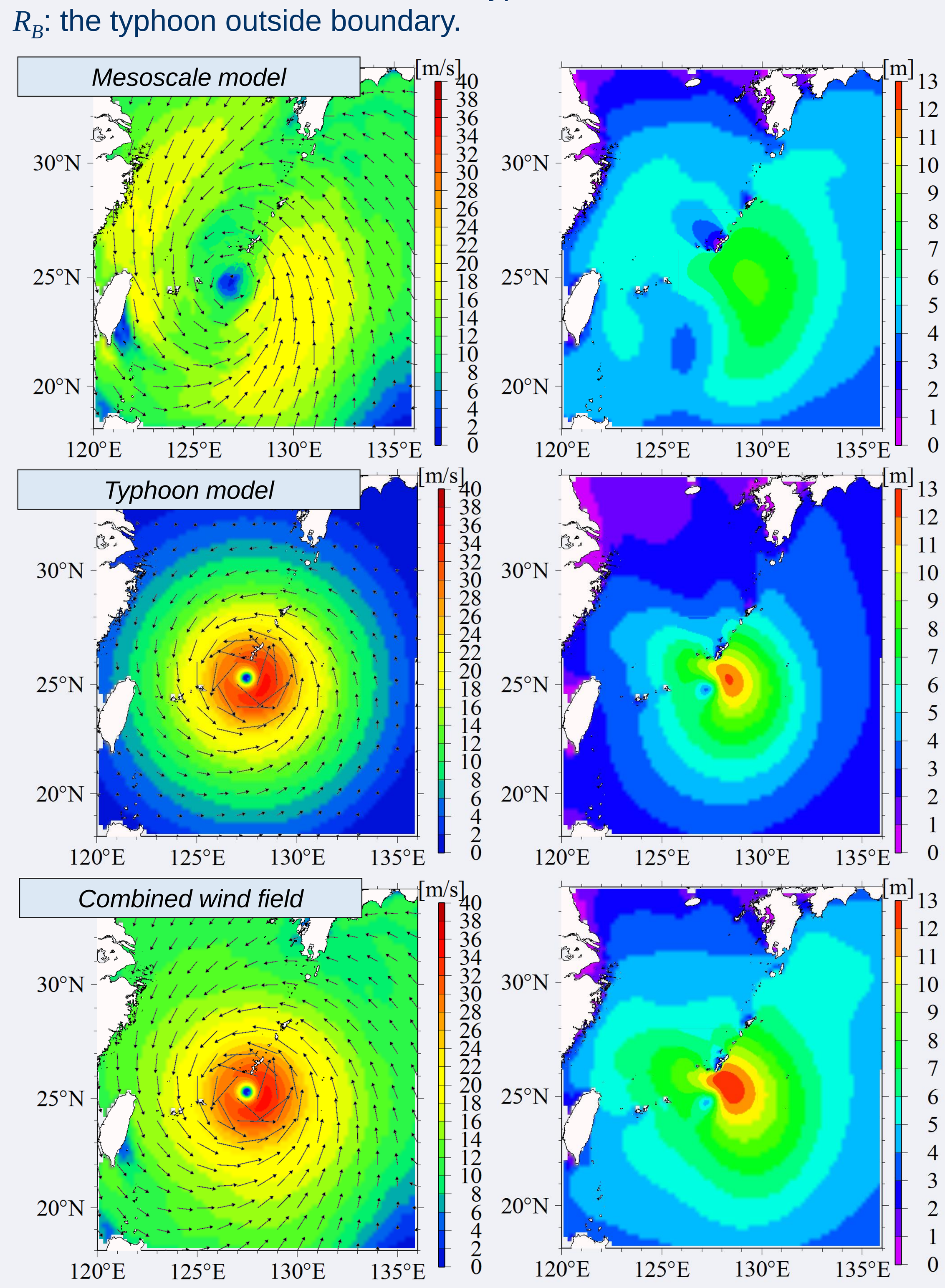
It is fount that tredicted wave spectra by using SWAN significantly underestimate observations at low frequency (f < 0.1Hz) range. Hereafter, WW3 is used for wave simulations.

Predicted wind and wave fields

In the combined wind field model, predicted wind speeds by mesoscale model U_M and typhoon model U_T are combined by using following equations:

$$U_C = WU_T + (1-W)U_M \qquad W = \left(\frac{R_B^2 - r^2}{R_B^2 + r^2}\right)^{0.5}$$

r: the distance from the center of a typhoon
R_B: the typhoon outside boundary.

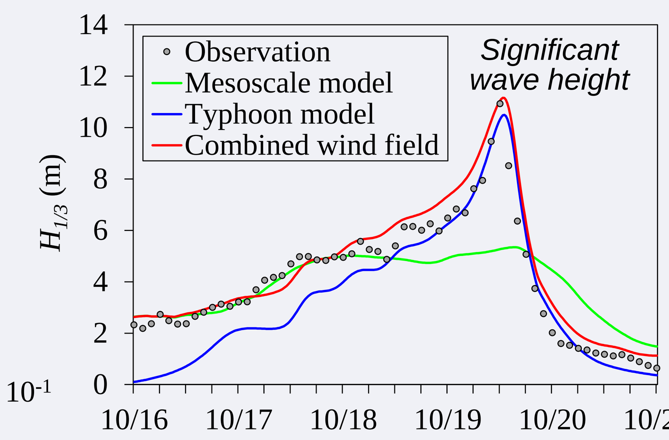


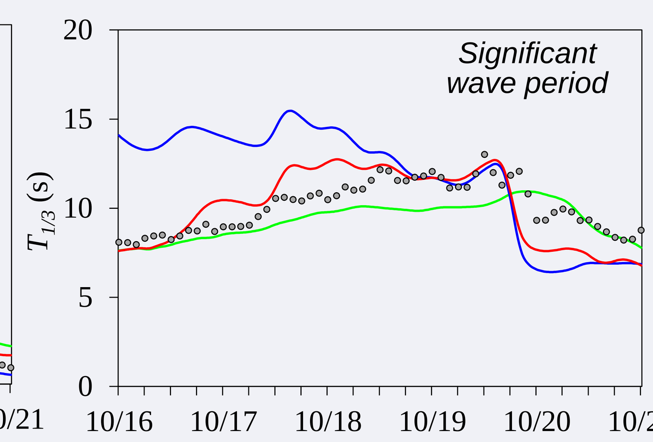
Predicted wave heights by using wind field obtained from mesoscale model are lower than those by typhoon model at the center of the typhoon. On the other hand, predicted wave heights using typhoon model become lower as the distance from the center of the typhoon is farther. Predicted wave heights by using combined wind field show close values of those by typhoon model near the center and those by mesoscale model for the region outside. It is noticed that the wave heights predicted by using combined wind field is a little higher than those by typhoon model, since the wave energy from wind in the center and outside of the typhoon is accumulated.

Validation of predicted waves by 3 wind fields

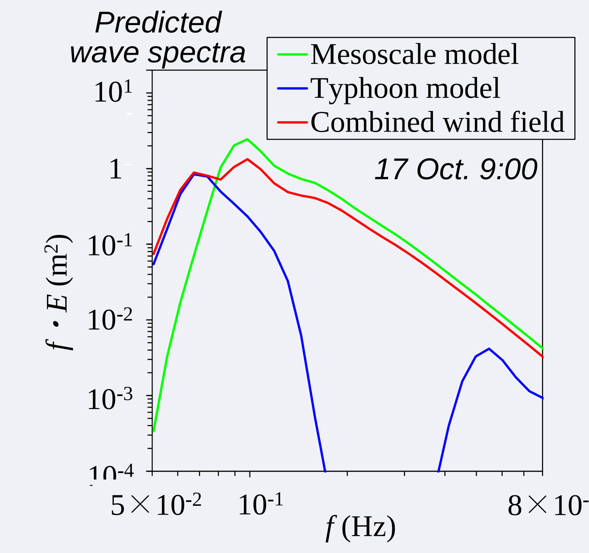
Predicted wave heights by using wind field obtained from mesoscale model underestimate observed wave height. These underestimations are improved by using typhoon model and combined wind field.

Predicted wave periods by mesoscale model are also underestimated. In contrast, those by typhoon model are overestimated before the typhoon attacked the site.





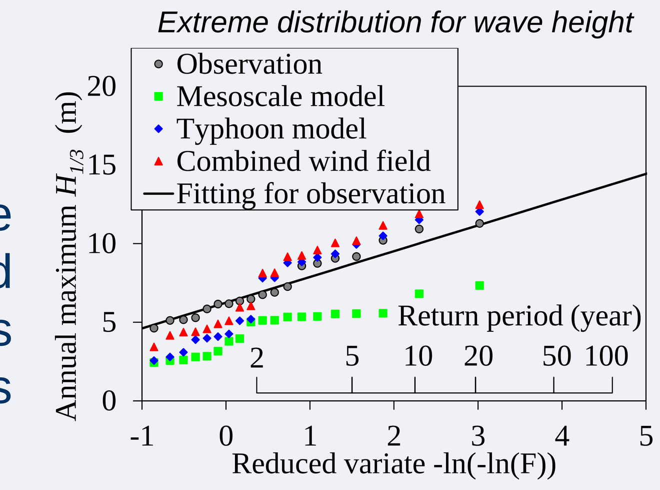
The reason is underestimations of wind waves before the typhoon attacked. As a result, waves are generated by the only the swell by the typhoon far from the site. These overestimations are also improved by using combined wind field.



Extreme wave height and period

Predicted maximum wave height and associated wave peiod in the 20 years by mesoscale model is underestimated.

Extreme distribution for wave height



These underestimation is improved by using typhoon model and combined wind field.

	Obs.	Mesoscale model	Typhoon model	Combined wind field
$H_{1/3,20}$	11.2m	7.3m (-34.8%)	12.0m (+7.1%)	12.4m (+10.7%)
$T_{1/3,20}$	14.7s	10.9s (-25.9%)	13.6s (-7.5%)	13.9s (-5.0%)

Conclusions

Numerical study for the prediction of wind wave and swell are conducted and following results are obtained.

1. Although predicted wave heights by SWAN show good agreement with observations, predicted wave periods are underestimated significantly due to underestimations of wave spectra in the low frequency range. WW3 predicts wave heights, periods and spectra correctly.
2. Predicted extreme wave height and period by using the wind field obtained from the mesoscale model underestimate tropical cyclone induced extreme wave height and period and these underestimations are improved by using the wind fields obtained from the typhoon model and the combined wind field.

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