IMPACT OF DATA ASSIMILATION FOR TYPHOON-GENERATED EXTREME WAVE BASED ON DRIFTING WAVE BUOY OBSERVATION

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INTRODUCTION

Typhoon-generated extreme waves are a major factor to be considered for coastal disaster risk management in the mid-latitude of the North Western Pacific and the North Atlantic. Therefore, improving the accuracy of the spectral wave model for extreme waves around typhoons is important. Also, compact and inexpensive drifting buoys have been developing in recent years, and their number has increased globally.

In this study, we developed a data assimilation system using drifting buoys for typhoon-generated extreme waves. First, we investigate the assimilation method of the significant wave heights into the wave spectral model. Second, the assimilation model of frequency spectra is developed. We show the effectiveness of the data assimilation of drifting buoy observations for the open ocean on extreme waves along the Japanese coast.

DATA AND METHOD

We used the spectral wave model WAVEWATCH III and performed wave simulation nesting from the North Pacific to the Western North Pacific domain. JRA-55 reanalysis wind speed and the JMA analysis wind speed were used as wind forcing for the North Pacific and Western North Pacific domains, respectively. The target is typhoon waves in the summer of 2022.

We obtained the observation data for data assimilation from the drifting buoy “Spotter” developed by Sofer Ocean. We used the data measured by 19 buoys deployed ourselves and 25 buoys deployed by Sofer Ocean in Western North Pacific. The drifting paths of buoys from 1st Aug to 30th Sep in 2022 are shown in Figure 1. We used Japanese nearshore observation network data (NOWPHAS) for model validation (green circles in Figure 1).

The optimal interpolation was used as a data assimilation method. The optimal interpolation method calculates the difference between the observed data and the simulated values, weights the difference, and interpolates it into the simulation grid. The difference ε is calculated by the following equation.

$$\varepsilon = y^{\mathrm{obs}} - Hy^{\mathrm{mod}} \tag{1}$$

H is the interpolation matrix that estimates model values at observed locations through bi-linear interpolation. y^{obs} is the observation value and y^{mod} is the value of the model simulation. Using this ε, the following equation gives the analysis values on the grid points of the model.

$$y^{\mathrm{an}} = y^{\mathrm{mod}} + K\varepsilon \tag{2}$$

Here K is the Kalman Gain matrix. It is set to minimize the variance of the analysis error and can be expressed as

$$K = \rho H^{\mathrm{T}}\left[H\rho H^{\mathrm{T}} + \left(\frac{\sigma^{\mathrm{obs}}}{\sigma^{\mathrm{mod}}}\right)I\right]^{-1} \tag{3}$$

ρ is the spatial cross-correlation function, σ^{obs} is the observation error standard deviation and σ^{mod} is the model error standard deviation (Smit et al., 2021). We used this method for both the assimilation of the significant wave heights data and the assimilation of frequency spectra.

INITIALIZED EXPERIMENT

The objective of this experiment is to verify the performance of the data assimilation. We calculated 61 cases in total, starting at 12:00 AM each day from August to September 2022. We assimilated the data only when calculating the initial conditions, and after that, we performed wave model simulation without data assimilation for three days. Figure 2 shows a comparison

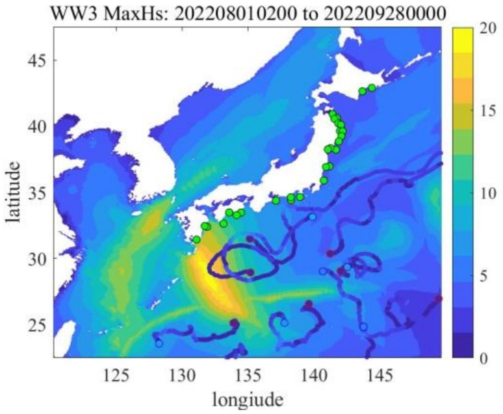


Figure 1 - Path of buoys and location of NOWPHAS for the target period (line: drifting buoy, background WW3).

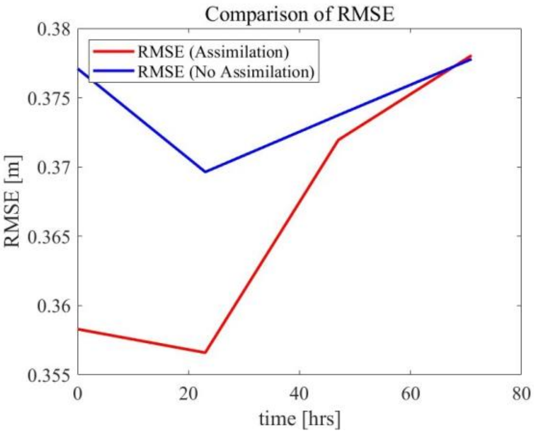


Figure 2 - Temporal changes of RMSE between assimilation and no data assimilation simulation from initial time (blue: no data assimilation, red: assimilation).

of RMSEs simulated using initial values with data assimilation and without data assimilation. The blue and red lines show the RMSE of the simulation without data assimilation and with data assimilation, respectively. It can be seen that immediately after data assimilation the RMSE is smaller. However, three days after the assimilation, the RMSE does not differ from that of the simulation without data assimilation. This is because waves modified by data assimilation propagate outside the simulation domain and along the coast, and their effect disappears. In addition, the mean period is not improved.

SEQUENTIAL ASSIMILATION EXPERIMENT

In this experiment, we assimilated the data into the wave model at fixed intervals targeting Typhoon NANMADOL, whose minimum pressure is 910 hPa. The assimilation intervals were set as 1 hour and 3 hours. Figure 3 shows the maximum significant wave height improvement of the wave model for the target period. The red dots mean the results in the case of a 1-hour interval, and the blue dots mean the results in the case of a 3-hour interval. The wave model was improved for all the target periods in both cases. In particular, the error was reduced by more than 1 m on the 17th and 18th, when several drifting buoys observed more than 8 m wave heights. Even with a 3-hour interval, the error was reduced by a maximum of 2.36 m. Figure 4 shows the spatial distribution of significant wave heights and the error at each station at 12:00 PM on 17th Sep 2022, when Typhoon NANMADOL arrived in Japan. Figures 4 (a) and (b) show the simulation results without and with data assimilation, respectively. The simulation without assimilation indicates large errors at some points where high waves were arriving, such as along the coast of the western part of Japan. On the other hand, with assimilation, the errors were significantly reduced. These results indicate that sequential data assimilation improves the accuracy of the simulation of typhoon-generated extreme waves.

CONCLUSIONS

We developed a wave reanalysis system by assimilating drifting buoy observation and demonstrated the effectiveness of data assimilation for simulating typhoon-generated extreme waves. We found the improvement contributed by the data assimilation disappears in about three days. This can be caused by the propagation of modified waves outside the computational domain or along the coast. Sequential assimilation reduced the error in significant wave height at the arrival of the typhoon by up to 2.36 m, even when the assimilation interval was set as 3 hours. This means that further improvement of the wave model can be expected with an increase in the number of drifting buoys. In addition, we suggested that the assimilation of the frequency spectra can improve wave statistics that cannot be improved by the assimilation of just significant wave height, especially for swell propagation.

REFERENCES

P. B. Smit, et al. (2021): Assimilation of significant wave height from distributed ocean wave sensors, Ocean Modelling, 159, 101738

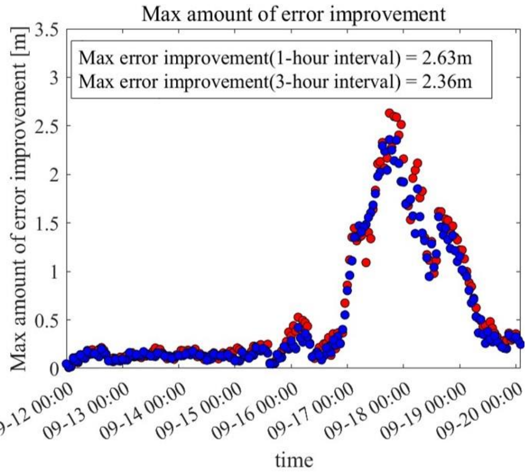
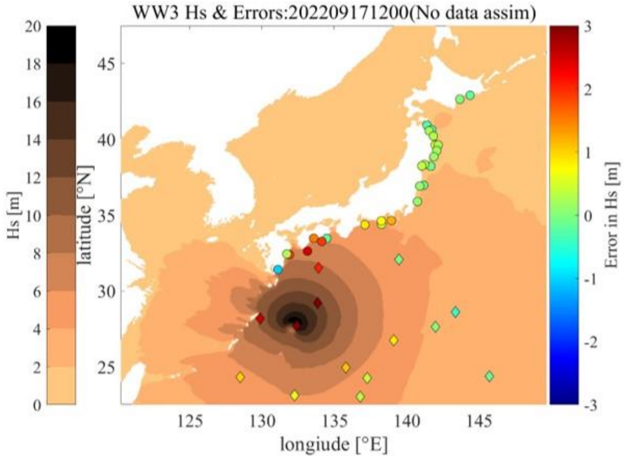
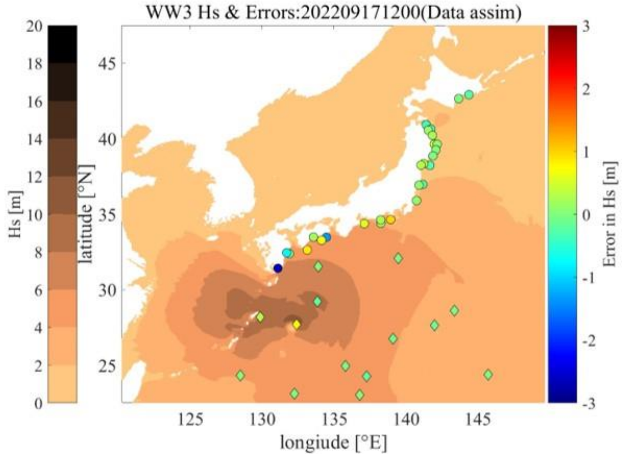


Figure 3 – Time history of maximum improvement of significant wave height by sequential assimilation experiments (blue: 1-hour interval, red: 3-hour interval).



(a) No data assimilation results



(b) Data assimilation results

Figure 4 – Snapshot of significant wave heights without and with data assimilation for typhoon Nanmadol (12:00 PM UTC 9/17/2022). (diamond: drifted buoy used for assimilation, circle: coastal buoy data for validation)