

# IMPACT OF OCEAN COOLING AND WAVE EFFECTS ON TYPHOON MODELING FOR 2018 TYPHOON JEBI

Koki Iida, Kyoto University, Japan, [iida.koki.43s@st.kyoto-u.ac.jp](mailto:iida.koki.43s@st.kyoto-u.ac.jp)

Nobuhito Mori, Kyoto University, Japan, [mori@oceanwave.jp](mailto:mori@oceanwave.jp)

Tomoya Shimura, Kyoto University, Japan, [shimura.tomoya.2v@kyoto-u.ac.jp](mailto:shimura.tomoya.2v@kyoto-u.ac.jp)

Takuya Miyashita, Kyoto University, Japan, [miyashita.takuya.4w@kyoto-u.ac.jp](mailto:miyashita.takuya.4w@kyoto-u.ac.jp)

## INTRODUCTION

In recent years, tropical cyclones in the northwestern Pacific have been predicted to intensify due to the warming ocean caused by global warming [1]. Especially in Japan, typhoons have caused severe wind and flood damage. Highly accurate typhoon modeling is required to evaluate future coastal hazards such as storm surges and waves. However, typhoon modeling is often based on only meteorological models and does not consider typhoon-induced ocean response and wave effects that control the boundary conditions between a typhoon and an ocean. Furthermore, the ocean characteristics are closely linked to typhoon ones. However, its representation has been incomplete. These factors lead to uncertainties in typhoon modeling, which also affects the assessment of coastal disasters such as storm surges. In this study, we simulated Jebi in 2018 using the coupled atmosphere-ocean-wave transport (COAWST) modeling System [2] to investigate the impact of ocean response and wave effects on a typhoon.

## METHODOLOGY AND DATA

The COAWST modeling system can compute and investigate the coupled process of the typhoon, ocean, and wave, namely air-wave-sea interaction. COAWST version 3.7 consists of the atmospheric model (the Weather Research and Forecasting; WRF v.4.2.2), the ocean model (the Regional Ocean Modeling System; ROMS v.3.9), and the wave model (the WAVEWATCH III; WW3 v.7.12). The Model Coupling Toolkit (MCT v.2.6.0) is used as the coupler.

Initial and lateral boundary conditions for WRF were obtained from NCEP GDAS Final Analysis (0.25 degree), and those for ROMS were obtained from HYCOM + NCODA Global 1/12° Analysis.

The sea surface boundaries for ROMS and WW3 are given by WRF. The horizontal resolution is about 9 km for each model. The simulation period was 60 hours from 00 UTC on 2 Sep to 12 UTC on 4 Sep, and coupled and uncoupled experiments were performed for WRF only, WRF-ROMS, and WRF-ROMS-WW3. The time interval time between the coupling of models is 600 seconds. The bulk exchange formulas were TAYLOR & YELLAND (TY) [3], DRENNAN (DRN) [4], and OOST [5] in WRF-ROMS-WW3. The bulk formulas are described as follows:

TAYLOR & YELLAND (TY):

$$Z_0 = 1200 \times H_s \left( \frac{H_s}{L_p} \right)^{4.5} + 0.11 \times \frac{\nu}{u_*} \quad (1)$$

DRENNAN (DRN):

$$Z_0 = 3.35 \times H_s \left( \frac{u_*}{C_p} \right)^{3.4} + 0.11 \times \frac{\nu}{u_*} \quad (2)$$

OOST:

$$Z_0 = \frac{25.0}{\pi} \times L_p \left( \frac{u_*}{C_p} \right)^{4.5} + 0.11 \times \frac{\nu}{u_*} \quad (3)$$

where  $Z_0$  is surface momentum roughness length,  $H_s$  is significant wave height,  $L_p$  is wavelength at peak frequency,  $\nu$  is the kinematic viscosity of the atmosphere,  $u_*$  is frictional velocity, and  $C_p$  is wave phase speed at peak frequency.

## TYPHOON-INDUCED SEA SURFACE COOLING

Figure 1 shows the sea surface temperature (SST) changes before and after the passage of Jebi using WRF-ROMS-WW3 (TY) and the track results, as well as the SST changes caused by Himawari-8. With the passage of Jebi, the SST decreases up to 3 degrees or more on the right side of the typhoon track, and the model results generally agree with the observed results. Thus, typhoon-induced SST cooling reduces the energy received by the typhoon from the ocean and affects the typhoon intensity.

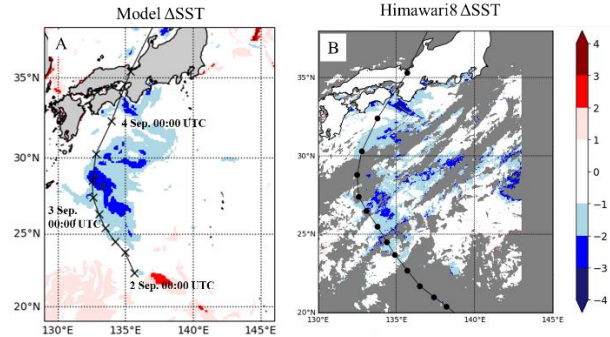


Figure 1: Jebi-induced SST changes and Jebi track. A: Results from WRF-ROMS-WW3 (TY) and the track (the result of simulation).  $\Delta$  SST is the amount of SST changes between 00 UTC on 2 Sep and 12 UTC on 4 Sep. B: Results from Himawari-8 and the best track (Joint Typhoon Warning Center: JTWC).  $\Delta$  SST is the amount of SST change between 00 UTC on 31 Aug and 00 UTC on 5 Sep. The gray color indicates missing points in the satellite data.

## INTENSITY CONSIDERING OCEAN COOLING AND WAVE EFFECTS

Figure 2 shows the typhoon tracks, minimum sea level pressure (Min. SLP), and maximum wind speed (Max. U10) for WRF only, WRF-ROMS, and WRF-ROMS-WW3 with different sea surface roughness wave parameterizations (TY, DRN, OOST). The track is compared with the best track, and it is confirmed that there is little difference between the models. The sea level pressures were 957.1, 957.2, 957.2, 957.2, 967.1 hPa at 00 UTC on 3 Sep (24 hours after the start of the

calculation) and 954.6, 962.2, 962.5, 962.1, 962.0 hPa at 00 UTC on 4 Sep (48 hours after the start of the calculation), respectively. The coupled Min. SLP is similar to the uncoupled in case Jebi passed the uncooled ocean region in Fig. 1. While the coupled Min. SLP is higher than the uncoupled model in case Jebi passed the SST-cooled ocean region. The ocean-only coupled and ocean-wave coupled cases are almost no different. On the other hand, Maximum U10 are 40.1, 38.8, 38.5, 38.4, 39.5 m/s at 00 UTC on 3 Sep and 46.7, 43.6, 40.9, 39.6, 42.9 m/s at 00 UTC on 4 Sep. The ocean-wave coupled model decreases the values by 1.3, 1.6, 1.7, and 0.6 m/s at 00 UTC on 3 Sep (Jebi passed the uncooled ocean region), 3.1, 5.8, 7.1, and 3.8 m/s at 00 UTC on 4 Sep (Jebi-induced SST cooling region). The time series of intensity in Fig. 2(B, C) shows that in some cases, the ocean-wave coupled model suppressed the decrease in intensity more than the ocean-only coupled. Thus, the impact of the typhoon differs depending on the bulk flux exchange formula of  $Z_0$ . TY and DRN formulas, considering  $H_s$ , are relatively similar intensity variations whereas OOST, which does not consider  $H_s$ , is sometimes stronger than that of ocean-only coupled. Therefore, it is important to consider the ocean cooling and wave effects and to suggest a new bulk exchange formula for typhoon intensity prediction.

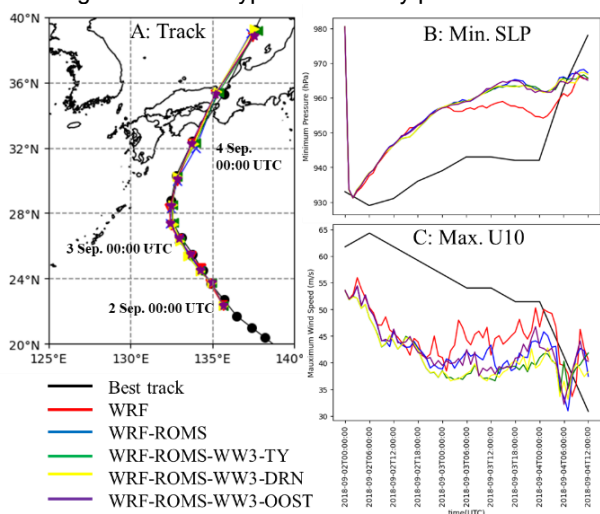


Figure 2: Track and Intensity time series from 00 UTC on 2 Sep to 12 UTC on 4 Sep each model and best track (JTWC). A: Track, B: Minimum sea level pressure, C: Maximum wind speed time series. Black is best track (JTWC), Red is WRF simulation, Blue is WRF-ROMS simulation, Green is WRF-ROMS-WW3 (TY) simulation, Yellow is WRF-ROMS-WW3 (DRN) simulation, Purple is WRF-ROMS-WW3 (OOST) simulation.

### WIND SPEED DISTRIBUTION

Figure 3 shows the sea surface wind speed distributions at 00 UTC and 18 UTC on 3 Sep, and 00 UTC on 4 Sep. Wind speed distribution is relatively axial symmetry at 00 UTC on 3 Sep, however, the axial wind speed distribution break and the structure changes significantly after Jebi passed the SST-cooled ocean region at 18 UTC on 3 Sep. The same as the intensity, TY, and DRN, considering  $H_s$  have relatively similar wind speed distributions, while OOST, which does not consider  $H_s$ , is different. OOST

shows a stronger wind speed distribution on the right side of the typhoon center than TY and DRN, but weaker on the left.

It changes the wind speed distribution due to the difference in the bulk flux exchange formula considering waves. It affects coastal waves and storm surges.

### CONCLUSION

We investigated the impact of ocean cooling and wave effects on Typhoon Jebi using the air-wave-ocean coupled model. Typhoon-induced ocean cooling weakened Jebi intensity because of decreased heat energy from the ocean to the typhoon. However, wave effects would suppress intensity decreases. Furthermore, the behavior changes with the bulk formulas for roughness length and also affects the wind speed distribution. Therefore, it is important for coastal hazard assessment to clarify the impact of ocean cooling and wave effects on typhoons. In the future, we will conduct detailed validation compared to observations and examine the bulk formulas (including enthalpy roughness length) considering other wave effects to propose an optimal bulk formula for typhoon modeling.

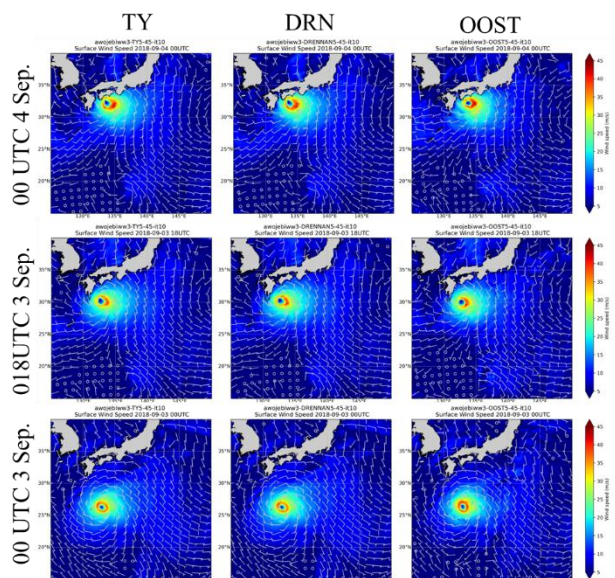


Figure 3: Snapshot of sea surface wind speed distributions by WRF-ROMS-WW3 model with different wave-related parameterization (TY, DRN, OOST) at 00 UTC and 18 UTC on 3 Sep, and 00 UTC on 4 Sep. Vertical direction is time series and horizontal is difference of models.

### REFERENCES

- [1] Mei, W. and S. P. Xie, (2016) Nat. Geoscience, 9, 753-757.
- [2] Warner, J.C. et al. (2010) Ocean Model, 35, 230-244.
- [3] Taylor, P.K. and Yelland, M.J. (2001) Journal of Physical Oceanography, 31(2), 572-590.
- [4] Drennan, W.M. et al. (2003) Journal of Geophysical Research, 108(C3), 8062.
- [5] Oost, W.A. et al.. (2002) Boundary-Layer Meteorology, 103(3), 409-438.