MODELING THE AIR—SEA-WAVE INTERACTION UNDER TYPHOON CONDITIONS: MODEL DEVELOPMENT AND A PRELIMINARY RESULT FOR TYPHOON IOKE (2006)

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1. INTRODUCTION

Air-sea interaction is primarily important for the generation and development of tropical cyclone (TC). The evaluation of heat and momentum fluxes at wave surfaces are critical for simulating TC. However the influences of surface waves on TC under strong wind conditions are not fully understood.

Powell et al.(2003) observed the wind profiles under hurricane conditions by GPS sonde and showed that the drag coefficient levels off as wind speed increases under hurricane conditions while decreases as wind speed further increases. Makin(2005) proposed the equations of roughness length which includes the effect of sea spray generated by wave breaking. He showed that the value of drag coefficient under strong winds behaves as the observations. Moon et al.(2004) conducted numerical experiments by using their original Wave Boundary Layer model, Wave Watch Ⅲ (WWⅢ) and atmospheric boundary layer model, and showed that the value of drag coefficient behaves similarly to the observation results. But there is little study that deals with the influence of wave field on typhoon development by taking into account the variability of drag coefficient under strong wind conditions.

For this purpose we developed a coupled model combining WRF-ARW and surface wave model for simulating the development of Typhoon under strong wind conditions. A preliminary result using this coupled model is also presented.

2. MODEL AND EXPERIMENTAL SETTINGS

2.1 WRF-ARW and WAVE-WATCHⅢ coupled model

In this study, we use WRF-ARW model, version 2.2 as atmospheric model and WWⅢ model as wave model. We couple these two models (hereafter we call this coupled model WWCPL). This WWCPL exchanges 10m wind speed with friction velocity every time step as shown in Figure 1. WWCPL provides 10m wind calculated by WRF-ARW to WWⅢ in order to drive surface waves. WWⅢ then returns friction velocity to WRF-ARW. As a result, WRF-ARW can include the influence of wave field.

Since the inertia of seawater is larger than that of air, the response of wave field to wind input is slow. On the other hand, the atmosphere is very sensitive to wave field, and therefore we need to consider the difference between wind direction and wave propagation direction to calculate the momentum. For this reason, the coupled model exchanges 10m wind from the atmosphere to the surface wave and exchanges friction velocity from the wave to the atmosphere.

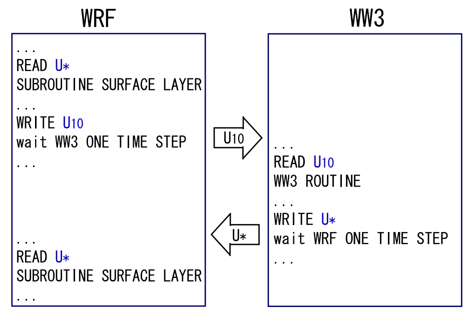

Figure 1: WWCPL (WRF-WWⅢ coupled model).

2.2 Parameterization of roughness length

In order to consider Typhoon development under the condition in which drag coefficient levels off as wind speed increases, the first thing we need to consider is to modify the profile of drag coefficient. It is also necessary to include the effect of sea spray for adopting the profile, because it is suggested that sea spray droplet has an important effect on the intensity of tropical cyclones (Andreas et al. 2001). To parameterize this effect into the atmospheric model, we modify equations of roughness length in WRF-ARW by using the equations of Makin(2005) which are shown as follows:

$$z_0 = c_l^{1-1/\omega} c_{z_0}^{1/\omega} \frac{u_*^2}{g} \tag{1}$$

$$\omega = min\Big(1, \frac{a_{cr}}{\kappa u_*}\Big) \tag{2}$$

$$c_l = h_l \frac{g}{u_*^2} \tag{3}$$

$$z_0^l = \omega z_0^w = c_{z_0} \frac{u_*^2}{g} \tag{4}$$

where h_l is the height of suspension layer which is described in Makin(2005), z_0^l is the local roughness length.

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Table 1: Types of Models using for the simulation.

	Drag equation	wave model
[1] WRF	—-	—-
[2] WWCPL	—-	coupled
[3] WRFCD	Eq.(1)∼(4)	—-
[4] WWCD	Eq.(1)∼(4)	coupled

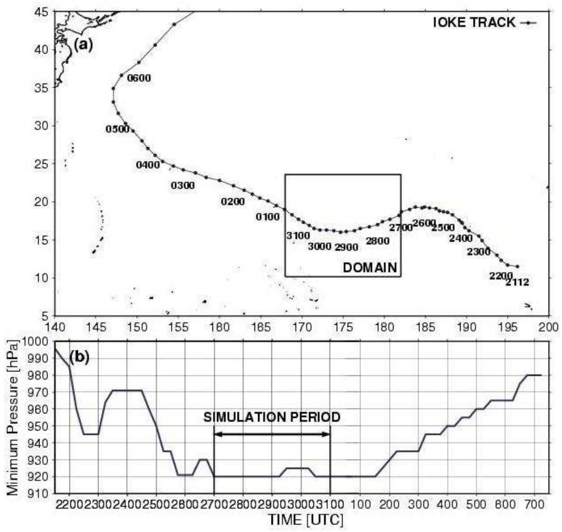

Figure 2: Properties of Typhoon IOKE:(a)best track and numerical domain, (b)center pressure the time series.

c_l and c_{z_0} represents Charnock coefficient for suspension layer and for local points, respectively. z_0^w is roughness length normally calculated in WRF. a_{cr} is critical terminal velocity for typical sea spray droplet; in this study we adopt the value of $0.64m/s$. ω is a function which includes the effect of sea spray, and z_0^l becomes z_0^w without the sea spray effect ($\omega = 1$).

We refer to the atmospheric model, WRF, including the above equations as WRFCD. In addition, the coupled model, WWCPL, which adopts these equations is referred to as WWCD.

2.3 Experimental settings

The case we examine here is Typhoon IOKE(2006). Table 1 summarizes the types of these models for the present simulations. We used NCEP final analysis meteorological data for the present simulation. The computational domain was 1500km by 1500km in horizontal (grid distance was 5km, grid number was 300×300) as shown in figure 2 and vertical grid number was 45. The center point of this domain was 175E, 17N and time step was 30 second. The period of this simulation was from 00UTC 27 to 00UTC 31 August. The behaviors of drag coefficients related to 10m wind speed in these models are shown in

Table 2: Numerical condition for Typhoon IOKE.

	WRF	WW3
initial, boundary data	NCEP data	WRF output
simulation period	2700–3100	
time step (s)	30	
grid interval (m)	5000	
horizontal grid number	300	
center of domain	175E,17N	
vertical level	45	—–
the number of freq.×dir.	—–	25×24

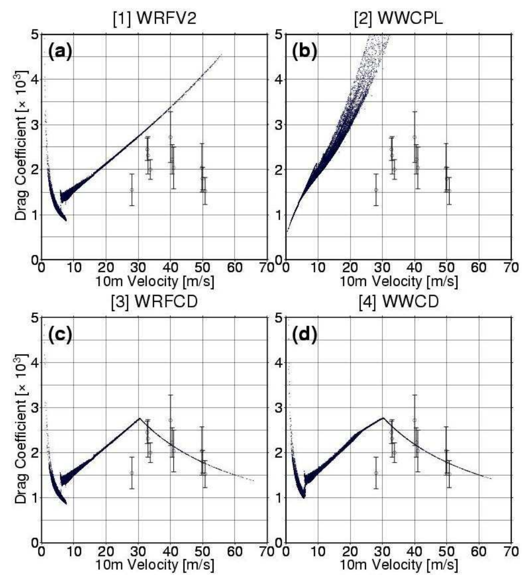

Figure 3: Relationship between lowest wind speed and drag coeffi cient in (a)WRFV2, (b)WWCPL (c)WRFCD (d)WWCD and the error bar represents the result of Powell et al.(2003).

figure 3. In WRFV2, the default drag coefficient is proportional to wind speed, as commonly used. The growth rate of the drag coefficient in WWCPL is even larger than that in WRFV2. This profile results from the relation in WW3. The profiles of drag coefficient in WRFCD and WWCD, which include the effect of sea spray, go along with the result of Powell et al.(2003).

3. A PRELIMINARY RESULT FOR TYPHOON IOKE (2006)

We have conducted four numerical simulations of Typhoon IOKE(2006): [1] WRF-ARW only(WRFV2); [2] WWCPL; [3] WRFCD and [4] WWCD. Figure 4 (a),(b) represents the time series of center pressure and maximum wind speed of the simulated Typhoon. It indicates that the Typhoon simulated in case [2] (by WWCPL) develops faster than in case [1] (by WRFV2), and the case [4] (by WWCD) also develops faster than [3] (by WRFCD). Thus

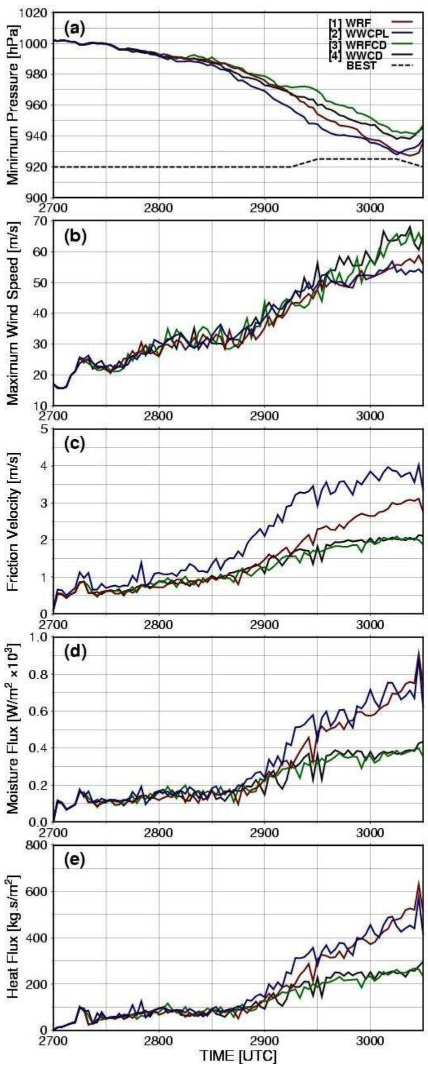

Figure 4: Time series of (a)central pressure, (b)maximum wind speed, (c)friction velocity, (d)moisture flux and (e) heat flux. Red, blue, green and black line shows the result of WRF, WWCPL, WPFCD and WWCD, respectively.

the Typhoon simulated by the coupled models (or, including sea-wave effects) develops faster than that by non-coupled models (atmospheric model only). On the other hand, the results of the models that employ the modified drag coefficient show slow development. In the case such as [3] or [4] in which drag coefficient levels off at increased wind speed, the wind speed is faster than that which adopts typical relation of drag coefficient. Although the center pressure of the Typhoon of [3] or [4] decreases slower, wind speed grows faster than that of [1] or [2] and it reaches the larger value. It also represents that there is little effect of coupling with sea-wave model for maximum wind speed. Figure 4 (c),(d),(e) represents the mean friction velocity, moisture flux and heat flux at the radius of

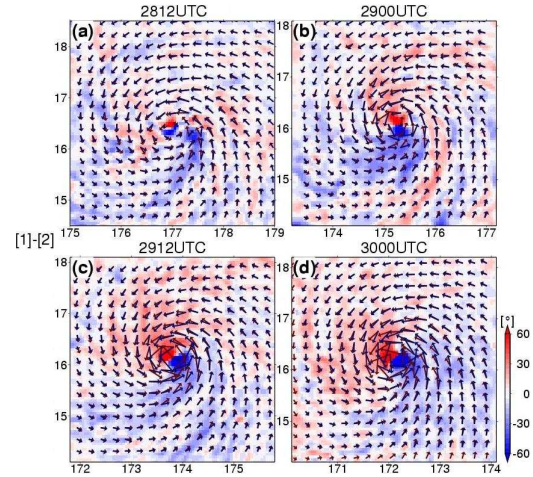

Figure 5: Anglar difference of wind direction (shading) between WRFV2 and WWCPL at (a)12UTC 28, (b)00UTC 29, (c)12UTC 29 and (d)00UTC 30 August.

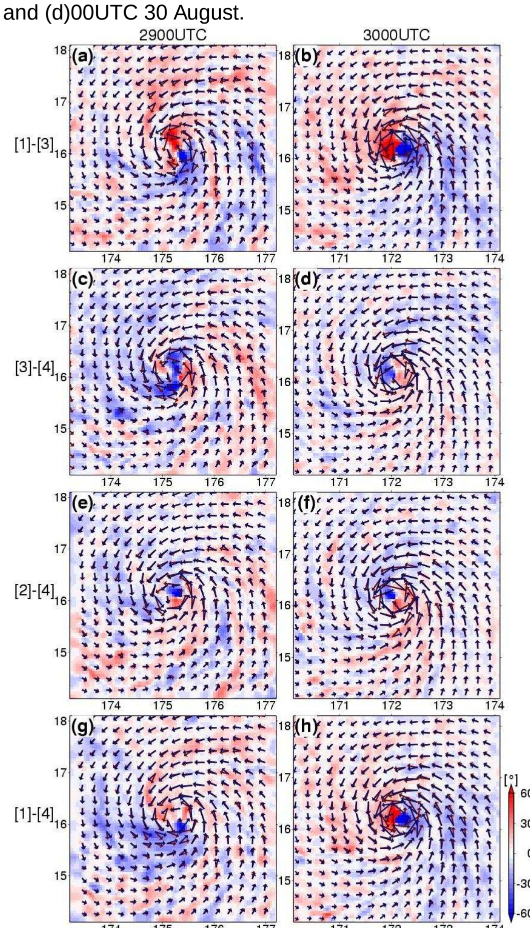

Figure 6: Same as Fig.5, the difference between (a),(b)WRFV2 and WRFCD, (c),(d)WRFCD and WWCD, (e),(f)WWCPL and WWCD and (g),(h)WRFV2 and WWCD, and the four on the left-side((a),(c),(e),(g))of this fi gure are at 00UTC 29 August, the others on the right-hand side((b),(d),(f),(h)) are at 00UTC 30 August.

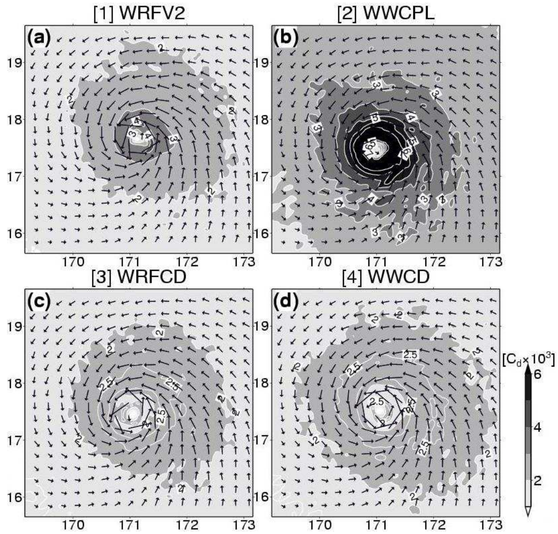

Figure 7: The distribution of drag coeffi cient (shading) and lowest wind (vectors) calculated by (a)WRFV2 (b)WWCPL (c)WRFCD (d)WWCD, at 00UTC 30 August.

maximum velocity. The results of [3] or [4] show the small value of all variables compared with those of [1] or [2]. These small values in the cases with the modified drag coefficient are due to the smaller fluxes of moisture and heat in [3] or [4]. It is suggested that a series of developing processes are followings: (i) the drag coefficient increases as wind speed increases, (ii) the friction velocity increases by (i), (iii) the heat and moisture fluxes become large with increased friction velocity, and as a result, (iv) the Typhoon develops the deeper.

Figure 5 and 6 represent a difference of the angle of the lowest wind direction between two of these models (thus a magnitude of the surface convergence) in the region near the center of Typhoon. The moving speed of Typhoon is subtracted to draw the vectors, and relative coordinate is adopted. In figure5, blue area means that the convergence of [2] is stronger than that of [1], red area shows the opposite sign. A contrasting distribution becomes obvious as the Typhoon develops as shown in figure 5. It indicates that the Typhoon of [2] has strong convergence in its rear side, while the convergence of the Typhoon of [1] is strong in its front side.

While the differences of the convergence between [3] and [4] (shown in figure 6 (c),(d)) and between [2] and [4] ((e),(f)) are not clear, the distribution of [1] contrasts with the other cases((a),(b),(g),(h)) as same sa case [2] (figure 5). Thus, the convergence of [1] in the front of Typhoon is stronger than that of the other models.

In figure 7, the distribution of drag coefficient calculated by each model is shown. [2] has the largest value of all models. The cases of [3] and [4] have the same profiles of drag coefficient that is smaller than that of [1] or [2] as shown in figure 3. However, the distribution of [3] and [4] are slightly different, and [4] has the larger area of high value of drag coefficient. Thus, the area of high value in coupled model([2],[4]) is large compared with that of non-coupled model([1],[3]). This means that the sea surface becomes rough by including the effect of wave field.

4. CONCLUSIONS

We have conducted numerical simulations for Typhoon IOKE(2006) by using four models based on the WRF model, and examined the influences of changing the profile of drag coefficient upon the Typhoon, especially the development, the surface convergence and the difference of the distribution of drag coefficient. It is found that Typhoons simulated by the models coupled with wave model develop slower than those simulated by non-coupled models. It is because the small fluxes of moisture and heat result from decreased drag coefficient under high wind speed. The value of the maximum difference of central pressure and maximum wind speed between WRF and WWCPL is 10.85hPa and 9.78m/s, respectively. The results of the models which adopt the modified relation of drag coefficient show the slow development of Typhoon compared with those of non-modified model.

It is also found that there are differences of the distribution of the convergence in surface region. In particular, the distribution of WRFV2 contrasts with the other models. The convergence of WRFV2 is strong in front side and weak in rear side as compaired with other models. However, the differences between other models are not significant. This point will be discussed in our future study.

Furthermore, the distributions of drag coefficient of four models are different. As shown in figure 3, WWCPL has the largest value of drag coefficient of all models. The profiles of drag coefficient in WRFCD and WWCD are the same; nevertheless, the distribution of significant drag coefficient in WWCD is larger than that in WRFCD. Thus, the area of high value in coupled model is also large compared with non-coupled model.

5. REFERENCES

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