PARAMETERIZATION OF COUPLED AIR-SEA INTERACTION FOR STORM SURGE AND OCEAN CURRENT STRUCTURE MODELING

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There are many researches and development for the coupled atmosphere, ocean and wave model due to the improvement of the models. On the other hand, the vigorous observations for the momentum transport between the atmosphere and ocean were carried out due to reconsider the bulk formulas for coupling model. A lot of formulas depending on the wind speed or on the wave information are proposed. Although a coupling model is useful for tropical cyclone assessment for coastal engineers, the parameterization at the air-sea interface give strong influence on storm surge modeling. In this study, the influences of the bulk formulas to ocean and wave models using the atmosphere-ocean-wave coupling model are examined.

Keywords: sea surface bulk flux; coupling model; typhoon; current

INTRODUCTION

There were many researches for the typhoon on ocean and coastal area.(e.g. Hayashi et al., 2012) Although the researches in the scientific field focused on the sea surface flux, they did not take account of the ocean current. The researches in the engineering field studied mainly the storm surge using the 2D ocean model, 3D ocean model and so on. Points of view of both research fields differ widely. There are a few researches for the ocean 3D change of the currents, temperature, and salinity from the surface flux, and almost all them study for the calm condition such as the typical summer thermocline. This is because the ocean modeling has the difficulties to take account of the influence for the open sea and the complex bathymetry from thousands meters to a few meters and the interaction between the atmosphere and the ocean.

Recently, there are many researches and development for the coupled atmosphere and ocean model due to the improvement of the calculator. In Japan, Murakami et al. (2004) and Yamashita et al. (2007) carried out the reanalysis of the storm surge with the coupling model. Furthermore, Warner et al. (2008, 2010) and Olabarrieta et al. (2012) carried out the hindcast for hurricane combined the large observation data, and reported that the coupling model improve the accuracy of the hurricane track, sea surface temperature and wave height. On the other hand, the vigorous observations for the momentum transport between the atmosphere and ocean were carried out due to reconsider the bulk formulas. Powell et al. (2003) and Black et al. (2007) pointed out that the high wind has smaller drag coefficient. However the bulk formulas are not established, a lot of formulas depending on the wind speed or on the wave information are suggested. In this study, the influences of the bulk formulas to ocean 3D parameters using the atmosphere, ocean, wave coupling model are studied.

BULK FORMULAS AT SEA SURFACE

In this research, four bulk formulas for the atmosphere roughness at the sea surface are used.

1. Charnock(1955, hereafter CH): Friction velocity

$$z_0 = max\left(\frac{\alpha_{CH}}{g}(u_*)^2, z_{0_{min}}\right) \tag{1}$$

2. Taylor and Yelland(2001, hereafter TY): Wave steepness

$$\frac{z_0}{H_s} = A\left(\frac{H_s}{L_p}\right)^B \tag{2}$$

3. Oost(2002, hereafter Oo): Wave age (Wave length)

$$\frac{z_0}{L_p} = \frac{C}{\pi}(u_*/C_p)^D \tag{3}$$

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4. Drennan(2003, hereafter Dr): Wave age (Wave height)

$$\frac{z_0}{H_s} = E(u_*/C_p)^F \tag{4}$$

where α_{CH} is the Charnock coefficient, u_* is the friction velocity, H_S is the wave height, L_p is the peak wave length, C_p is the wave speed and **A** to **F** are the empirical constants with the original value.

CALCULATION SETUP

Figure 1 shows the diagram of the atmosphere, ocean, wave coupling model. This model use WRF for the atmosphere model, ROMS for the ocean model and SWAN for the wave model. WRF gives the wind, air pressure, relative humidity, temperature, precipitation and radiation. ROMS gives the sea surface temperature, ocean current, sea surface elevation, and bathymetry. SWAN gives the wave height, length, direction, frequency and energy dissipation. Target typhoon is TC Melor and figure 2 shows the typhoon track and calculation domains. The domain of the atmosphere model is large due to the spin up for the stability of the typhoon.

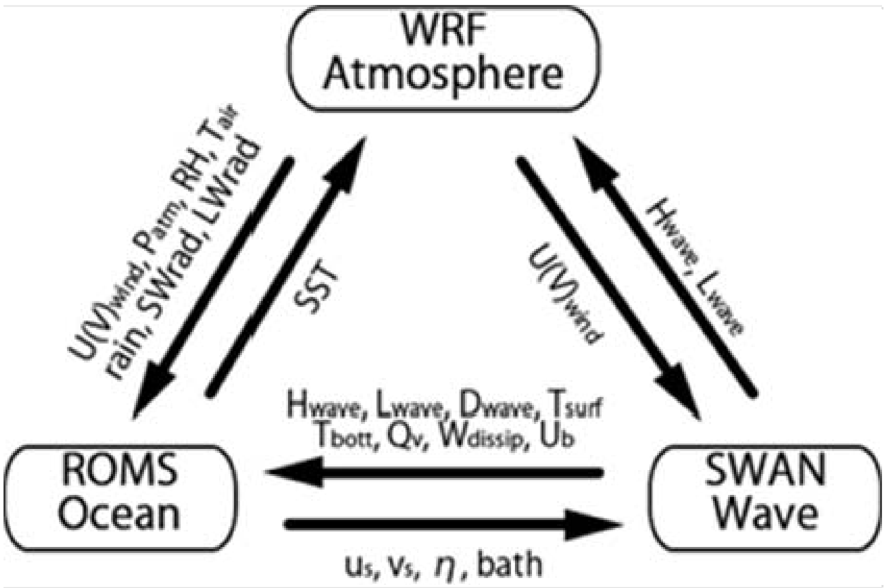


Figure 1. Diagram of coupling model

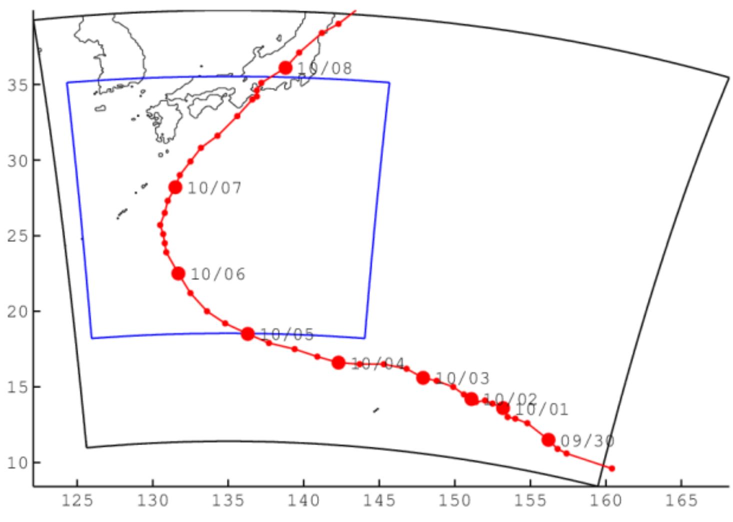


Figure 2. Typhoon track and calculation domain

The data for topography is GTOPO 30 and bathymetry is GEBCO. Both data has 30 seconds spatial resolution. For the initial and boundary condition, WRF use the NCEP FNL data that the spatial resolution is 1 degree and the time resolution is 6 hours. ROMS use the JCOPE2 data that the spatial resolution is 1/12 degrees and the time resolution is 1 day. SWAN use the NOAA WWIII reanalysis data that has the spatial resolution is 1/2 degrees and the time resolution is 3 hours.

RESULTS OF CALCULATION USING DIFFERENT BULK FORMULAS

Figure 3 shows the comparison of the typhoon track. Black line is JMA Best Track, blue, green, red and cyan lines are the results of CH, TY, Oo and Dr, respectively. For the duration which the typhoon goes west, the typhoon tracks of the calculation results are good agreement with Best Track but after turning to north the travel speed gets slow though the track agrees. The typhoon track is not affected by the difference of the bulk formulas. Figure 4 shows the time series of the minimum pressure, maximum wind speed, radius of maximum wind in the domain of ocean and wave model. Oo had small minimum pressure and maximum wind speed, but there is not large difference.

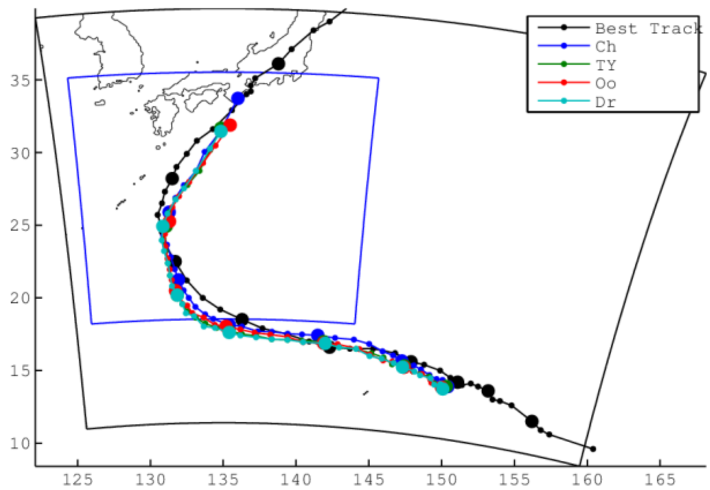


Figure 3. Comparison of typhoon track (Black: Best Track, Blue: Ch, Green: TY, Red: Oo, Light blue: Dr)

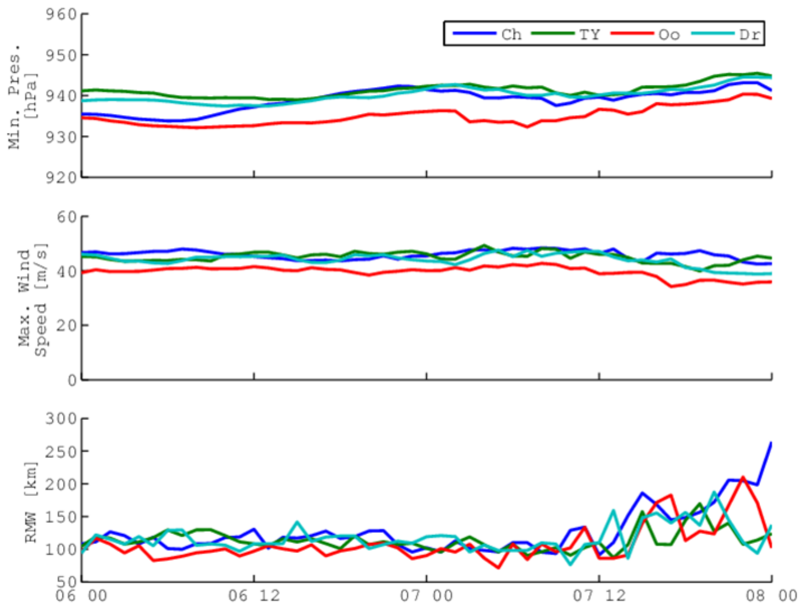


Figure 4. Time series of minimum pressure, maximum wind speed, radius of maximum wind in ocean and wave domain

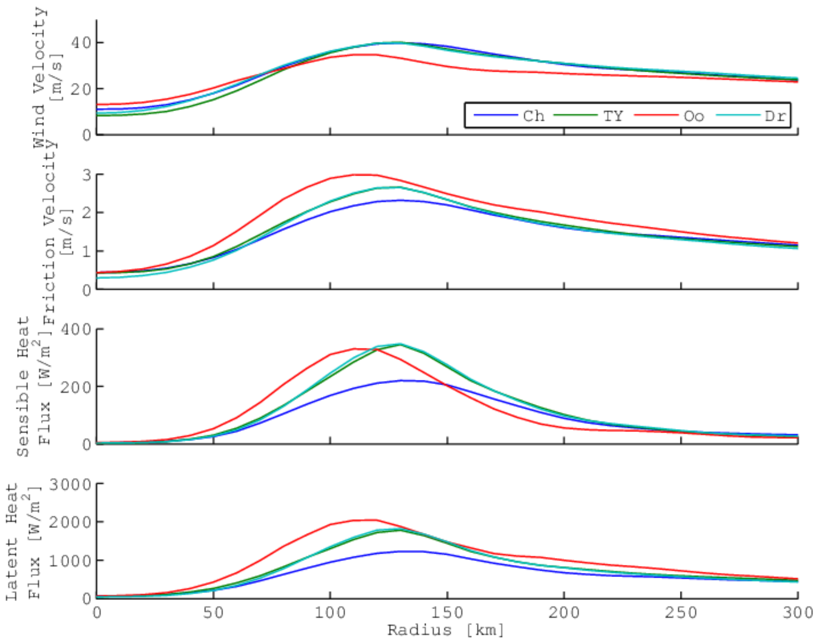


Figure 5. Radial direction change of the time and direction averaged wind speed, friction velocity, sensible and latent heat flux

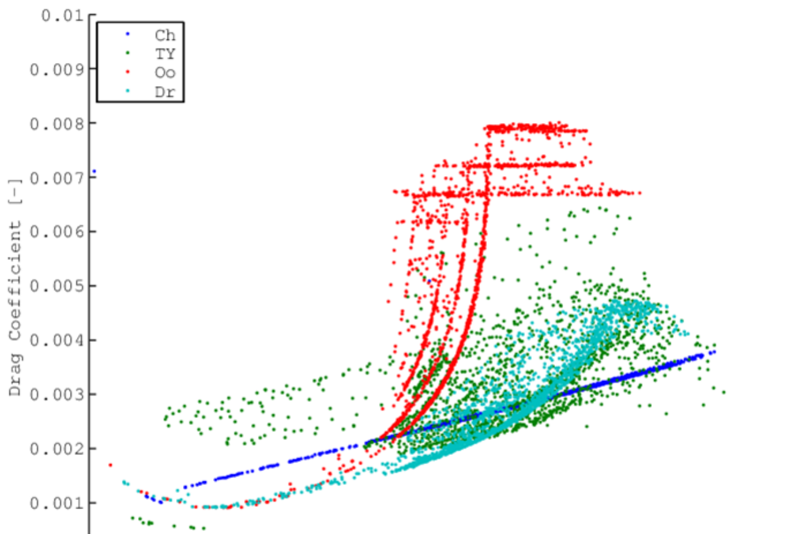


Figure 6. Relation between wind speeds and drag coefficient within a radius of 200 kilometers

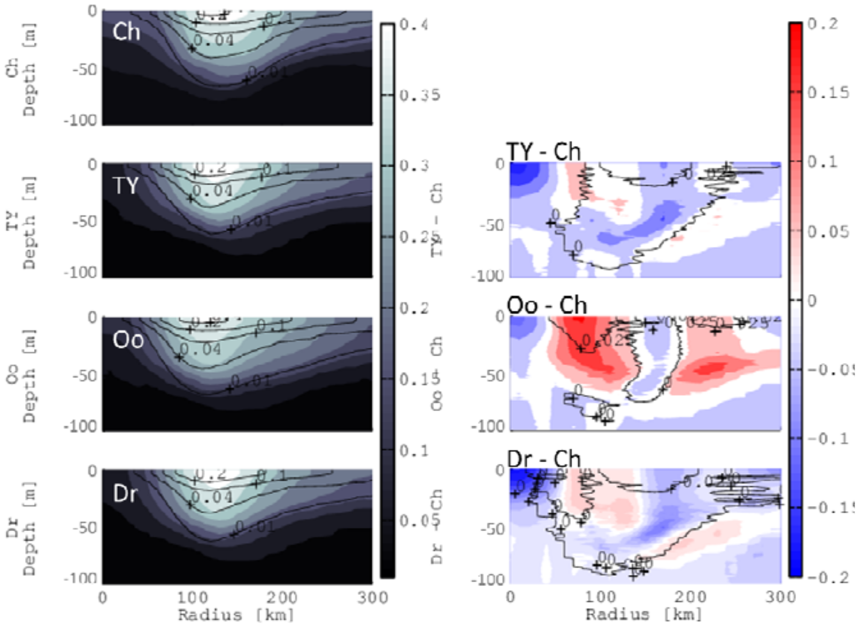


Figure 7. radial direction-depth distribution of the direction averaged current velocity and TKE, and differences from the result of bulk formula depending wind speed

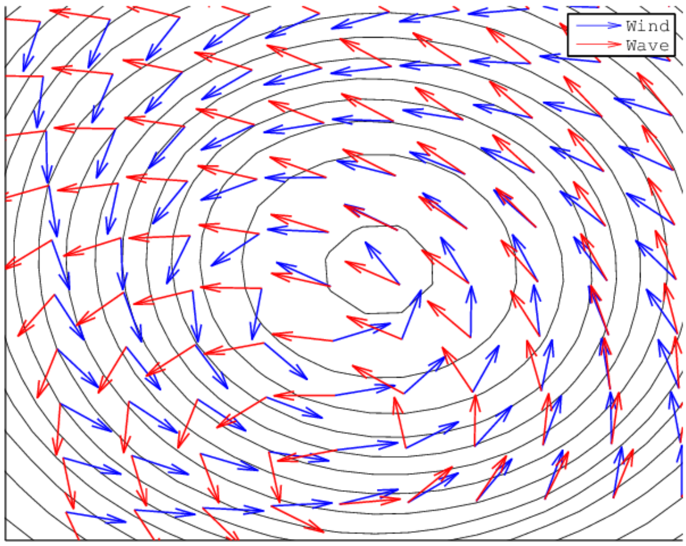
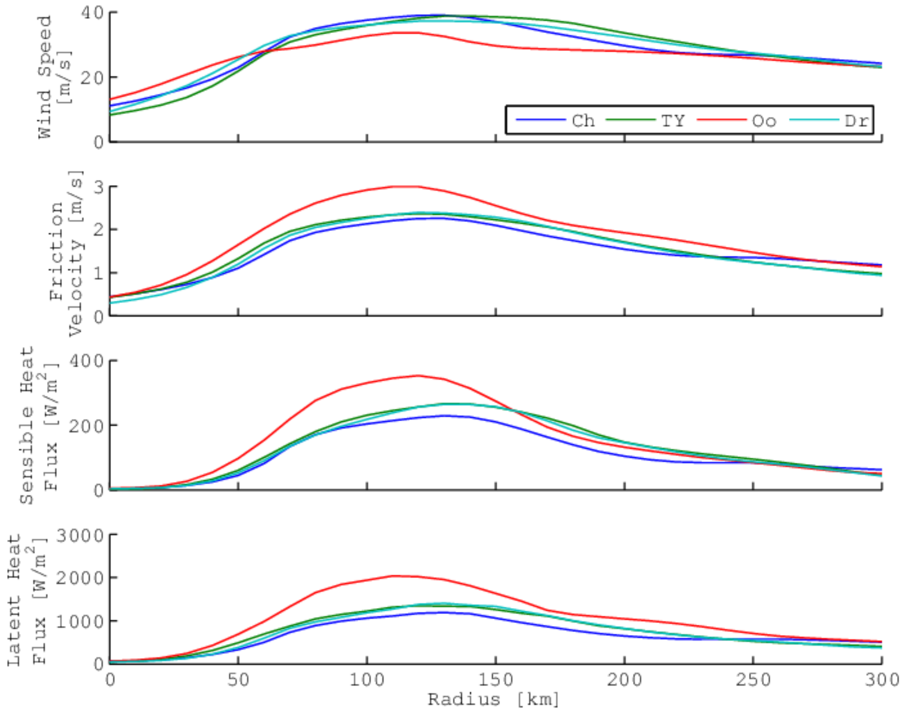


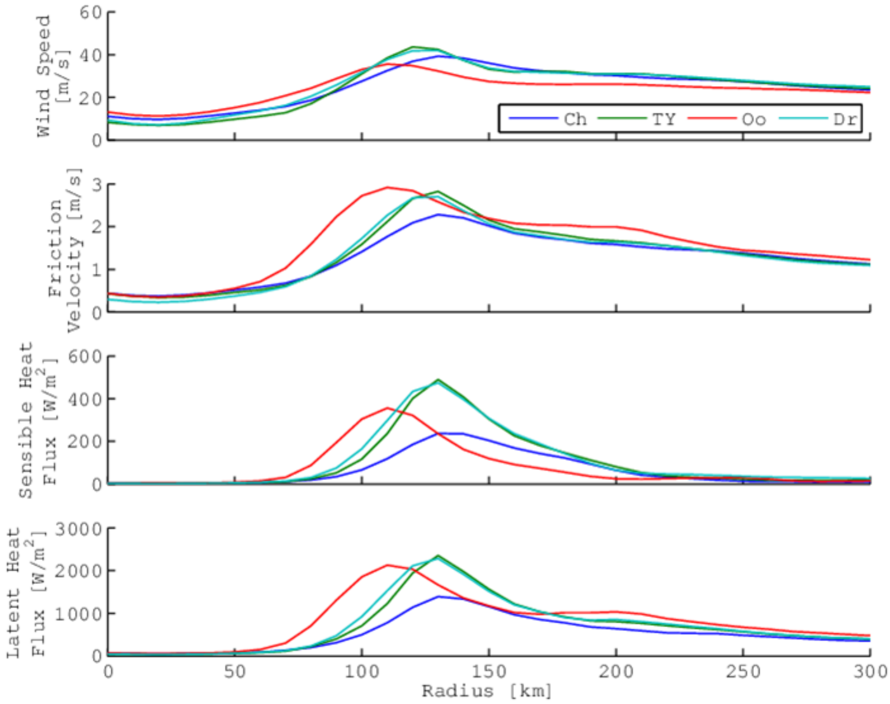
Figure 8. Directions of the wind and wave around the center of typhoon

Figure 5 shows the radial direction change of the time and direction averaged wind speed, friction velocity, sensible and latent heat flux. Oo estimated small wind speed due to large friction velocity. Heat flux is calculated mainly the temperature difference between atmosphere and ocean. Three bulk formulas depending on wave had the peak sensible and latent heat flux of the same degree. Oo estimated the peak value at closer to a center of the typhoon.

Figure 6 shows the relation between wind speeds and drag coefficient within a radius of 200 kilometers. The drag coefficient of Oo is large in more than 25 m/s. The bulk formulas depending on wave has larger drag coefficient than the formula depending on wind speed in more than 35 m/s. These relations are equal to the relation of the friction velocity in figure 5. Figure7 shows the radial direction-depth distribution of the direction averaged current velocity and TKE, and differences from the result of bulk formula depending wind speed. The distributions of the surface current velocity are same as the



(a)Front side of typhoon



(b)Rear side of typhoon

Figure 9. radial direction change of the time averaged wind speed, friction velocity, sensible and latent heat flux

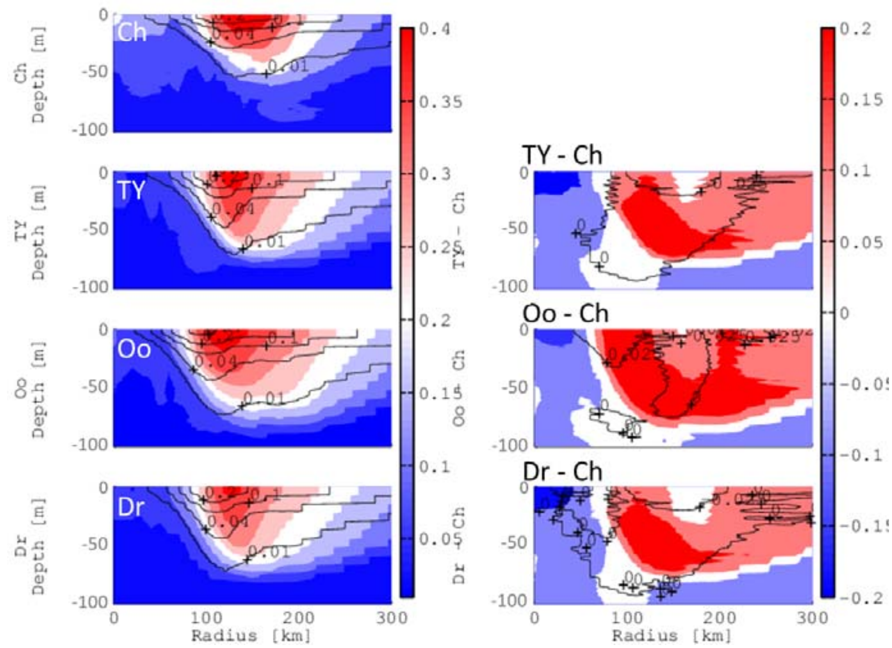


Figure 10. radial direction-depth distribution of the direction averaged current velocity and TKE, and differences from the result of bulk formula depending on wind

friction velocity distribution. The results of the bulk formulas depending wave estimate a little larger current velocity.

Figure 8 shows the directions of the wind and wave around the center of typhoon. The directions of wind and wave in the direction of the typhoon movement agree well, but they in the rear are different more than 90 degrees. The empirical coefficient of the bulk formula depending on wind is decided using the stable observation results such as the condition matching the directions of the wind and wave. Because the rear of the typhoon movement has the rapid change of the wind direction, the effects of the bulk formula difference become large. Figure 9 shows the radial direction change of the time averaged wind speed, friction velocity, sensible and latent heat flux in the front and rear direction of the typhoon. In the front area of the typhoon, Oo results have large friction velocity, but the other results do not have difference. On the other hand, in the rear area of the typhoon, though the wind speed results have good agreement, the friction velocity results of the bulk formulas depending wind and wave have about 30 % difference at the peak value and the heat flux results have about 50 % difference.

Figure 10 shows the radial direction-depth distribution of the direction averaged current velocity and TKE, and differences from the result of bulk formula depending on wind speed in the rear of the typhoon. The friction velocity and heat flux results of the bulk formulas depending wave estimate large. The characteristic results of it have large current velocity a place far from the center of the typhoon. This result is the reason is the continual difference of the momentum flux due to the friction velocity around the peak wind speed in the rear of typhoon.

CONCLUSIONS

In this study, the numerical experiments using four different bulk formulas of sea surface roughness were carried out.

1. Radial distribution of direction averaged value

The influence of the bulk formulas on the typhoon track, central pressure, maximum wind speed and radius of maximum wind was not remarkable. The results of the bulk formulas depending on wave estimated larger friction velocity and heat flux than the one on wind around the radius of maximum wind. The results of surface current velocity showed the same results of friction velocity and the results of the formulas depending wave estimated larger current velocity.

2. Radial distribution in the front and rear of typhoon

In the front of the typhoon, the influence of the bulk formulas on wind speed, friction velocity and heat flux was not remarkable. In the rear of the typhoon, the results of wind speed were same, but the results of the formulas depending wave estimated large friction velocity and heat flux. In the rear of the typhoon, the formulas depending wave estimated large current velocity and a place far from the center of the typhoon is influenced.

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