Drag coefficient under extremely high winds of typhoon Hai-Tang (2005)

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1. Introduction

Sea states at the interface between the atmosphere and the ocean play a crucial role in calculating air-sea exchange coefficients for momentum, heat and moisture fluxes. Breaking surface waves occurred at the interface underneath a tropical cyclone (TC) result in variations in sea states and then TC-induced sea-surface cooling (SSC) due to an increase in turbulent kinetic energy near the surface (Wada et al., 2010). SSC leads possibly to reduce turbulent heat and moisture fluxes in the vicinity of the center of a TC due to a small difference in air-sea temperatures and moistures. The reduction in the fluxes is responsible for slower intensification and changes in inner-core eye-eyewall mixing processes at the intensification phase.

This report addresses the other aspect of sea states on TC intensification. That is a role of surface friction in TC intensification through changes in oceanic roughness lengths, frictional velocities, and drag coefficients (C_d). Recent studies indicated that C_d leveled off at very high wind speed (30 to 40 m s^{-1}) (Powell et al., 2003; Donelan et al., 2004), while the average of enthalpy coefficients (C_k) seems to keep constant up to 30 m s^{-1}. When C_k keeps constant at the very high wind speed, the ratio (C_k/C_d) turns to increase due to a decrease in C_d. According to 'Wind-Induced Surface Heat Exchange' mechanism proposed by Emanuel (1995), high C_k/C_d provides a favorable condition for forming a stronger TC with high maximum potential intensity. The purpose of this report is therefore to investigate effects of sea states on TC intensity predictions using an atmosphere-wave-ocean coupled model developed by the author.

2. Experiment design

The atmosphere-wave-ocean coupled model consists of a nonhydrostatic atmosphere model (NHM) developed at the Japan Meteorological Agency (JMA) and Meteorological Research Institute (MRI), the third generation ocean wave model for operational developed at the JMA and mixed-layer ocean model developed at the MRI (Wada et al., 2010). It should be noted that the effect of breaking surface waves on an entrainment at the mixed-layer base is incorporated into the mixed-layer ocean model (Wada et al., 2010).

The computational domain of the coupled model is 4320 km in the longitudinal direction and 2520 km in the meridian direction with the horizontal grid spacing of 3 km. The time step of NHM is 8 s, that of the mixed-layer ocean model is 48 s and that of the ocean wave model is 600 s. NHM has 40 vertical levels, and the interval between levels varies from 40 m near the surface to 1180 m for the uppermost layer. The model top height of NHM is nearly 23 km. The number of layers in the mixed-layer ocean model is four, which is the same as Wada et al. (2010). Oceanic initial conditions are obtained from daily oceanic reanalysis data in 2005 with a horizontal grid spacing of 0.5°, calculated by the MOVE system (Usui et al., 2006).

The specification of the coupled model is as follows. No convective parameterization scheme is used. The roughness length is estimated by Taylor and Yelland (2001). Two kinds of numerical simulations are carried out (Table 1): one uses a scheme of Louis et al. (1982) for determining exchange coefficients, which is based on the Monin-Obukhov similarity theory (hereafter TYL). The other uses a scheme of Kondo (1975), assuming the dependency of exchange coefficients on surface wind speed (hereafter TYK).

Table 1 Designations of the numerical-prediction experiments and surface boundary processes (roughness lengths and exchange coefficients) used to conduct the experiments.

Experiments	Surface boundary processes	
	Roughness lengths	Exchange coefficients
TYL	Taylor and Yelland (2001)	Louis et al (1982)
TYK	Taylor and Yelland (2001)	Kondo(1975)

To set the initial and boundary atmospheric conditions, a hydrostatic global spectral model (GSM) version T213L40 with a horizontal grid spacing of nearly 60 km was previously run for 72 h. To avoid gaps in the horizontal resolution of downscale calculations, a hydrostatic regional spectral typhoon model (TYM) with a horizontal grid spacing of nearly 20 km was subsequently run for 72 h as a preparation. The TYM provides initial and boundary atmospheric conditions every 3 h to the coupled model. The integration time of GSM, TYM and the coupled model in TYL and TYK is 72h, starting from 1200 UTC 1 July 2005.

3. Results

Predicted central pressures (CPs) are compared to best-track CP archived by the Regional Specialized Meteorological Center Tokyo-Typhoon Center (Fig.1a). Relatively low predicted CPs compared to best-track CP are similar results to Wada et al. (2010). The evolution of best-track CP indicates intensification from 12 h to 36 h, while the evolutions of predicted CPs indicate little intensification. A difference in surface boundary schemes between TYL and TYK hardly affects a northwestward track error reported in Wada et al (2010) (not shown).

A difference in predicted CPs between TYL and TYK begins to appear clearly after 36 h. A rapid decrease in the predicted CPs from 36 h to 72 h indicates rapidly intensification, which is partly seen in best-track CP (60 h to 72 h). The predicted CP in TYK is lower than that in TYK during the period. The predicted CP in TYK is lower than that in best-track CP at 72 h, while the predicted CP in TYL is higher than that in best-track CP.

As 10-m wind is higher, C_d is usually high when some bulk formulas (e.g. Kondo, 1975) are used for the estimate of C_d. The result in this report, however, shows that C_d levels off at very high winds (higher than 40 m s^{-1}) with greater standard deviations. A difference in the values of C_d between TYL and TYK becomes clear when 10-m wind is higher than 40 m s^{-1}. C_d rapidly levels off in TYK, which is consistent with the observational result of Powell et al. (2003). In contrast, C_d tends to keep constant in TYL, similar to the experimental result of Donelan et al (2004).

A difference in dependencies of the ratio C_k/C_d on 10-m wind becomes clear when 10-m wind is higher than 50 m s^{-1} (Fig.2). The ratio calculated in TYK is higher than that calculated in TYL, implying that maximum potential intensity, proposed by Emanuel (1995), in TYK is stronger than that in TYL. This implication is consistent with the numerical-prediction result shown in Fig.1a.

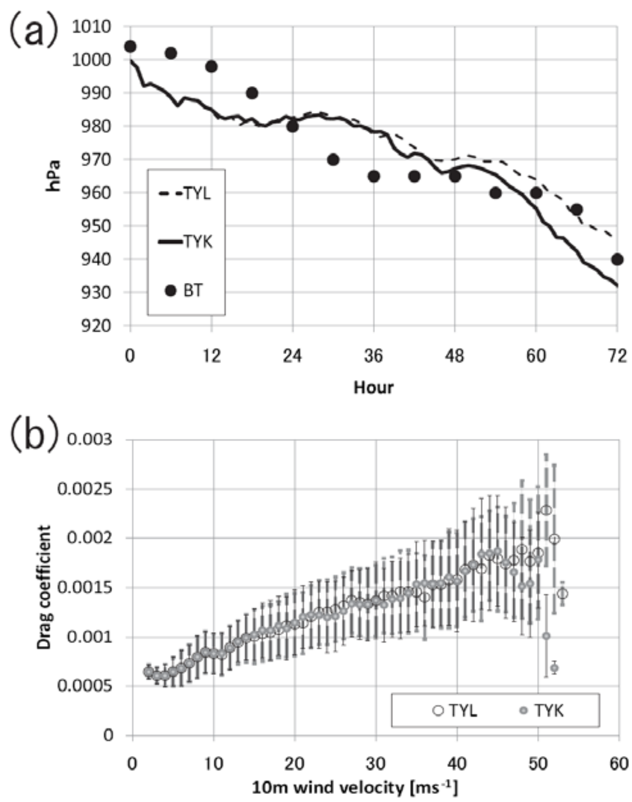

Figure 1 (a) Time series of best-track central pressure (CP), predicted CP in TYL and TYK, and (b) A scatter diagram of 10-m wind velocity and drag coefficient (C_d) in TYL and TYK at 72h.

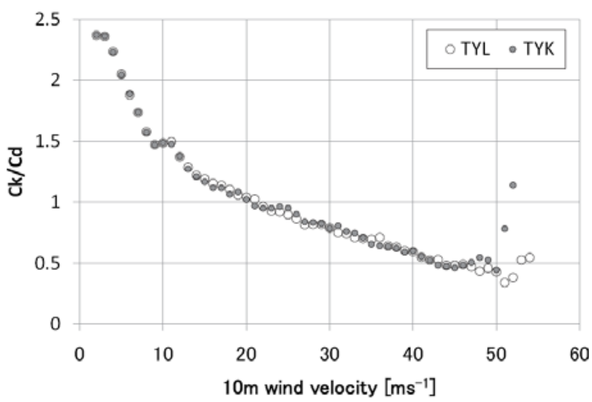

Figure 2 A scatter diagram of 10-m wind velocity and the ratio C_k/C_d in TYL and TYK.

4. Concluding remarks

A difference in surface boundary schemes incorporated into an atmosphere-wave-ocean coupled model results in a difference in the dependencies of C_d on 10-m wind particularly at very high winds. However, the values of C_d obtained in the present numerical predictions are relatively low compared with previous studies (e.g. Powell et al., 2003; Donelan et al, 2004). The couple model will be needed to be modified particularly in variations in roughness lengths such as a modification of the coefficients of the empirical formula of Taylor and Yelland (2001) in order to improve the estimate of the underestimation of C_d.

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