Impact of surface roughness lengths on simulations of Typhoon Fanapi (2010)

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1. Introduction

Surface roughness lengths over the ocean are varied by ocean waves. The surface roughness length is used in the atmosphere model to determine exchange coefficients for momentum, sensible and latent heat fluxes. The sensible and latent heat fluxes play a crucial role in developing a tropical cyclone, while the momentum flux drives the upper ocean, resulting in sea-surface cooling by passage of a tropical cyclone. The exchange coefficient for the momentum flux is also important to estimate the effect of surface friction near the surface on angular momentum transport, which plays a role in reducing tangential winds and producing radial inflow and thus secondary circulation.

In order to understand the effect of surface roughness lengths on simulations of tropical cyclones, the impact of surface roughness lengths on simulations of tropical cyclones is investigated for Typhoon Fanapi (2010) using a nonhydrostatic atmosphere model coupled with an ocean wave model and a multi-layer ocean model (Wada et al., 2010). The surface roughness length calculated by the coupled model is determined by the following five methods, respectively; functions of wave-induced stress (Janssen, 1991), wave age (Smith, 1992), wave steepness (Taylor and Yelland, 2001), the assumption of Charnock constant (Charnock, 1955), and drag coefficients depending on 10-m wind speed (Kondo, 1975).

2. Experimental design

Ten numerical simulations were performed for Fanapi, which was one of targeted typhoons in the Impacts of Typhoons on the Ocean in the Pacific (ITOP) program ITOP, by the coupled model incorporating the above-mentioned surface roughness length scheme (Table 1). The coupled model covers a 2000 km x 1800 km computational domain with a horizontal grid spacing of 2 km. The coupled model has 40 vertical levels with variable intervals from 40 m for the near-surface layer to 1180 m for the uppermost layer. The coupled model has maximum height approaching nearly 23 km. The integration time is 72 hours with a time step of 6 s in the atmosphere model.

Table 1 List of numerical simulations, surface roughness scheme used, and horizontal resolution of oceanic initial condition.

Experiment		Surface roughness scheme	Horizontal resolution of MOVE
CH	CH1	Charnock (1955)	0.1°
	CH5		0.5°
JA	JA1	Janssen (1991)	0.1°
	JA5		0.5°
KO	KO1	Kondo (1975)	0.1°
	KO5		0.5°
SM	SM1	Smith (1992)	0.1°
	SM5		0.5°
TY	TY1	Taylor and Yelland (2001)	0.1°
	TY5		0.5°

Oceanic initial conditions were obraied from the oceanic reanalysis datasets with horizontal resolutions of 0.1° and 0.5°, calculated by the Meteorological Research Institute multivariate ocean variational estimation (MOVE) system (Usui, et al., 2006). Because the southern limit of the domain in the MOVE system with a horizontal resolution of 0.1° was 15°N, the oceanic reanalysis data with a horizontal resolution of 0.5° were merged south of 15°N when the dataset with a horizontal resolution of 0.1° was used as an oceanic initial condition.

After surface roughness lengths are calculated by each above-mentioned method, wind speeds at 10-m height and drag coefficients are calculated by the method proposed by Louis et al., (1982). Except the method of Taylor and Yelland (2001), an iteration method is applied for determining surface roughness length and frictional velocity. The dependency of wave steepness on a wind direction is applied only in the method of Taylor and Yelland (2001): When the wind direction is perpendicular to the wave direction, this study assumes that wave steepness does not grow up and reduces by half.

3. Results

The numerical result indicates that the simulated track of Fanapi had a northward bias, which was independent of the choice of surface roughness length scheme (Fig.1a). In addition, the result of track simulation is not affected by the horizontal resolution of oceanic initial data (not shown).

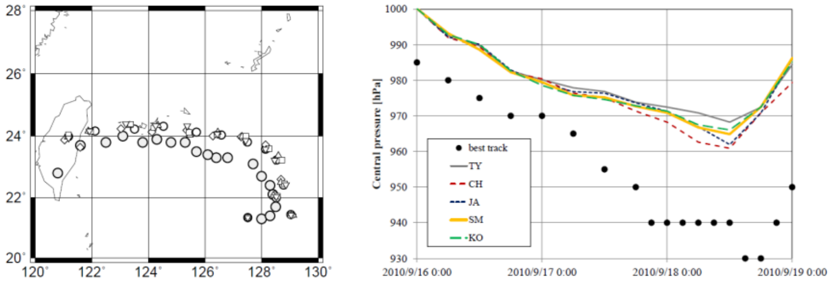

Figure 1 (a) Best track of Fanapi (Large gray circles) and simulated tracks (TY: small open circles, CH: open diamonds, JA: open triangles, SM: open squares, and KO: open inverse triangles). (b) time series of best-track central pressure and simulated ones.

The horizontal resolution is also irrelevant to the central-pressure simulations (not shown). However, the central-pressure simulations depend on a surface roughness length scheme even though all simulated central pressures are higher than the best-track central pressure. A difference in the average of simulated central pressure among five schemes is nearly 10 hPa at 60 h (Fig.1b). The difference becomes markedly when the simulated Fanapi undergoes intensification.

Figure 2 indicates that drag coefficients are high at 60 h under relatively low winds. Edson et al. (2007) reported that drag coefficients were relatively high under extremely low winds. The drag coefficient may be overestimated compared to the result of Edson et al. (2007). The dependency of 10-m wind speed on drag coefficient indicates that drag coefficients monotonically increase with an increase in 10-m wind speeds except that derived from Taylor and Yelland (2001) (Fig.2). The dependency derived from Taylor and Yelland (2001) indicates that drag coefficients clearly level off and are saturated when 10-m wind speed is higher than 30 m s^{-1}. This dependency is also seen in the dependency of surface roughness lengths on 10-m wind speeds (Fig. 3).

In contrast, drag coefficients increases linearly when the wave age, the ratio of the phase speed to frictional velocity, is used for determining surface roughness lengths, which are calculated by the formula of Smith et al. (1992), except at 35 m s^{-1}. The values of drag coefficients and surface roughness lengths are much higher than those by any other formulae. However, there is little impact of high values of drag coefficient and surface roughness length on simulations of the track of Fanapi and a small impact on its intensity at the mature phase.

Not only Smith et al., (1992) but also other methods except Taylor and Yelland (2001) had a strong dependency of drag coefficients and surface roughness lengths on frictional velocity. This is why surface roughness lengths must be solved by iteration algorithm. Wave steepness, however, is determined from a wave-length scale and wave height, not directly dependent of frictional velocity.

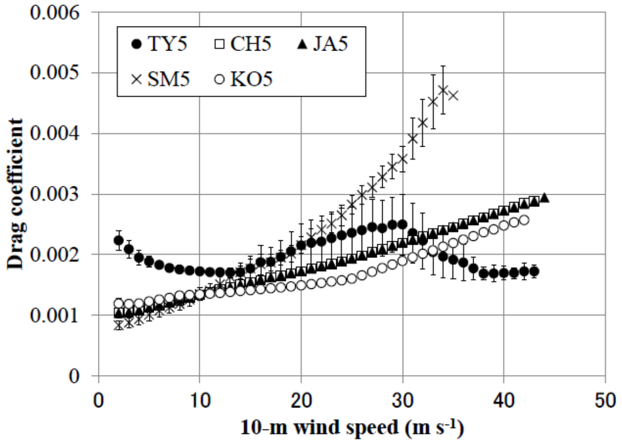

Figure 2 The relation of 10-m wind speed to drag coefficients obtained from numerical simulations listed in Table 1.

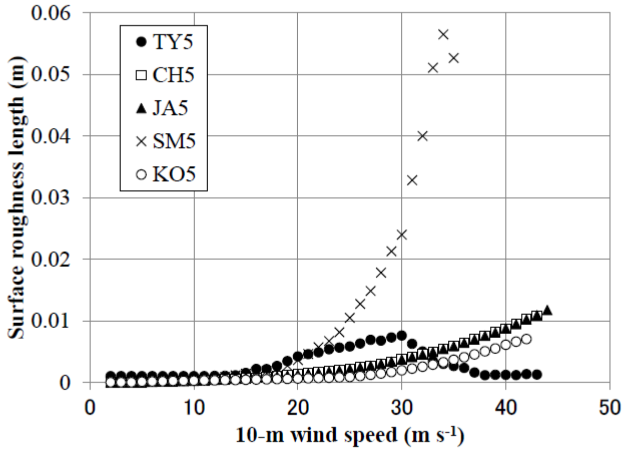

Figure 3 The relation of 10-m wind speed to surface roughness lengths obtained from numerical simulations in Table 1.

4. Discussion and conclusion

From numerical simulations for Fanapi, drag coefficients derived from the formula of Taylor and Yelland (2001) alone markedly level off when 10-m wind speeds are over 30 m s^{-1}. There is little impact of surface roughness lengths on the track of Fanapi and a small impact on its intensity at the mature phase, but there may be impacts on the structure such as the radius of maximum wind speed and precipitation pattern. In addition, we need to investigate the impacts not only at the intensification phase but also the mature and decaying phases.

Acknowledgement

This work was supported by the Japan Society for the Promotion of Science (JSPS), Grant-in-Aid for Scientific Research (C) (22540454) and on Innovative Areas (Research in a proposed research area) (23106505).

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