Impacts of short-term variation in sea-surface temperature and the sea state on the evolution of stationary tropical-cyclone-like vortex

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1. Introduction

Previous studies reported that tropical-cyclone (TC) induced sea-surface cooling (SSC) directly affect the intensification and maximum intensity of a TC (Wada, 2009). However, the impact of short-term variation in sea-surface temperature (SST) such as diurnally-varying SST on TC intensification and its maximum intensity has not been investigated in detail so far. In addition, sea states varied at a short time scale are known to play a crucial role in determining exchange coefficients for momentum, sensible and latent heat fluxes. Sea states also enable to affect vertical turbulent mixing in the oceanic mixed layer due to breaking surface waves. Thus, variation in sea states can be considered as a crucial factor affecting TC intensification and its maximum intensity. This study addresses impacts of diurnally-varying SST (or noisy SST variation) and sea states on the development and maximum intensity of TC-like vortex using an atmosphere-wave-ocean coupled model (Wada et al., 2010).

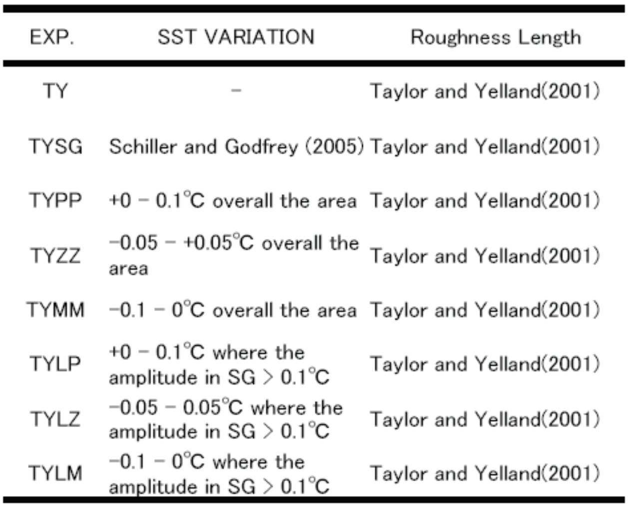
2. Experiment design

The specification of the present numerical experiment is almost the same as Wada and Niino (2008) and Wada (2009) except that 1) an atmosphere-wave-ocean coupled model (Wada et al., 2010) is used instead of a nonhydrostatic atmosphere model coupled with mixed-layer ocean model, 2) integration time is 96 hours (h), not 81 h, 3) SST at the initial time is 30℃ and 4) the coupled run begins from the initial time.

The formulation of Schiller and Godfrey (2005) (hereafter SG) with a short-wave absorption/penetration scheme of Ohlmann and Siegel (2000) is incorporated into the atmosphere-wave-ocean coupled model in order to calculate skin temperature in the vicinity of sea surface. The abbreviation 'SG' indicates the inclusion of the Schiller and Godfrey scheme into the coupled model. In order to investigate the significance of the impact of diurnally-varying SST on TC intensification and its maximum intensity, we perform the numerical experiments in TY and TYSG (Table 1) and the other numerical experiments given uniform random real numbers in the interval (0, 0.1] generated using the multiplicative congruence method. How to provide random noises to calculated SST is presented in Table 1.

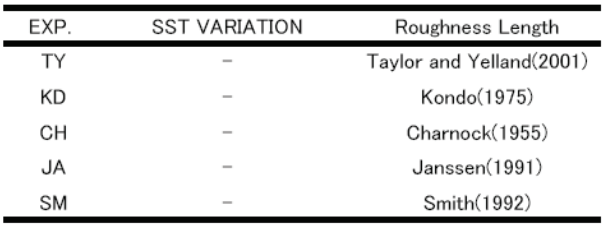
Table 2 shows what roughness-length scheme is used for each numerical-prediction experiment. The roughness length derived from Taylor and Yelland (2001) is based on wave steepness. The roughness length derived from Kondo (1975) is based on the dependency of 10-m wind speed.

Table 1 Abbreviations of numerical-prediction experiments, method of SST variation, and scheme of roughness length. The character '-' means an experiment without using an oceanic sublayer scheme (Schiller and Godfrey, 2005).



EXP.	SST VARIATION	Roughness Length
TY	－	Taylor and Yelland(2001)
TYSG	Schiller and Godfrey (2005)	Taylor and Yelland(2001)
TYPP	+0 – 0.1℃ overall the area	Taylor and Yelland(2001)
TYZZ	−0.05 – +0.05℃ overall the area	Taylor and Yelland(2001)
TYMM	−0.1 – 0℃ overall the area	Taylor and Yelland(2001)
TYLP	+0 – 0.1℃ where the amplitude in SG > 0.1℃	Taylor and Yelland(2001)
TYLZ	−0.05 – 0.05℃ where the amplitude in SG > 0.1℃	Taylor and Yelland(2001)
TYLM	−0.1 – 0℃ where the amplitude in SG > 0.1℃	Taylor and Yelland(2001)

Table 2 Same as Table 1.



EXP.	SST VARIATION	Roughness Length
TY	－	Taylor and Yelland(2001)
KD	－	Kondo(1975)
CH	－	Charnock(1955)
JA	－	Janssen(1991)
SM	－	Smith(1992)

The roughness length derived from Charnock (1955) is based on the constant value of the ratio of gravity acceleration multiplied roughness length to frictional velocity squared. Janssen (1991) proposed the formulation of roughness length that the Charnock constant value varied depending on the ratio of wave-induced stress to wind stress, while Smith et al. (1992) proposed it that the Charnock constant value varied depending on the ratio of frictional velocity to the wave age. It should be noted that the impact of diurnally-varying SST on TC intensification and its maximum intensity is investigated only by the atmosphere-wave-ocean coupled model with the roughness length scheme of Taylor and Yelland (2001), while the impact of sea states is investigated by the atmosphere-wave-ocean coupled model without the inclusion of the Schiller and Godfrey scheme.

3. Results

The evolutions of central pressures (CPs) of TC-like vortex calculated by the atmosphere-wave-ocean coupled model with the SG scheme or various SST noises (Table 1) are shown in Figs. 1 and 2. TC-like vortex undergoes slow intensification from 0 h to 24 h and the vortex turns to experience rapid intensification to 48 h in all numerical experiments. Then the vortex gradually weakens due to SSC. The range of SSC defined as a decrease in SST from the initial time is -6.8 to -7.9°C at 96 h. The minimum value of a decrease in SST from the initial time is -8.0 to -8.6°C occurred while the vortex gradually weakens at the mature phase.

A difference in CPs between TY and TYSG is comparable to that between TY and the other numerical experiments given various SST noises. This result indicates that the impact of diurnally-varying SST on the evolution of CP is regarded as the impact of noisy SST variation on it when TC-like vortex is stationary. The impact of noisy SST variation is remarkable from 36 h to 48 h in TYSG, TYZZ, TYMM, TYLP and TYLM corresponding to the rapid intensification phase. The impact of noisy SST variation is independent of the area of noisy SST variation whether it is overall the computational domain or limited where the amplitude of skin temperature is greater than 0.1°C.

In contrast, a difference of roughness-length schemes shown in Table 2 directly affects the evolution of CP from 24 h to 48 h, corresponding to the rapid intensification phase, while the difference turns to be relatively small after 48 h, corresponding to the mature phase of TC-like vortex. This reveals that roughness length plays a crucial role in rapidly intensifying TC-like vortex. This phase corresponds to eye-eyewall mixing process inside the eyewall. Mesovortices appear within the core of TC-like vortex and they are merged into a vorticity ring during the phase.

In summary, rapid intensification is affected by surface friction changed by roughness-length schemes at the early rapid intensification phase, while it is also affected by noisy SST variation, including diurnally-varying SST, at the late rapid intensification phase.

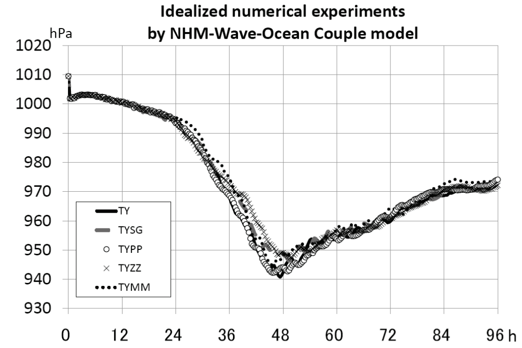


Figure 1 Time series of simulated central pressure of TC-like vortex in TY, TYSG, TYPP, TYZZ and TYMM (Table 1).

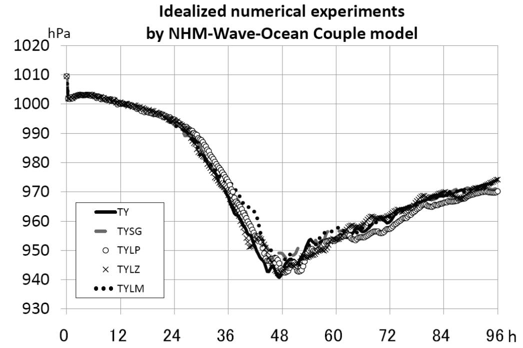


Figure 2 Same as Fig. 1 except in TY, TYSG, TYLP, TYLZ and TYLM (Table 1).

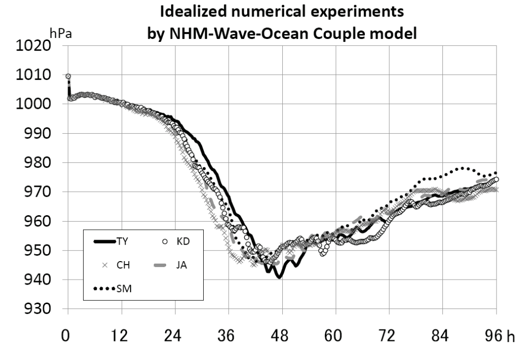


Figure 3 Same as Fig. 1 except in TY, KD, CH, JA and SM (Table 2).

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