Effects of atmospheric planetary and surface boundary-layer schemes on simulations of intense tropical cyclones

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1 Introduction

A simulation of the development of tropical cyclones (TCs) is strongly affected by atmospheric planetary and surface boundary–layer schemes. In this study, the sensitivity experiments are conducted for an intense TC by using a nonhydrostatic atmospheric model [Saito et al., 2007] with a horizontal resolution of 2 km (NHM2). The planetary boundary layer (PBL) schemes used in this study are the Mellor–Yamada–Nakanishi–Niino (MYNN) scheme [Nakanishi and Niino, 2004]: level 3 ('CNTL2' or no index in Table 1) and the Deardorff–Blackadar scheme ('dd' in Table 1), respectively. The surface boundary schemes are Beljaars and Holtslag [1991] ('H' in Table 1) and Louis et al. [1982] ('L' in Table 1), respectively. Beljaars [1994] ('B' in Table 1) and Kondo [1975] ('K' in Table 1) are used for calculating the surface roughness length (z_0).

2 Model descriptions

The computational domains covered an area of 2600 km × 2400 km, centered at 22.5°N, 142.5°E with 50 vertical levels with variable height, from 40 m for the lowermost layer near the surface to 904 m for the uppermost layer. The top height was approximately 22 km. The boundary conditions including sea surface temperature were provided every 6 hours from the experiment by an atmospheric general circulation model with a horizontal resolution of 20km [AGCM20, Mizuta et al., 2012]. The integration period was 6 days from 0600 UTC, 16 September 1983, which targeted a TC (MCP, 866 hPa) simulated by AGCM20, that was the most intense at 0600 UTC on 21 September. Detail of the model descriptions are summarized in Kanada et al. [2012].

3 Results

Figure 1 clearly shows differences in the central pressure (CP) evolution between experiments in Table 1. Minimum CP (MCP) was 916 hPa in CNTL2, 886 hPa in 2HK, 914 hPa in 2LB, 888 hPa in 2LK, 910 hPa in 2dd, and 877 hPa in 2ddLK (Table 1). Regardless of the PBL and surface boundary schemes, all K–experiments (2HK, 2LK and 2ddLK) showed rapid intensification exceeding 30 hPa day^{-1} and have MCPs lower than 890 hPa. On the other hand, all B–experiments (CNTL2, 2LB and 2dd) gradually developed, and had MCPs higher than 910 hPa. These results indicate the largest impact of the z_0–settings on the development of TC in the experiments. Little difference was found between H– and L–experiments (See CNTL2 and 2LB, and 2HK and 2LK). CPs in dd–experiments developed more rapidly than those in MYNN–experiments (See CNTL2 and 2dd, and 2LK and 2ddLK). Note that AGCM20 which attained the lowest MCP of 866 hPa, did not show the rapid intensification.

Table 1 List of control and sensitivity experiments [PBL, surface boundary schemes and surface roughness length (z_0)]

Experiment	PBL and surface schemes
CNTL2 (2HB)	Mellor-Yamada-Nakanishi-Niino Level 3 [*Nakanishi and Niino*, 2004] / *Beljaars and Holtslag* [1991] / *Beljaars* [1994]
2HK	Mellor-Yamada-Nakanishi-Niino Level 3 [*Nakanishi and Niino*, 2004] / *Beljaars and Holtslag* [1991] / *Kondo* [1975]
2LB	Mellor-Yamada-Nakanishi-Niino Level 3 [*Nakanishi and Niino*, 2004] / *Louis et al.* [1982] / *Beljaars* [1994]
2LK	Mellor-Yamada-Nakanishi-Niino Level 3/ [*Nakanishi and Niino*, 2004] / *Louis et al.* [1982] / *Kondo* [1975]
2dd	*Deardorff* [1980], *Blackadar* [1962] / *Beljaars and Holtslag* [1991] / *Beljaars* [1994]
2ddLK	*Deardorff* [1980], *Blackadar* [1962] / *Louis et al.* [1982] / *Kondo* [1975]

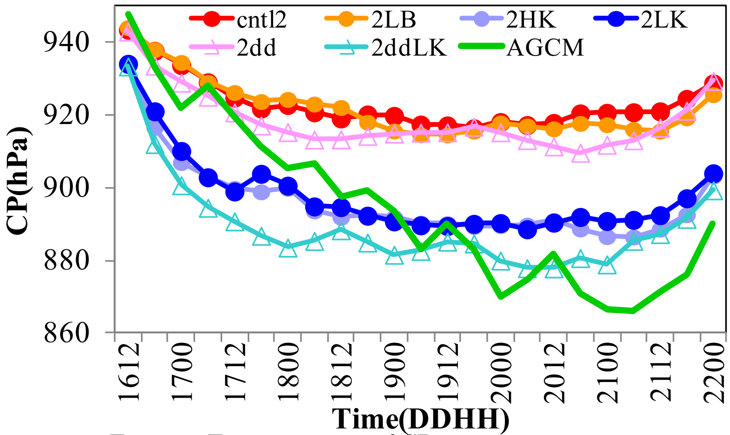

Figure 1 Time variation of CP.

The distributions of hourly precipitation amounts showed differences between the MYNN– and dd–experiments (Figure 2). At the most intense phase, a region of moderate precipitation exceeding 10 mm h^{-1} widely expanded on the eastern side of the TC center in MYNN–experiments (CNTL2 and LK: Figures 2a and 2c). On the other hand, a region of precipitation was relatively small in dd–experiments (2dd and 2ddLK: Figures 2b and 2d) and a region of intense precipitation exceeding 70 mm hr^{-1} concentrated around the inner–core. Radial profiles of 24–hourly mean azimuthally averaged winds revealed that large radial winds (V_r: inflow is represented by a positive value) exceeding 20 m s^{-1} were found in dd–experiments regardless the values of MCP (Figure 3d), while those in MYNN–experiments were smaller than 20 m s^{-1}. Tangential winds (V_t) were sensitive to the setting of z_0 (Figure 3c).

4 Summary and Remarks

Our results indicate that both the PBL and the surface roughness length (z_0) have a large impact on the structure and the development of an intense tropical cyclone (TC). The settings of z_0 have the largest impact on the rapid intensification of the simulated TC. In addition, differences among the experiments with two PBL schemes are found in the CP evolutions, horizontal distributions of precipitation and wind fields. Further analysis is required to study the essential factors for the development of an intense TC.

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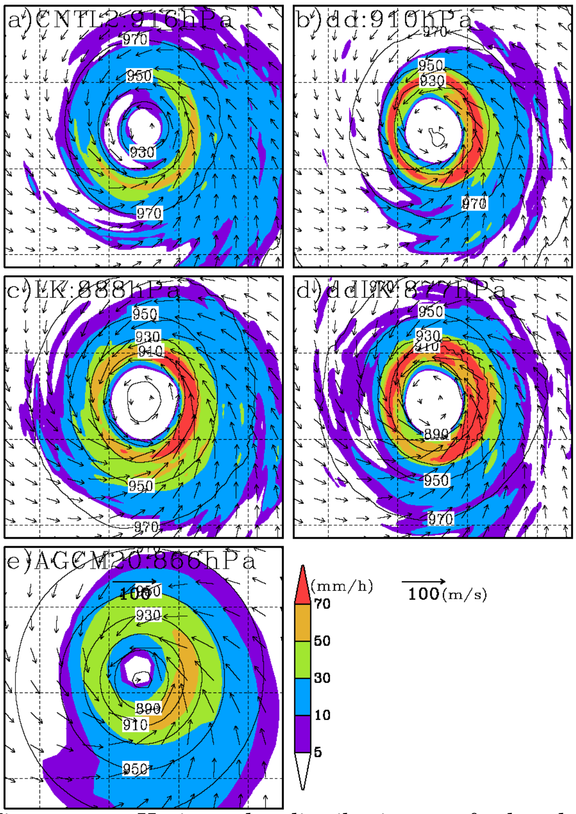

Figure 2 Horizontal distributions of hourly precipitation amounts in the 1 h preceding the most intense phase of the TC: a) CNTL2, b) 2dd, c) 2LK, d) 2ddLK and e) AGCM20. The MCP is indicated in each panel. Arrows indicate 10 m level winds.

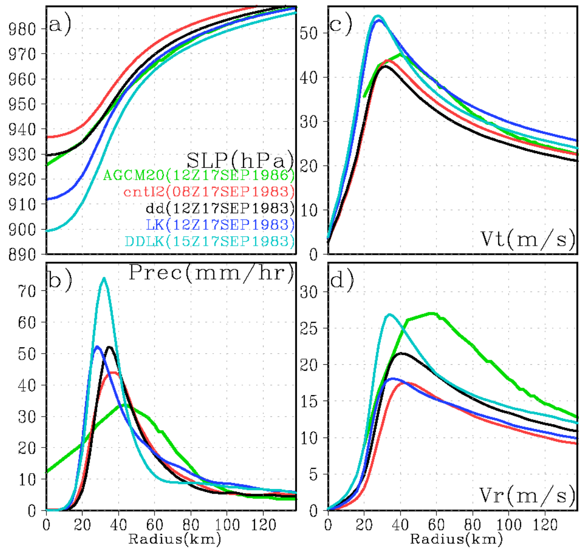

Figure 3 Radial profiles of 24-hourly mean azimuthally averaged a) sea level pressure, b) precipitation, c) tangential wind and d) radial wind speed at a height of 10 m during the rapid intensification phase. AGCM20: green, CNTL2: red, 2dd: black, 2LK: blue, 2ddLK: cyan.