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RAPID INTENSIFICATION OF TROPICAL CYCLONES IN THE NORTHWESTERN PACIFIC OCEAN

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1. INTRODUCTION

The rapid intensification (RI) is usually defined as the approximately the 95th percentile of the maximum wind speed (V_{max}) change in 24 hours in both Western North Pacific and Atlantic Oceans (Kaplan and DeMaria 2003; Shu et al. 2012; Hendricks et al. 2010), except Holliday and Thompson (1979) ever proposed to define RI with the 24-h variation of central sea-level pressure (P_{min}), i.e., $\Delta_{24}P_{min} \le -42$ hPa . With the best-track data from Japan Meteorological Agency (JMA) and the reanalysis dataset of the European Center of Medium Range Weather Forecasts (ECMWF) in the period between 1980 and 2013, the rapid intensification of tropical cyclone (TC) in the Northwestern Pacific area was examined in this study with the focus on the relationship between 24-h variations of V_{max} and P_{min}.

2. RESULTS

It is found that the rapid intensification processes in the tropical cyclones (TCs) in this study are divided into three categories, i.e., 1) both V_{max} and P_{min} vary dramatically in the 24 hours, so that the $\Delta_{24}V_{max}$ is greater than 30knot and $\Delta_{24}P_{min}$ is deeper than -35hPa (RIP group); 2) V_{max} strengthened significantly while P_{min} decreases slowly ($\Delta_{24}V_{max} \ge 30$ knot and $\Delta_{24}P_{min} > -35$ hPa) (SIP group); and 3) V_{max} enhanced slowly while P_{min} decreased abruptly ($\Delta_{24}V_{max} < 30$ knot and $\Delta_{24}P_{min} \le -35$ hPa). Categories 1-3 occupied 60.6%, 23.1% and 16.3% of the rapid intensification cases in the Northwestern Pacific in the past 33 years, respectively (Table 1). Besides, the cases only satisfying the wind speed change condition occurred nearly 1° north and 6° west of the other two groups.

TABLE 1. Characteristics of the TCs satisfying with two thresholds

	$\Delta V_{24} \ge 30$knots/day		$\Delta P_{24} \le -35$hPa/day	
Number	185		170	
Ratio (/868)	21.3%		19.6%	
	$\Delta P_{24} \le -35$hPa/day	$\Delta P_{24} > -35$hPa/day	$\Delta V_{24} \ge 30$knots/day	$\Delta V_{24} < 30$knots/day
Number	134	51	134	36
Ratio (/221)	60.6%	23.1%	60.6%	16.3%
Average Latitude	14.61°N	15.97°N	14.61°N	14.87°N
Average Longitude	140.13°E	134.93°E	140.13°E	141.82°E

The composite analysis shows that the RIP (Figs.1a and c) usually occurs under the conditions that the tropical upper-tropospheric trough locates in the near east of the storm and the western Pacific subtropical high is strong and locates in the north of the storm in the middle levels. The former favors the development of the "dual-channel outflow" in the upper troposphere while the later protect the storm from the intrusion of cold and dry air in the middle levels. Furthermore, the low-to-mid troposphere is very humid and exhibits evident cyclonic rotational tendency in the case of RIP. As a contrast, the large-scale background of SIP (Figs.1b and d) is featured with less moisture and weak cyclonic vorticity in the low-to-mid troposphere, relatively weak western Pacific subtropical high in the north and less evident tropical upper-tropospheric trough in the near east of the storm.

In the system scale, the storm experienced RIP is usually strong with large diabatic heating rate and the convection is nearly symmetric in the inner-core area

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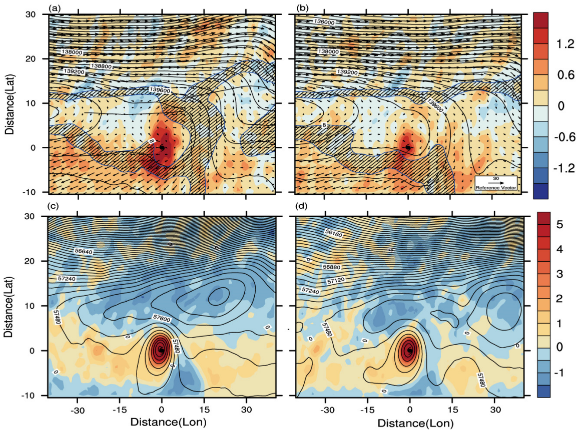

FIG. 1. The composites of (top) the 150hPa geopotential height at 20 gpm intervals (contour), vector winds and the divergence (shading, $10^{-5} m \cdot s^{-2}$) and the composites of (bottom) the 500-hPa geopotential height at 60 gpm intervals (contour) and the 850hPa relative vorticity (shading, $10^{-5} m \cdot s^{-2}$)for (left) RIP and (right) SIP group at time RI-00h. The black shadow is stand for the wind speed between 8 to 12m/s. The black typhoon symbol denotes the center of TC.

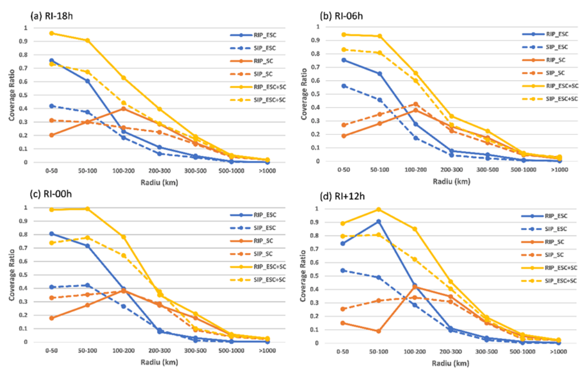

FIG. 2. The occurrence frequency of the strong convections (SC, orange), extremely strong convections (ESC, blue) and the convections (including SC and ESC, yellow) for (soild) RIP and (dash) SIP group at time (a) RI-18h, (b) RI-06h, (c) RI-00h and (d)RI+12h in radius.

(Fig. 2). According to the total number of extremely strong convection (ESC) and strong convection (SC) in two groups, it is clear that the structure in RIP was more symmetric than that in SIP. In the pre-RI stage (Figs.2a and b), the convections in the RI almost cover the whole inner core area, that is the coverage ratio within the 100km radius was above the 0.9, while the ratio in SIP was just around 0.7 at the RI-18h and increased to the 0.8 at the RI-06h. It should be notice that, at the onset of RI, strong and extreme strong convections were nearly covered the whole inner-core area in RIP, but in the SIP, the ratio within 50km radius dropped back to 0.7. As the intensification of the cyclones, the range of the symmetric area is larger in

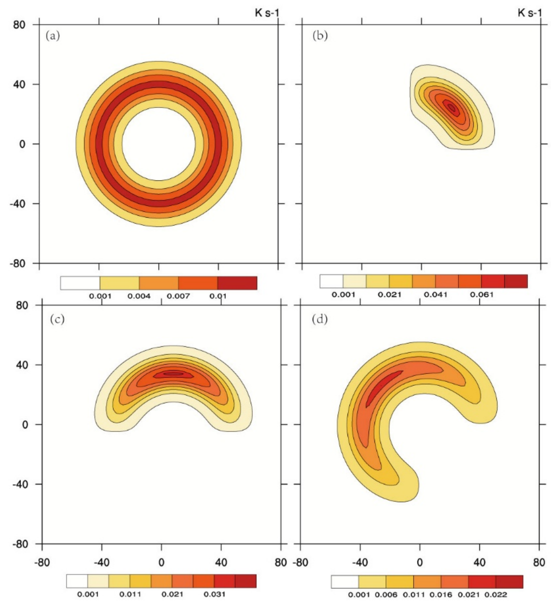

FIG. 3. The heating distributions of the convective heating fields at the height of 6km for (a) EXP_{sym}, (b) EXP_{asy}, (c) EXP_{asy2} and (d) EXP_{asy3} experiments.

RIP than the SIP. The hypothesis is proposed that the rapid increase of V_{max} and weakly decrease of P_{min} in SIP are basically induced by the asymmetry of inner-core deep convection which is influenced by the less favorable synoptic environmental conditions.

A dry but thermally forced version of the Weather Research and Forecasting Model (WRF) is used to clarify the effect of the symmetric and asymmetric diabatic heating on the rate of V_{max} and P_{min} change. By modifying the structure of heating sources, four experiments were conduced with symmetric (EXP_{sym}) and asymmetric (EXP_{asy}, EXP_{asy2} and EXP_{asy3}) heating (Fig. 3). Figure 4 shows the time distribution of the maximum wind speed in the lowest model level and the central surface pressure in each experiment. It is clear that the tendency and the magnitude of the maximum wind speed in four simulations are quite similar, while the final central surface pressure is pretty different. The $\Delta_{24}P_{min}$ is nearly 50-hPa in EXP_{sym}, which is nearly 30-hPa deeper than the $\Delta_{24}P_{min}$ (~20-hPa) in EXP_{asy}. The $\Delta_{24}P_{min}$ is about 25-hPa in EXP_{asy2} and about 30-hPa in EXP_{asy3} in final state. The difference of the central surface pressure variation and the uniformity of the maximum wind speed change in the four experiments indicates that the rapid increase of V_{max} and weakly decrease of P_{min} in SIP could be induced by the asymmetry of inner-core deep convection.

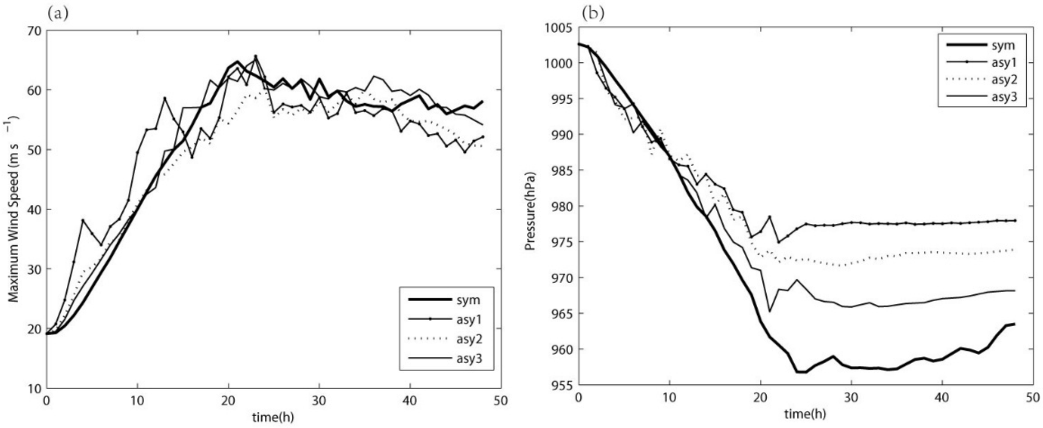

FIG. 4. The time distribution of (a) the maximum wind speed (m/s) in lowest model level and (b) the central sea surface pressure (hPa) in each experiments (EXP_{sym}, EXP_{asy}, EXP_{asy2} and EXP_{asy3}).

3. CONCLUDING REMARKS

Based on the JMA best-track data and the ECMWF reanalysis dataset, the rapid intensification of TC was examined in the Northwestern Pacific in this study. It is found that the 24-h changes of V_{max} and P_{min} could be asynchronous in the RI processes in Northwestern Pacific Ocean. Compare to the cases with slow variation in P_{min} but rapid increase of V_{max}, the synoptic environment condition was more favorable for the convective activity in the case with sharp decrease of P_{min} and fast increase of V_{max}. Moreover, the asymmetry of convection could lead to the rapid intensification of a TC featured with slow variation in P_{min} but rapid increase of V_{max}.

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