13D.4 EXTRATROPICAL TRANSITION OF WESTERN NORTH PACIFIC TROPICAL CYCLONES: MIDLATITUDE AND TROPICAL CYCLONE CONTRIBUTIONS TO RE-INTENSIFICATION

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1. INTRODUCTION

This study of extratropical transition (ET) of western North Pacific tropical cyclones (TCs) addresses the re-intensification stage during which the TC remnants develop as an extratropical cyclone. The hypothesis examined here is that re-intensification depends on the interaction between the midlatitude circulation contributions from mid-and upper-level dynamic processes, low-level thermal processes from the decaying TC, and upper-level outflow characteristics from the decaying TC. Re-intensification occurs when the combination of the dynamic and thermodynamic processes define a region that is favorable for extratropical cyclone development.

In prior studies of ET, re-intensification of the TC remnants has been described as being similar to Type-B extratropical cyclogenesis (Petterssen and Smebye 1971). In this framework, the TC (and associated low-level patterns of cold and warm advection) translate poleward to phase with a region of upper-level positive vorticity advection (PVA) that must exist in a midlatitude circulation pattern.

Based on a sample of 30 cases of ET (Klein et al. 2000) that occurred in the western North Pacific during 1 June through 31 October 1994-98, a region that is favorable for Petterssen-Smebye Type-B cyclone development is defined by a combination of upper-level PVA greater than 20×10^{-10} s^{-2} and a dipole of low-level temperature advection greater than +/-10 x 10^{-5} K s^{-1}. In previous studies of ET, upper-level divergence was also related to the interactions between the outflow from the decaying tropical cyclone and the midlatitude circulation. Because of this interaction and the possible influence of latent heat release associated with heavy precipitation during ET, upper-level divergence greater than 3×10^{-5} s^{-1} (threshold based on the Klein et al. 2000 sample) may also be included as a representative measure to define a region favorable for extratropical cyclone development. Hereafter, a region defined by any combination of these three forcing mechanisms will be referred to as a *development region*.

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2. ANALYSIS

The degree to which the midlatitude circulation is favorable for extratropical cyclogenesis during a particular case of ET is defined based on a simulation using an atmosphere-only version of the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS) in which the TC remnants have been removed (hereafter labeled NOTC). A midlatitude contribution to the re-intensification stage (Fig. 1) is defined when a development region is forecast to be favorable for extratropical cyclogenesis in a NOTC simulation such that an extratropical cyclone with a central sea-level pressure (SLP) less than 1000 hPa occurs. If no such region is forecast and yet weak (SLP>1000 hPa) extratropical cyclogenesis occurs, the midlatitude contribution is classified as neutral. When no region favorable for extratropical cyclone formation occurs in the NOTC simulation, the midlatitude contribution is classified as unfavorable.

The TC contribution to re-intensification is defined by first generating a control forecast. Additional forecasts are

Re-intensification Stage of ET	Midlatitude Contributions: Unfavorable	Neutral	Favorable
TC Contributions: Significant	Little or	Deep and/or Rapid Re-intensification	
Minor		Moderate	
None	Decayers		Re-intensification

Fig. 1 Characterization of the midlatitude circulation and TC contributions to the re-intensification stage of ET depicted as a matrix, where the combinations of these contributions may produce three outcomes: (i) deep and or rapid re-intensification (upper right; SLP at the end of ET< 980 hPa);(ii) little or moderate re-intensification (shaded boxes along the diagonal; SLP at the end of ET>980 hPa); or (iii) decay of the TC without completing ET (lower left). See text for the definition of midlatitude and TC contributions.

generated after displacing the initial TC position such that the interaction of the TC with the development region defined to be favorable for extratropical cyclone formation is altered. The objective is to achieve more (less) deepening relative to the control when the displaced TC produces more (less) interaction between the TC and the midlatitude extratropical cyclone formation region.

As an example, Typhoon (TY) Bart (Fig. 2) passed over southern Japan and the Sea of Japan to undergo ET in the Sea of Okhotsk. In the control simulation, the ET of TY Bart resulted in an extratropical cyclone with a minimum SLP of 984 hPa (Fig. 2b). Based on the NOTC simulation, the midlatitude contribution to ET was favorable since extratropical cyclogenesis with a central SLP<1000 hPa occurred. Therefore, TY Bart would be placed in the right column of Fig. 1. Since the control simulation did not result in deep and/or rapid re-intensification (control minimum SLP was not<980 hPa), the tropical cyclone contribution is considered minor.

In the initial conditions, the TC remnants were displaced northeast of the control position, which resulted in only a slightly weaker extratropical cyclone. Therefore, the relative contributions to ET were not different from the control simulation. When the TC remnants were displaced southwest of the control position, deep and rapid re-intensification occurred. The interactions between the TC remnants and midlatitude circulation defined by the development region were enhanced significantly such that the TC contribution became significant.

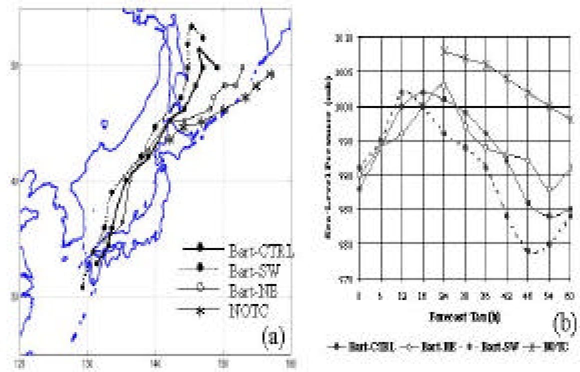

Fig. 2 The control, displaced-TC, and NOTC simulations in the case of TY Bart beginning at 0000 UTC 9 SEP 1999 depicting (a) the storm track at 6 h intervals, and (b) the SLP of each storm.

3 RESULTS

An important aspect of the interaction between the TC remnants and midlatitude circulations revealed by the simulation of TY Bart and other cases (not shown) is that the altered phasing of the TC vortex with the evolving midlatitude circulation modified their interaction later in the forecast sequence. In this context, phasing signified the contribution to Type-B cyclogenesis due to interactions between the mid- and upper-level dynamic contributions from the midlatitude circulation and low-level thermal advection and upper-level outflow characteristics associated with contributions from the TC remnants. In some of the simulations, the TC phased with the development region and achieved deep re-intensification after the initial displacement. In other displaced vortex simulations, the TC remnants failed to phase with the development region and either achieved moderate or little re-intensification or dissipated.

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REFERENCES

Petterssen, S., and S. Smebye, 1971: On the development of extratropical cyclones. *Quart. J. Roy. Meteor. Soc*., **97**, 457-482.

Klein, P. M., P. Harr, and R. Elsberry, 2000: Extratropical transition of western North Pacific tropical cyclones: An overview and conceptual model of the transformation stage. *Wea. Forecasting*, **15**, 373-395.