12D.2 SIMULATIONS OF THE EXTRATROPICAL TRANSITION OF TROPICAL CYCLONES: CONTRIBUTIONS BY THE MIDLATITUDE UPPER-LEVEL TROUGH

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1. Introduction

The extratropical transition of a tropical cyclone has been described as a continuous process that can be divided into two stages by Klein et al. (2002 – hereafter K02). The first stage, which they call *transformation*, includes the initial structural changes that a recurving tropical cyclone undergoes as it begins to interact with a pre-existing baroclinic zone and the associated vertical wind shear. If the transformed storm begins to re-deepen as a baroclinic cyclone, the second stage, which K02 call *re-intensification,* commences.

Prior studies of ET (e.g., DiMego and Bosart 1982) have described reintensification of the transformed tropical cyclone in terms of Type-B development following Peterssen and Smebye (1971). Klein et al. reason that if Peterssen-Smebye Type-B cyclogenesis is the method by which a transformed tropical cyclone re-intensifies during ET, the tropical cyclone (and low-level patterns of cold and warm advection) must translate poleward to phase with mid-level positive vorticity advection (PVA) that exists in a midlatitude circulation pattern. This lead K02 to define a “development region” as the region where any one of the three main factors in the Peterssen development equation (upper-level divergence, midlevel PVA, and low-level temperature advection) attains threshold values set as 3×10^{-5} s^{-1}, 20×10^{-10} s^{-2}, and $\pm 10 \times 10^{-5}$ K s^{-1}, respectively, based on their 30 case sample. Klein et al. assigned a value of one for each parameter that reached its threshold value, so a maximum possible development value of three indicates that the region has strong extratropical development potential.

The purpose of this study is to simulate the role of the midlatitude trough strength during the re-intensification stage of ET using interpretations based on the development region criteria of K02. Idealized simulations are used to examine how three trough strengths affect the transformation and subsequent reintensification of a tropical cyclone.

2. Methodology

Based on vertical profiles of the azimuthally averaged winds from 30 cases, a basic environment is specified to represent the baroclinic zone during extratropical transition. An upper-level potential vorticity perturbation is then added to the environment to represent the upper-level trough. The strength of the trough is varied from weak (15 m/s wind perturbation) through strong (35 m/s wind perturbation). To simulate the interaction between a tropical cyclone and midlatitude trough, a tropical cyclone vortex is inserted into the environment 15°S and 25°E of the upper-level trough. The tropical cyclone has been spun up for 48 h in a quiescent environment until the cloud fields are fully developed and the surface pressure is steady. An advective flow of 5 m/s from the southwest is added to the tropical cyclone circulation so that the initial motion is 5 m/s to the northeast.

Simulations are performed using the U.S. Navy Coupled Ocean-Atmosphere Model Prediction System that is described in detail by Hodur (1997). An ocean prediction model is not included in this study. The primitive equations are solved on a Lambert conformal grid, with a terrain-following σ-coordinate in the vertical. The model has 36 layers from σ=0 to 1, with the vertical boundaries at 30 km and the ocean surface. The model domain is configured with a coarse and fine mesh with grid spacing of 81 km and 27 km, respectively. The coarse domain of 87 x 93 grid points is large enough to allow an adequate representation of the idealized baroclinic zone during the integration. The fine domain of 124 x 190 grid points captures the primary structural modifications of the tropical cyclone as it interacts with the baroclinic environment.

3. Results

The interaction between a tropical cyclone and weak midlatitude trough represents the most extreme contrast of development when compared to the no-TC control simulations. In the comparable control, the midlatitude trough was so weak that almost no surface development (1003 mb) occurred during the integration period (Figs. 1a and 1b). When a transforming tropical cyclone was properly phased with the trough, then strong reintensification (967 mb) of the tropical cyclone remnants resulted (Figs. 1c and 1d). Not only was the surface pressure decrease during reintensification the largest of all simulations (31 mb), but it also had the longest period of rapid intensification (pressure falls >1 mb h^{-1}) (Fig. 2).

One key reason why the cyclone in the simulation with the tropical cyclone intensifies so much more than the trough-only simulation is due to differences in the upper-level fields. At 36 h, the trough- only and the trough-with-TC cases have similar upper-level patterns, and the jet maxima have comparable strengths, and are at about the same relative locations (not shown). However, the tropical cyclone center is still more than 1000 km south of the upper-level jet maximum. By 60 h,

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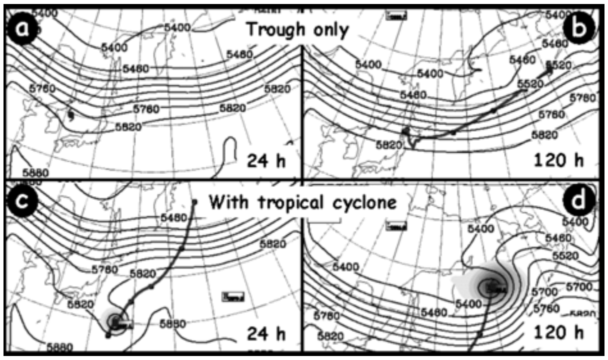

Figure 1. 500 mb height field (contours are 60 m) and surface pressure (shading 4 mb < 1000 mb) of a weak upper-level trough: a) 24 h; b) 120 h; and the interaction between a tropical cyclone and a weak upper-level trough c) 24 h; d) 120 h.

the maximum wind speed in the trough-only case is about 2500 km east of where the surface cyclone is in the tropical cyclone case, so that any development potential associated with divergence in the upper-level jet maximum is far away. However, the maximum wind speed in the tropical cyclone case is just east of the development region, and this maximum speed has increased more than 15 m s^{-1} compared with the trough-only case (not shown). This increase is because the warm upper-tropospheric outflow associated with the tropical cyclone interacts with the polar jet stream (e.g., DiMego and Bosart 1982) such that the horizontal temperature gradient below the jet increases and the height of the adjacent tropopause increases. As the wind speed in the jet maximum increases, the associated upper-level divergence increases. Thus, it appears that upper-level divergence is considerably enhanced in the development region by the outflow from a tropical cyclone compared to the simulation with no tropical cyclone present.

The enhancement of the upper-level divergence in the trough-with-TC case compared with the trough-only case results in a substantial increase in the areal extent and strength of the development potential (Fig. 3). Whereas only weak development potential is predicted at 24 h and 48 h for the trough-only simulation (Figs. 3qand 3b), much stronger potential is predicted when a tropical cyclone is included (Figs. 3c and 3d). In addition, the trough-with-TC case is already indicating enhanced development associated with the trough portion of the domain at 48 h (Fig. 3c) when compared with the trough-only case (Fig. 3b). This enhanced development potential is directly associated with the increased jet dynamics due to the outflow of the tropical cyclone interacting with the upper-level trough.

The development potential is enhanced for the trough-with-TC case (Fig. 3d) until about 120 h, when the system begins to occlude, and by 128 h it approaches its maximum intensity of 967 mb (Fig. 2) and begins to weaken. Based on these and other simulations, the development region parameter provided a good indication of the potential for intensification of the extratropical cyclone both with and without a tropical cyclone. However, more study is needed to determine if a critical value can be found to predict when periods of rapid intensification may occur. In the presentation, more discussion of the effects of differences attributed to the midlatitude circulation will be provided.

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4. References

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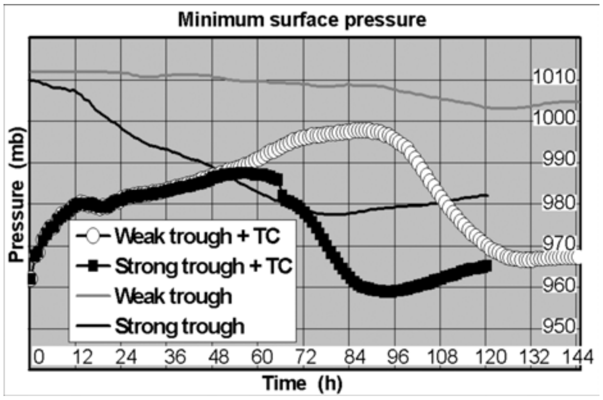

Figure 2. Time series of the minimum surface pressures for two trough-only and two troughs with a tropical cyclone.

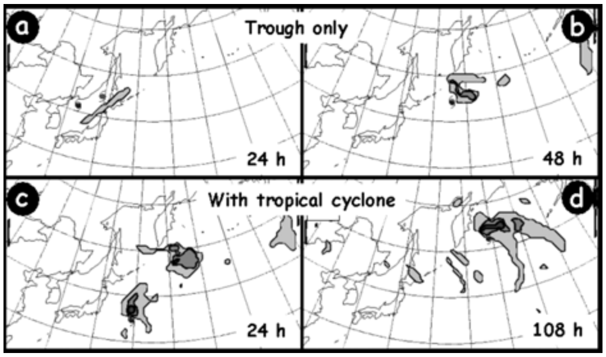

Figure 3. Development potential based on the three main factors in the Petterssen cyclogenesis development equation proposed by K02: trough-only at (a) 24 h and (b) 48 h; and trough-with-TC at c) 48 h; and d) 108 h.