Reply

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DeMaria and Chan's (1984) comments on my paper on the Fujiwhara effects of tropical cyclone pairs (Chang, 1983, hereafter referred to as Paper I) raises two questions: 1) Do two barotropic vortices merge? 2) Are the diabatic effects and the associated irrotational component of the circulation responsible for the merging of the tropical cyclones? I will try to answer them separately.

DeMaria and Chan (1984) brought up a point, concerning the first question, that I did not dwell on in Paper I. I hope my paper did not leave the impression that *no* barotropic vortex pair will ever merge from *any* initial separation distance. The values of r_c for the two types of vortices in Paper I are approximately 250 and 300 km (as shown in Fig. 2 of Paper I). I decided not to show in my paper the merging of the vortices with initial separation distances smaller than r_c, because two distinct circulation centers cannot be reasonably identified due to their proximity. The vortex pair that DeMaria and Chan showed to have merged (Fig. 3 in their comments) have a very slow decay of tangential winds and therefore, it is hard to distinguish the two vortices even at a separation distance of 500 km. The streamfunction for such vortex pairs have four contours encompassing the two vortices and no cutoff contours (Fig. 1). It is unlikely that two vortices will be initiated in the atmosphere so close together, nor will they form somewhere else and converge by barotropic process from a distance greater than r_c. The relevancy of the experiment conducted by DeMaria and Chan to the interaction of two tropical cyclones is questionable.

As for the second question, one additional numerical experiment was conducted. Results from that experiment are subsequently presented and discussed to further illustrate that the divergent components in tropical cyclones are crucial for the merging of a tropical cyclone pair. As shown in Fig. 2, the radial distribution of the quasi-steady wind speeds of the three-dimensional model tropical cyclone (Fig. 4 in Paper I) falls between the $b = 0.5$ and 1.0 vortices discussed by DeMaria and Chan (1984). It is conceivable that the $b = 0.5$ type vortex pair will have the strongest interaction due to its slow decay of tangential winds. Experiment 1, as discussed in Paper I, was

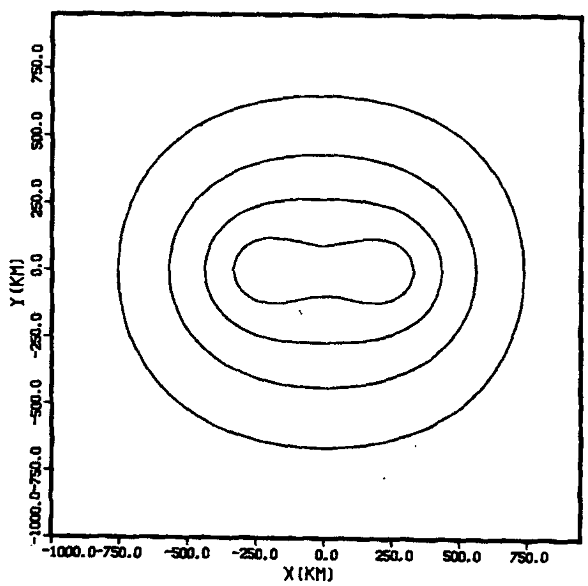

FIG. 1. The streamfunction for a $b = 0.5$ type vortex pair at a separation distance of 500 km. Contour intervals are 4×10^6 $m^2 s^{-1}$.

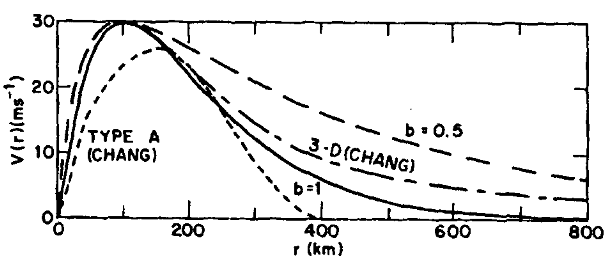

FIG. 2. The radial distributions of tangential winds for $b = 0.5$ and $b = 1.0$ vortex types defined in DeMaria and Chan's (1984) comment, type A vortex (Chang, 1983) and the three-dimensional (3-D) model tropical cyclone in Chang (1983).

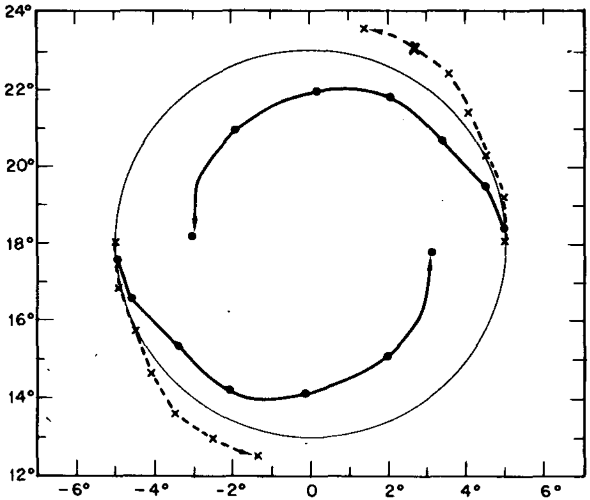

FIG. 3. Storm tracks (heavy solid lines) of Exp. 1 [shown in Fig. 8 in Chang (1983)] and of the $b = 0.5$ type vortex pair (dashed lines) suggested by DeMaria and Chan. Locations of storm centers are dotted at 12 h intervals. It is clear that the pair in Exp. 1 attracted each other while the pair of the $b = 0.5$ type did not. The circle has a radius of 5°.

repeated except that the $b = 0.5$ type vortex pair was initialized by a standard nondivergent, nonlinear initialization scheme. All diabatic effects, including heating, surface friction and horizontal diffusion, were suppressed in the tropical cyclone model to prevent the growth of nonrotational components. The storm tracks (dash lines) are plotted in Fig. 3, superimposed on those of Exp. 1 of Paper I (Fig. 8 of that paper). The tracks were clearly divergent; and the speed of the mutual rotation was much slower in spite of the stronger swirl winds of the $b = 0.5$ vortices. The conclusion in Paper I that the irrotational components of the circulation associated with tropical cyclone pairs are crucial for their merging, thus remains unchanged. This should not be interpreted, as in DeMaria and Chan's (1984) comments, that the vorticity advection is unimportant in the interaction processes; merely, that the diabatic effects and the associated irrotational components are the overriding factors for merging of tropical cyclone pairs.

Corrigendum. Please note, there should be a minus sign in the exponential term in Eq. (6) of Paper I.

REFERENCES

Chang, S. W., 1983: A numerical study of the interactions between two tropical cyclones. *Mon. Wea. Rev.,* **111,** 1806–1817.
DeMaria, M., and J. C. L. Chan, 1984: Comments on "A numerical study of the interactions between two tropical cyclones." *Mon. Wea. Rev.,* **112,** 1643–1645.