Comments on "Comparison of Tropical Cyclone Motion and Environmental Steering"

SIMON WEI-JEN CHANG
Science Applications, Inc., McLean, VA 22102

RANGARAO V. MADALA
Naval Research Laboratory, Washington, DC 20375

2 September 1981 and 20 August 1982

In a recent paper, Brand *et al.* (1981) investigated the directional deviation of paths of northwestern Pacific tropical cyclones from steering currents, which were defined as the temporal and spatial means of the 500 mb geostrophic winds surrounding the tropical cyclones. The results were presented for areal boxes of 5° latitude × 10° longitude between 2.5–52.5°N and 95°E–175°W. By averaging the values in the areal boxes, they concluded that the tropical cyclones move, on the average, at an angle of 6° to the *left* of the steering currents. However, the large variations in their computed directional deviations (from 37.6° biased to the right, to 32.7° biased to the left) lead us to suspect the propriety of using 500 mb geostrophic flows as the steering currents, especially in low latitudes. They have also neglected other parameters that can affect the motions of tropical cyclones.

Contrary to the conclusions of Brand *et al.*, analytical and numerical studies have indicated that tropical cyclones tend to move to the *right* of the basic currents. Earlier analytical models (e.g., Yeh, 1950; Kuo, 1969) investigated the interactions between solid, rotating vortices and the uniform basic currents. Results from these studies have established that the motions of atmospheric vortices embedded in uniform currents consist of a trochoidal oscillation, due to the magnus effect, and a mean path biased to the right of the basic current, resulting from the surface drag.

Tropical cyclones, of course, are not best represented by solid vortices, but later numerical experiments on *f*-planes with three-dimensional models have substantiated the findings of the above-mentioned analytical studies. For example, Jones (1977) conducted a numerical experiment with an initial uniform basic current of 10 m s^{-1} to study the motion of a hurricane. He found that as the domain for calculating the average current increased to a radius of 600 km, the average current became invariant. The invariant average current was then defined as the steering current, which corresponded to the initial basic current, except for in the boundary layer where the flow was retarded. The model hurricane in Jones (1977) translated at an angle 5° to the right of the steering current. Recently, Chang and Madala's (1980) investigation confirmed Jones' results that tropical cyclones travel at 5° to the right of the mean current over ocean of uniform temperature.

Numerical experiments also show that the latitudinal variations of the Coriolis parameter introduce northwestward drifts to the movements of tropical cyclones. Madala and Piacsek (1975) demonstrated that the path of their model hurricane on a β-plane is to the right of the eastly steering current, which was defined as the pressure-weighted mean current within the model domain. Most recently, Tuleya and Kurihara (1982) found all westward traveling tropical disturbances, with intensities ranging from a weak easterly wave to a tropical cyclone, have northward displacements in their paths. These results are in agreement with other numerical investigations (e.g., Anthes and Hoke, 1975; Kitade, 1980).

We note that results from these models agree at least qualitatively with each other despite the vast differences in spatial resolution, numerical technique and physical parameterization. One can draw the following conclusions based on the numerical studies (for Northern Hemisphere):

1) The relative magnitudes of the surface and lateral frictions in a tropical cyclone are equivalent to a right bias in its paths.
2) The beta effect causes a *northwestward* shift.
3) The pressure-weighted mean current out to a radius of at least 600 km may be the steering current.

Based on these results, the frictional and the beta effects enhance the rightward bias in a westward moving tropical cyclone, and the two effects oppose each other in a eastward moving tropical cyclone. Therefore, differentiation between the eastward and west-

0027-0644/82/122070-02$04.50

ward storms must be made in studying the relationship between the storm tracks and steering currents.

It is interesting to note that the results in Brand *et al.* seem to indicate that the tropical cyclones' movements have, despite their ill-defined steering currents, a right bias in low latitudes and a left bias in high latitudes. This may simply be because that in their movements most tropical cyclones have a westward component in low latitudes and an eastward or northward component in high latitudes. Numerical experiments are now being undertaken to examine this conjecture.

There are many other effects, such as topography and ocean surface temperature, which can cause local anomalies in tropical cyclones' movements. In analyzing observational data, one must be very cautious in defining the steering current, in stratifying the data, and in sorting out the influence of various factors. The steering of tropical cyclone is an interesting topic in tropical meteorology, but a consensus from the modeling and observational approaches is yet to emerge. We hope our note will call attention to the discrepancy and bring about more research in this area.

REFERENCES

Anthes, R. A., and J. E. Hoke, 1975: The effect of horizontal divergence and the latitudinal variation of the Coriolis parameter on the drift of a model hurricane. *Mon. Wea. Rev.*, **103,** 757–763.

Brand, S., C. A. Buenafe and H. D. Hamilton, 1981: Comparison of tropical cyclone motion and environmental steering. *Mon. Wea. Rev.*, **190,** 908–909.

Chang, S. W., and R. V. Madala, 1980: Numerical simulation of the influence of sea surface temperature on translating tropical cyclones. *J. Atmos. Sci.*, **37,** 2617–2630.

Kitade, T., 1980: Numerical experiments of tropical cyclones on a plane with variable Coriolis parameter. *J. Meteor. Soc. Japan*, **58,** 471–488.

Kuo, H. L., 1950: The motion of atmospheric vortices and the general circulation. *J. Meteor.*, **7,** 247–258.

——, 1969: Motions of vortices and circulating cylinder in shear flow with friction. *J. Atmos. Sci.*, **26,** 390–398.

Jones, R. W., 1977: Vortex motion in a tropical cyclone model. *J. Atmos. Sci.*, **34,** 1518–1527.

Madala, R. V., and S. A. Piacsek, 1975: Numerical simulation of asymmetric hurricane on a β-plane with vertical shear. *Tellus*, **27,** 453–467.

Tuleya, R. E., and Y. Kurihara, 1982: A note on the sea surface temperature sensitivity of a numerical model of tropical storm genesis. *Mon. Wea. Rev.*, **110,** 2063–2069.

Yeh, T. C., 1950: The motion of tropical storms under the influence of a super-imposed southerly current. *J. Meteor.*, **27,** 108–113.