An objective method to diagnose the contribution of steering flow at each level to tropical cyclone motion

Mitsuru Ueno
Typhoon Research Department, Meteorological Research Institute
e-mail: mueno@mri-jma.go.jp

Tropical cyclone (TC) motion is one of the most important forecasting issues both in the numerical weather prediction (NWP) and operational forecasting. Even with the state-of-the-art NWP models significant disagreements can be sometimes observed in TC track forecast among them although it has been believed that TC movement is primarily determined by the large-scale flow field and therefore should be well predicted with such models. A number of numerical studies demonstrate that the evolution of TC vortices is highly sensitive to the formulation of convective heating. So in this study our primary concern lies in (1) how significantly the environmental flow fields are affected by the formulation of convective heating, (2) whether or not asymmetric convective heating directly and significantly drives the TC vortices, and (3) how much the difference in vortex structure is responsible for the track difference.

In order to clarify the role of convective heating in TC motion, we conducted an idealized experiments using an f-plane version of a numerical prediction model, in which a tropical cyclone is embedded in a vertically sheared environment. A wide variety of TC motion shows up in the presence of the vertical shear, depending upon the formulation of convective heating (Ueno 2000). A preliminary analysis of the experimental results suggests that the difference not only in the steering flow but also in the axisymmetric structure of simulated TCs is responsible for the diversity of simulated TC motions. The latter's contribution can be defined by a set of weighting factors (referred to as steering weight) which is mathematically derived from surface pressure tendency equation and reflects upon the thermal structure of the individual vortex. Letting the steering weight at k-th model layer W_k and the steering flow at the same layer $\mathbf{v}_k$, the steering component of three-dimensional TC motion $\mathbf{v}_{STR}$ may be expressed as

$$\mathbf{v}_{STR} = \sum_{k=1}^{k\max} w_k \mathbf{v}_k \Delta\sigma_k \ , \ \Delta\sigma_k \equiv \Delta p_k / p_{srf}$$

where Δp_k is thickness in pressure of k -th model layer and p_{srf} is pressure at the sea surface. Figure 1 shows the vertical profile of the steering weight averaged over the integration period of 72 hours for two extreme track cases in Fig.1 of Ueno (2000), that is, B&M (experiment with Betts and Miller scheme) and KUR (experiment with Kurihara scheme). The profiles seem reasonable in that the weight is very small at the highest two layers near the tropopause, which is consistent with previous observational studies. Note that the two profiles significantly differ each other in the troposphere. Once we get the steering weight W_k , the steering motion component $\mathbf{v}_{STR}$ is easily computed using the steering flow $\mathbf{v}_k$ which is defined as an areal-mean asymmetric flow near the storm center. Figure 2 compares the track reproduced from hourly $\mathbf{v}_{STR}$ with "actual" one which is obtained as successive MSLP center locations. To see the impact of steering weight on the reproduced track, the tracks obtained by using mismatched steering weight (i.e., KUR-weight for B&M and B&M-weight for KUR) are shown in the same figure. The result demonstrates that the long-term vortex motion is well reproduced by the proper combination of the steering weight and steering flow. An additional experiment shows that the steering weight is somewhat inherent to the convection scheme used and robust against the change of environment. Details of the discussions may be found in Ueno (2002).

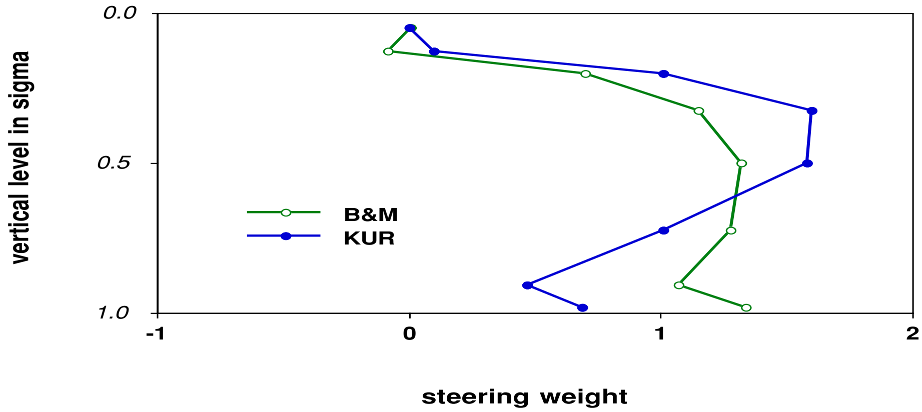

Figure 1: Vertical profile of steering weight. Symbols are put at each model level.

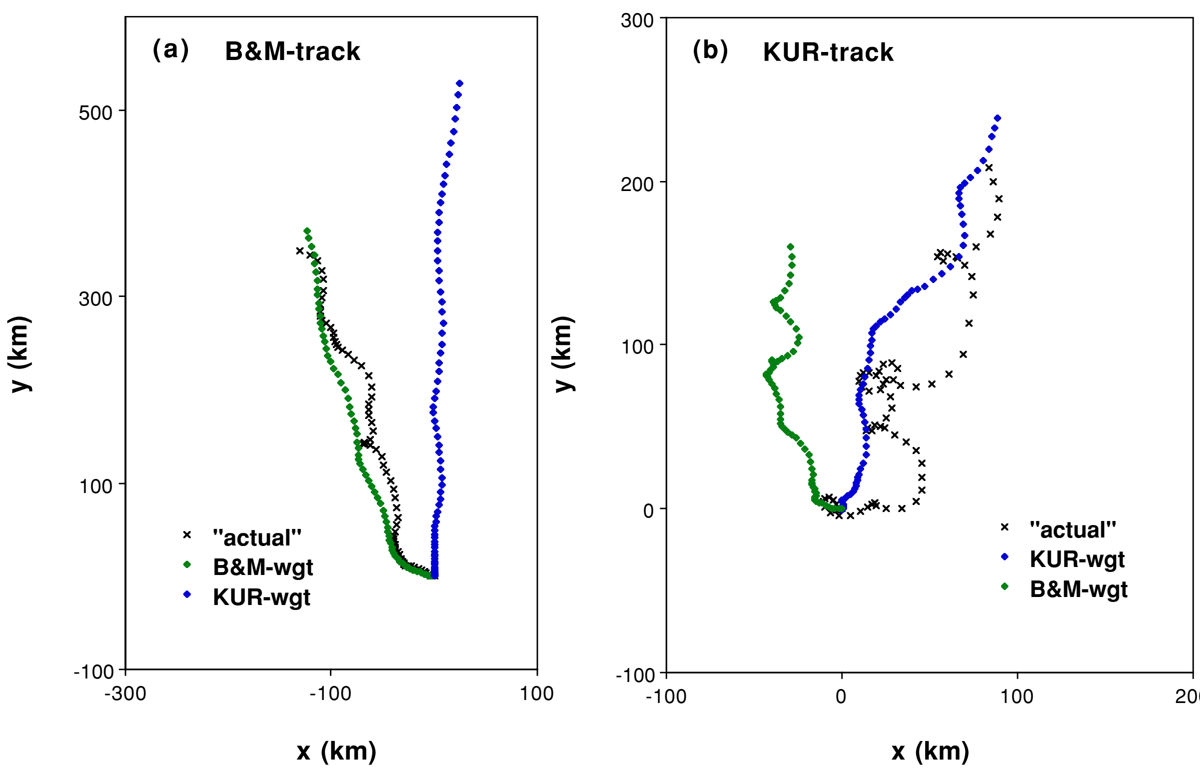

Figure 2: Vortex tracks reproduced from velocity components for (a) B&M and (b) KUR. The vortex is placed at (0,0) initially and symbols indicate hourly positions up to 72 h.

References

Ueno, M., 2000: Impact of upper-level flow on the tropical cyclone motion in a vertically sheared ambient flow. *WMO/TD-No.987*, 5.39-40.

Ueno, M., 2002: Steering weight concept and its application to tropical cyclones simulated in a vertical shear experiment. Submitted to *J. Meteor. Soc. Japan*.