A strong dependency of simulated TC structure on model physics: Steering-weight perspective

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In an attempt to diagnose the mechanism by which a typhoon moves through vertically sheared environmental flows with keeping its vertical coherency, a series of idealized numerical simulations of typhoon are carried out and eventually a new approach termed "steering weight concept" was proposed based on the numerical results (Ueno 2003). The steering weight is a set of weighting factors numerically derived from the surface pressure tendency equation and can be a measure of the relative contribution of the steering flow at each vertical level to the storm motion. The weight varies significantly depending on the simulated storm structure, and is somewhat inherent to the convection scheme used.

In this paper the inherent aspect of steering weight is examined through some real typhoon simulations. The simulations are performed using the Meteorological Research Institute / Numerical Prediction Division unified nonhydrostatic model with an Arakawa-Schubert cumulus parametrization scheme (AS) or an explicit moisture scheme only (EX). It should be noted that the model uses so-called z* coordinate in the vertical and therefore the model variables are defined on constant height surface over the sea, allowing us to calculate the steering weight in a straightforward manner.

The steering weight $\boldsymbol{W_{sx}}$ (or $\boldsymbol{W_{sy}}$) at a model level is calculated from simulated thermodynamic fields based on a least-square-minimum approach as follows;

$$\boldsymbol{W}_{sx} = \boldsymbol{p}_{sc}/\rho_{c} \times \sum_{i,j}\left[\mathbf{u}\cdot\nabla_{h}\rho\times\partial\boldsymbol{p}_{s}/\partial\boldsymbol{x}\right] \Big/ \sum_{i,j}\left(\partial\boldsymbol{p}_{s}/\partial\boldsymbol{x}\right)^{2}$$

$$\boldsymbol{W}_{sy} = \boldsymbol{p}_{sc}/\rho_{c} \times \sum_{i,j}\left[\mathbf{u}\cdot\nabla_{h}\rho\times\partial\boldsymbol{p}_{s}/\partial\boldsymbol{y}\right] \Big/ \sum_{i,j}\left(\partial\boldsymbol{p}_{s}/\partial\boldsymbol{y}\right)^{2}$$

$$\mathbf{u}\equiv\mathbf{i}+\mathbf{j}$$

where $\mathbf{i}$ and $\mathbf{j}$ are unit vectors in the x- and y-directions, respectively, and $\boldsymbol{p_s}$ and ρ are surface pressure and air density at the level, respectively. $\nabla_{\boldsymbol{h}}$ is the horizontal gradient operator applied with height held constant. Suffix $\boldsymbol{c}$ denotes that the quantity is evaluated at the storm center. The summation is performed all over the grid points $(\boldsymbol{i},\boldsymbol{j})$ within a radius of 350 km from the center. The quantity $\boldsymbol{p_{sc}}/\rho_{\boldsymbol{c}}$ is a kind of adjustment parameter necessary to correctly evaluate the steering contribution of the flow at each level from the steering weight in conjunction with the mass-weight. The quantity could be evaluated differently (e.g., by using areally-averaged values instead of those at the center) but with an insignificant impact on the resulting weight values. Although $\boldsymbol{W_{sx}}$ and $\boldsymbol{W_{sy}}$ take generally different values each other, the difference is very small for tropical cyclones at the mature stage because of their near-axisymmetric structures. For simplicity, we use a mean value as steering weight in the present study.

Figure 1 shows the vertical profile of the steering weight averaged over the whole integration period of 39 hours for the two types of experiments (AS and EX). For the AS group the results from the model runs with different setting of tuning parameters (i.e., lowest cloud base height and adjustment time) are presented together in the figure. On the other hand, target typhoon or horizontal resolution is different each other in the members of the EX group. The figure suggests that the weight is largely controlled by and inherent to the formulation of moist process, although it is found from other experiments that such a parameter as entrainment rate significantly affects the weight in the AS group (not shown). The gross features of the weight profile are primarily determined by the warm core structure of simulated TCs. To demonstrate the close relationship between the two, vertical cross sections of temperature anomaly obtained from the two types of experiments are presented and compared in Fig. 2.

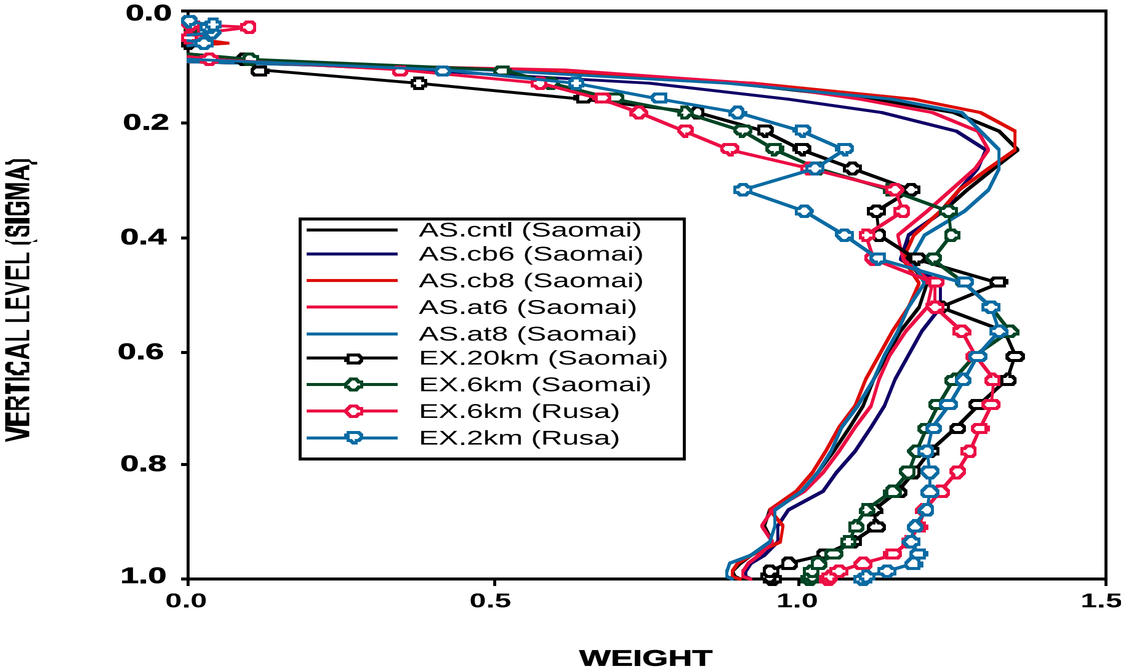

Figure 1: Vertical profile of steering weight.

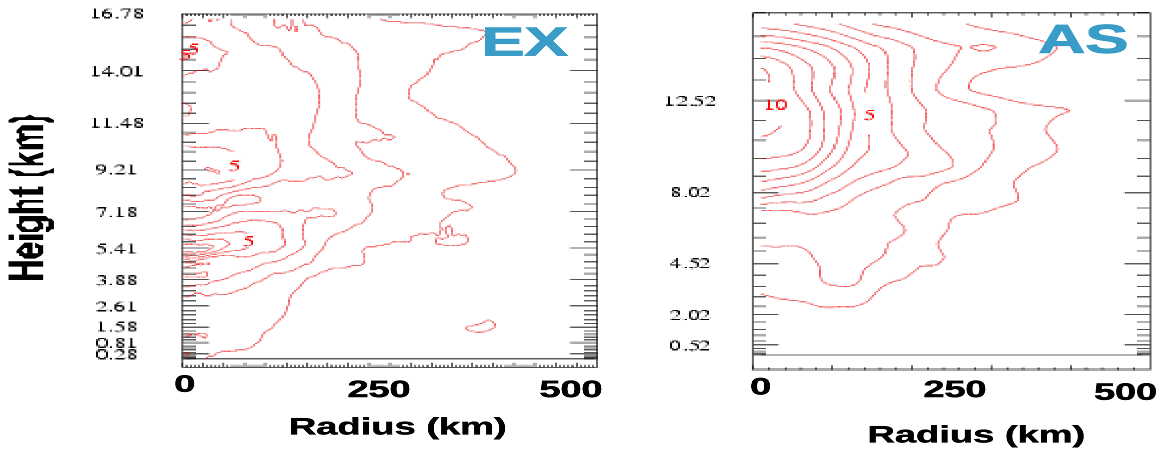

Figure 2: Vertical cross section of temperature anomaly at the 36-h simulation time for AS and EX.

Reference

Ueno, M., 2003: Steering weight concept and its application to tropical cyclones simulated in a vertical shear experiment. ***J. Meteor. Soc. Japan*****, 81**, 1137-1161.