On the phase and amplitude of shear-induced wavenumber-one convective asymmetry in the inner-core region of tropical cyclones

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It is well known that mature tropical cyclones exhibit highly axially symmetric structure in the core with respect to the center. On the other hand, previous observational and numerical studies have shown that convective activities tend to be enhanced on a side of the eyewall rather than evenly significant in the eyewall annulus. Some of the studies attributed the convective asymmetry to the ambient vertical wind shear in which the storms were embedded. However, the precise mechanisms by which the environmental shear controls the convective asymmetry are not yet clearly established. In the present study, the factors to determine the phase and amplitude of wavenumber-one vertical motion asymmetry are investigated separately for each of the phase and amplitude.

As for the amplitude, a simple analytical formula for the magnitude of shear-induced wavenumber-one vertical motion at the radius of maximum wind was derived as a function of both the shear and storm strengths, based on the thermal wind balance consideration (Ueno 2007a). To examine the validity of the derived analytical formula, a set of idealized numerical experiments were performed (ditto). It was found from the validation study that very high correlation coefficients are calculated between rainfall asymmetry and analytical vertical motion, suggesting that both the shear and storm strengths are dominant factors in determining the magnitude of rainfall asymmetry. In the present study, the validation is extended to a real data simulation for the case of Typhoon Chaba in 2004. Figure 1 compares the analytical vertical motion with the simulated one over the entire integration period. Although the analytical formula tends to significantly underestimate the simulated omega due to diabatic enhancement of simulated vertical motion fields, the correlation coefficient between analytical and simulated omega is as high as 0.78, while that between shear itself and simulated omega is 0.44. Higher coefficient for the analytical omega is consistent with Ueno (2007a) and confirms that the vortex structure parameters as well as shear are contributing factors to the vertical motion asymmetry.

As for the phase, it is known from previous observational and numerical studies that convective activities tend to be enhanced on the downshear-left side of storms rather than just downshear. To discover the processes that govern the directional preference, a Lagrangian trajectory approach is applied to the numerical model data. The results suggest that asymmetric water vapor distribution caused by shear-forced vertical motion is a primary factor to locate the rainfall maxima on the downshear-left side rather than right downshear of the storm center. Figure 2 shows a horizontal plan view of net moisture changes due to vertical motion and diabatic processes (left) and resultant moisture asymmetry (right) at a midtropospheric level. While moisture increase tends to occur downshear due to shear-induced upward motion there, high moisture area is found about 90° of azimuth counterclockwise from the azimuth of the net moistening maximum (i.e., on the downshear-left side) due in part to horizontal advection. The moisture asymmetry could account for the simulated convective asymmetry. Details of the present study can be found in Ueno (2007b).

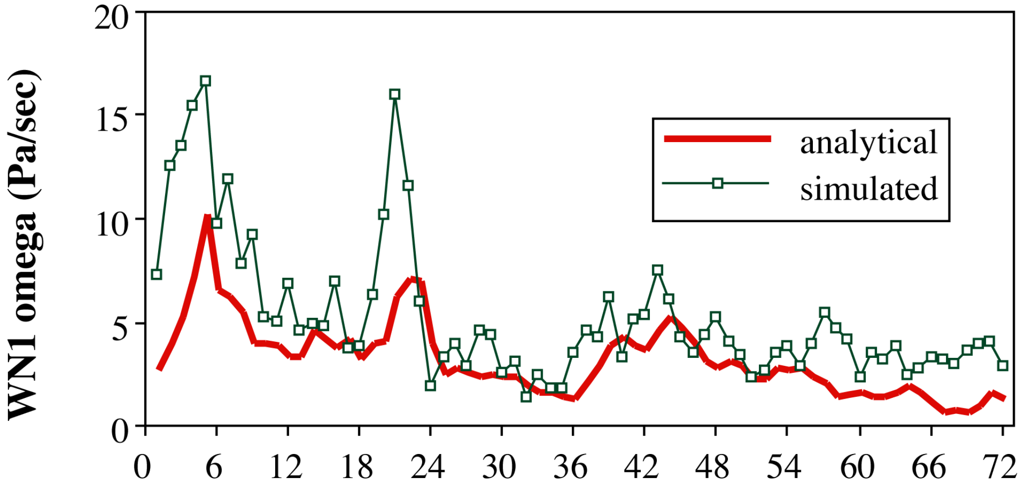

Figure 1: Comparison of "analytical" (thick red line) and model-simulated (thin green line with open squares) wavenumber-one omega (i.e., vertical p-velocity in units of Pa s^{-1}) at RMW and at 700 hPa. The horizontal axis denotes the integration time.

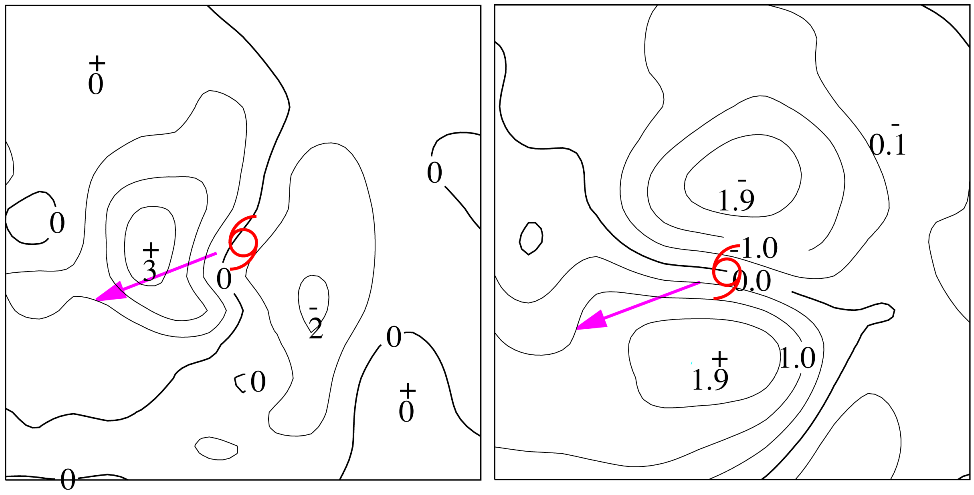

Figure 2: 6-hour composite from 24 to 30 h of simulation for specific humidity change at 5350 m due to vertical motion plus diabatic processes in units of g Kg^{-1} h^{-1} (left) and asymmetric specific humidity field at the same altitude in units of g Kg^{-1} (right). Plotted domain is 280 km x 280 km in size and the arrow indicates the direction of mean shear vector during the period.

References

Ueno, M., 2007a: Observational analysis and numerical evaluation of the effects of vertical wind shear on the rainfall asymmetry in the typhoon inner-core region. ***J. Meteor. Soc. Japan*, 85**, 115-136.

Ueno, M., 2007b: Effects of ambient vertical wind shear on the inner-core asymmetries and vertical tilt of a simulated tropical cyclone. Submitted to ***J. Meteor. Soc. Japan.***