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Atmospheric Chemistry and Physics Discussions

Interactive comment on "The vorticity budget of developing Typhoon Nuri (2008)" *by* D. J. Raymond and C. López Carrillo

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Recommendation: accept after minor revision

This study examines the vorticity dynamics of the tropical cyclone formation using radar data and dropsonde data. The vorticity budget diagnosis identified the spinup and spindown processes at different stages of the storm evolution, and illustrated the important role of a closed Lagrangian circulation: In the precursor disturbance of Nuri, a closed circulation retained vorticity inside and spawned a tropical cyclone; in TCS30, the vorticity flux was exported outside and this wave failed to develop. This is consistent with Dunkerton et al. (2009), Montgomery et al. (2010) and Wang et al. (2010), which showed that the Kelvin cat's eye within the wave critical layer provides a favorable environment for vorticity aggregation for tropical cyclone formation.

One question that is not answered in this study is how the "pre-existing tropical-depression-scale circulation" forms within the wave disturbance. It was stated in section 4: "Intensification of a tropical cyclone in shear thus takes on the character of a "chicken and egg" problem; in order for spinup to occur, there must be a pre-existing broad distribution of relative vorticity through the low to middle troposphere. However, creation of this vorticity anomaly is difficult without protection against ventilation by the environment." I would like to point out here that the formation of a meso-alpha scale closed circulation, or the so-called wave "pouch" (Dunkerton et al. 2009), does not rely on the convective processes. Or in other words, a wave critical layer is a kinematic structure of the wave due to the nonlinear interaction between the wave and the ambient flow, instead of being generated by convection (although convection can enhance the cat's eye circulation). The dry idealized simulations in Montgomery et al. 2010 (ACP, in press) showed that the cat's eye circulation can develop even without moist processes. In the real atmosphere, the cat's eye circulation provides a favorable local environment for convection development and is also enhanced by convection.

The authors also discussed the displacement or vertical tilt of the tropical-depression-scale circulation induced by the vertical shear. In the schematic in Fig. 20, three motions of different spatial scales are displayed: the system-relative ambient wind, the synoptic-scale wave motion (associated with the broad region of positive relative vorticity), and the tropical-depression-scale circulation. An implicit assumption is that the wave structure and propagation speed do not change with height, which is a reasonable assumption for many waves. On the other hand, some waves do have different structures and propagation speeds at different vertical levels. As shown in Dunkerton et al. 2009, the vertical shear of the ambient flow may help bring a tilted structure to vertical alignment.

The authors also suggested that the overlapping area (in Fig. 20) is likely the location for TC genesis because it is protected from environmental intrusion between the PBL and 5 km. I agree that a closed circulation of sufficient depth, for example, extending from the mid-to-lower troposphere to the PBL, is likely a necessary condition for tropical cyclone formation, but I picture the wave pouch as a material entity of certain depth, which is resilient to moderate vertical shear and can still protect the moist air within even if it has a vertical tilt. When convection becomes more active, the wave pouch will become more vertically aligned, and the center of the closed circulation is likely to fall in the overlapping area, where the vorticity centroid of the (3D) wave pouch is.

Specific points:

1. P16591: "Postulating a steady state flow in which the tilting term is ignored in the vorticity equation leads". Is it worth mentioning that this assumption is most likely to be valid in the PBL, where convergence (and thus the stretching term) is strong and vertical wind shear (and the tilting term) is relatively weak?

2. P16592: "In any case it is this balance, when evaluated in a storm-relative frame, which applies to a steady or nearly steady tropical cyclone if vortex tilting is insignificant." Can this balance be applied to tropical cyclone development, which is not a steady process?

3. P16593: "As we shall see, this may be a plausible assumption in the very earliest stages, but it is incorrect in the tropical storm stage." I appreciate the first author's professional attitude to criticize his own work.

4. P16594: "This supports the hypothesis of Dunkerton et al. (2009) that the region of the wave at the critical latitude is favored for development due to the weak wave-relative winds and the lack of import of dry environmental air at this latitude." The closed circulation within the wave critical layer is also a region of weak deformation, which favors vorticity aggregation for tropical cyclone formation.

5. What time does the track start in Fig. 1? At the TW stage or during the first mission, the track shows many zigzags, and the uncertainty of the propagation speed seems larger than $\pm 1 \mathrm{ms}-1$. Also note that the propagation speed during mission 1 (table

1) is much smaller than those in the following three missions. If a larger propagation speed were used in Fig. 4, the low-level circulation may be better defined and the 5-km circulation center would shift northward to the more convective region.

6. "The 1.2 km circulation centers are listed in Table 1 and shown Fig. 1." Add period before this sentence.

7.Fig. 10: As shown in Fig. 4-6, the closed circulation is displaced with height, and the circulation centers are also off the domain center. The storm-generated wind would thus contribute to the averaged wind in the domain. The vertical shear may be overestimated.

8. P16605: "The pattern of vorticity transport in TCS030 is not closed, allowing vorticity maxima in the PBL to be exported from this system." Fig. 14 actually indicates the presence of a closed circulation at 1.2 km, but a closed circulation is absent at 5 km. This suggests the important role of a closed circulation above the PBL, which can protect the moist air within from dry air intrusion.

9. In Nuri 3 (Fig. 17) the stretching term weakens in the lower troposphere compared to Nuri 2. Fig. 2 shows that M2 took place after a convective burst. The weakening of the low-level stretching is probably due to the contribution of the stratiform processes. M1 and M3 also took place during the cloud top warming period. If the flight missions had taken place during an active convection phase, we should see a larger contribution from the stretching term.

10. "In the tropical storm stage (Nuri 3) the PBL inflow was less strong overall, resulting in a net spindown tendency in the PBL" The authors attributed this to a decrease of the spatial scale during the TS stage. However, as shown in Figs. 16-18, area-averaged vorticity keeps increasing. The spindown may be temporary and associated with the time of mission 3 (the decay phase of a convective burst). Again, if the flight missions had taken place during an active convection phase, we should see a larger contribution from the stretching term. The question is how typical the vorticity budget in Fig. 17 is

for a tropical storm stage?

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