ACPD-15-8479-2015
Responses to Reviewer 3 (Prof. C. Rozoff)
Date: 9 July 2015

Title: A numerical study of convection in rainbands of Typhoon Morakot (2009) with extreme rainfall: roles of pressure perturbations with low-level wind maxima
Authors: C.-C. Wang, H.-C. Kuo, R. H. Johnson, C.-Y. Lee, S.-Y. Huang, and Y.-H. Chen

1. General comments:

This manuscript documents a numerical simulation of Typhoon Morakot on 8 August 2009, during its multi-day historic interaction with Taiwan in which catastrophic flooding occurred, due in part from the repeated formation and west-to-east passage of intense convective cells that impacted a significant proportion of Taiwan, particularly the southern half of Taiwan. The numerical simulation of this study produces a realistic simulation of the rainband activity observed in Morakot on 8 August. The authors focus on the back-building behavior and merger of cells within within east-west-oriented rainbands that impinged upon the Central Mountain Range at a time in which such convective cells were particularly vigorous. A pressure perturbation analysis applied on a characteristic convective cell clearly shows the local shear vector (associated with a strong low-level jet) produced a favorable dynamic pressure perturbation force that favored upstream development of new updraft, a slowing of mature convection, and thereby a favored mechanism for convective updraft mergers. This is an excellent study that likely applies to many more tropical cyclone cases than this particular Morakot example. I therefore enthusiastically recommend that the manuscript should be published after some minor revisions. The minor revisions are listed below as specific comments and are only meant to enhance the current analysis, which appears to be sound overall.

Reply:

We appreciate the positive views and critical comments from all three reviewers, and have revised the paper accordingly. Among the changes, we have (1) added the diagnostic results at 0645 UTC (besides 0630 UTC) to show a dominant and persistent effect from the dynamical pressure perturbation in the mature cell, (2) employed 10-min radar CAPPI data at 3 km to show the back-building and merging behavior of convective cells, and (3) estimated the contribution from convection versus stratiform clouds over Taiwan plain area in the event. In addition, the figures are polished and font sizes enlarged, the method of diagnosis is validated, the scale of the low-level jet is clarified, the cold pool is examined, and the evolutions of model convective cells are discussed in more detail, as suggested.

The changes in the manuscript are marked in red, blue, and green for Reviewer 1, Reviewer 2, and Reviewer 3, respectively. The modifications made by ourselves during the revision are in orange (mostly to correct mistakes), and those made during the production stage of ACPD since our first submission (to meet the format requirements) are in pink. The point-by-point responses to each of the comments/suggestions from this reviewer are listed below.

2. Specific comments:

1. In several of the figures, axis, contour, and colorbar labeling is very difficult to read due to small font size (e.g., Figs. 2, 10-15 are very difficult, and Figs. 1b, 3a, 7, 9 are marginal). Please consider resizing the fonts to be more legible.

Reply:

All the figures in question are improved in font size to be more legible, as suggested.

2. p. 8489, l. 6-8: An interesting question that arises is what percentage of the accumulated rainfall is accomplished by the intense cells that are the focus of this study vs. the more widespread stratiform rain associated with the rainbands (seen in all panels of Fig. 7)? This is not an essential question to answer in revisions, but, as a suggestion, if the calculation is readily available, it may bolster the practical significance of this study.

Reply:

The rainfall on 8 August from deep convection versus stratiform over the plains is estimated using hourly rain-gauge data, and is described in the revision, as suggested. For sites over the southwestern plains with a 24-h total rainfall amount of ≥700 mm on 8 August, at least 84% (and up to 95%) came from convective rainfall with an intensity of 20 mm h^{-1} or more. Thus, the practical significance of the present paper can indeed be enhanced.

3. Fig. 10b. It is easy to see that this convective cell does not produce an intense cold pool characteristic of some storms (such as midlatitude continental convection), but it is difficult to conclude whether there may be a weak cold pool or not. It seems conceivable even a 0.5 to 1-K magnitude cold pool (not uncommon in moist tropical cyclones) could produce some low-level lift, but such a cold pool would be difficult, if not impossible, to see in Fig. 10b. If possible, it might be nice to see a snapshot or two of the lowest model level's temperature field in the box shown in Fig. 7a at 0630

UTC with sufficiently small contouring intervals to discern the magnitudes of “cold” pools produced here.

Reply:

A new plot (Fig. 11) is produced for detailed examination of possible cold pool, as suggested. The results show only very weak cold pool (with surface temperature deficit within 0.5 K) and the weak outflow cannot reach the location of new cell development, and these results are described and discussed in the revision. The work of Yu and Chen (2011) is also cited for a comparison with the cold pool strength in the present case.

4. p. 8493, l.4: Equation (9) is not linearized.

Reply:

Corrected in the description, as suggested.

5. p.8493, l.6: This is the anelastic approximation, but not quite the Boussinesq approximation since the density is a function of height in the continuity equation. The fourth fluid extension term would disappear in eqn (13) in a Boussinesq fluid.

Reply:

Corrected in the description, as suggested.

6. This analysis may benefit from presentation (or verbal explanation) of the temporal evolution of vertical motion forcing mechanisms. For example, do the relative vertical motion forcing mechanisms (dynamic PGF, buoyant PGF, and buoyancy) maintain relative proportions of magnitude throughout the lifecycle of a given convective cell and/or birth of a new cell? This may help demonstrate also whether there are feedback loops. For example, higher buoyancy (even if transient) could induce stronger dynamic and buoyant pressure perturbations. Likewise, as I think is somewhat alluded to in this analysis (Fig. 14), the shearing terms in the dynamic pressure perturbation equation may induce a vertical motion pattern that reinforces the fluid extension term in a positive feedback loop. The temporal perspective may provide a deeper intuition into these complexities.

Reply:

In the revision, the diagnostic results associated with cell A1 at 0645 UTC are also shown in a new figure (Fig. 17) and compared with those at 0630 UTC (Figs. 15 and 16), as suggested. The results show similar patterns and the effect from p_d' continue to dominate over those from buoyancy and p_b' at the rear side of A1 (mature cell), so that they are persistent throughout the mature stage. The time evolution of the pair A1 and A2 after 0630 UTC is shown in Fig. 8, and it is described in more detail in relation to the results of dynamical pressure diagnostics in the revision, as suggested. It is noted that cell A1 maintains its strength through 0645 UTC, in agreement with the vertical PGF induced by p'_d. It is also noted that by strengthening the upward acceleration in the updraft, the shearing terms appear to also act to reinforce the fluid extension term (EX3) in Eq. (13), as suggested.

7. Fig. 15 is a very important figure that really brings together the manuscript as it clearly illustrates the impacts of the pressure perturbation forces vs. buoyancy on the vertical accelerations, particularly the importance of the dynamic PGF induced by the strong vertical shear structure. Still, in reference to the discussion on p. 8498, I recommend plotting the sum of the buoyancy and buoyant pressure perturbation gradient force alone (i.e., B - d pb / dz) as a separate panel, since it does appear that throughout a significant portion of the updraft, the buoyancy term B still dominates the buoyant pressure perturbation gradient force. Typically buoyancy dominates the PGF associated with buoyant pressure perturbations in mature updrafts in other idealized studies of convection.

Reply:

A new panel showing the sum of the buoyancy and buoyant pressure perturbation gradient force (in the vertical) has been added in Fig. 16 as Fig. 16d (old Fig. 15) as suggested, and the related description is also modified accordingly. In the newly-added Fig. 17, their sum (total buoyant effect) is also shown for 0645 UTC.

3. Technical corrections:

1. Eqn (13): The friction term from eqn. (12) mysteriously drops.

Reply:

Corrected in the description as suggested.

2. p. 8493, l.17: Simplify/spell check “are the Piosson equations of the laplacian of” to just “Poisson’s equations of” since the Laplacian operator is implicit to Poisson’s equation, by definition.

Reply:

Corrected and simplified as suggested.