Reply to G. Zhang on "Interaction between dynamics and thermodynamics during tropical cyclogenesis" by S. Gjorgjievska and D. J. Raymond

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G. Zhang's comments are in black. Author's comments are in blue.

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The existence of the interactions between thermodynamics and dynamics in tropical cyclone development has been long speculated. This study explores some of the most intriguing aspects related with the interactions between thermodynamics and dynamics during cyclogenesis, using the data from two recent field campaigns. The authors insightfully linked the stratification with the vertical mass flux and thus the convergence of mass, vapor and vorticity. Furthermore, this link was nicely used in supporting the "top-down" perspective of tropical cyclone development, which features with the mid- level vortex that tends to stabilize the atmosphere. This study also suggests some counter-intuitive ideas on TC genesis, e.g., the enhanced low-level vorticity aggregation can spin down the protective mid-level pouch circulation, given certain stratification profiles.

The last sentence of the above paragraph is not a true statement. In this study we found that more stable troposphere is linked to a stronger low-level vorticity convergence, but have not implied how does the low-level vorticity convergence affects the mid-level vortex. This subject becomes more important in a mature, warm core vortex and we have not speculated anything regarding this in the current manuscript.

The paper was also written with great clarity and overall reads very smooth. The following are some comments and questions:

1. In the original draft and the reply to Dr. John Molinari, the authors have shown considerable efforts in addressing the subjectivity of averaging area choice when analyzing individual disturbances. But in some circumstances this subjectivity can become a more severe issue.

I agree that in some circumstances the subjectivity in choosing areas for analysis can become a more severe issue. Though, this goes for objectively selected areas too (as discussed in the manuscript). We don't think this is an issue in our analysis, however, since the areas chosen cover most of the convective activity associated with the respective disturbances.

Wang (2012) demonstrates some interesting sensitivity related with the area of averaging in its Fig. 12. In Karl's case, the vertical profile of equivalent potential temperature seems to evolve differently when the wave pouches were examined on different spatial scales. This is not a surprise, as the vortex axis of Karl was tilted. In this case, the results will be influenced by the choice of the level of the pouch center around which the averaging is done. Wang chose the 850 hPa level pouch center. This means that the smaller averaging box does not enclose much, if any of the upper level circulation centers. This discrimination among levels becomes less pronounced when averaging is done over larger areas, because a larger fraction of vorticity at other levels enters the picture. In Gaston's case, the vertical profiles calculated with a smaller averaging area appear quite different from those with a bigger averaging area. Besides, a bigger averaging area tends to include more stratiform precipitation samples and potentially contribute to a vertical profile that seems more "top-heavy". The sensitivity may also have different implications for the "top-down" and "bottom-up" perspective. For example, the numeric simulation in Wang (2012) suggests "bottom-up" development follows the very brief "top-down" period and dominates the ensuing development on the mesobeta scale (its Fig. 2a).

Gaston 1 had only small area with convective activity. Outside the black box in Fig. 10 of our manuscript, there was no convective activity. No updrafts or downdrafts. The black box encloses the updrafts as well as updraftes. The vertical mass flux profile averaged over the black box is different than that one averaged over the red box, but it is still bottom-heavy (the red line in Fig. 1b in our manuscript represents an average over the black box) and does not affect our conclusions.

As for "top-down" vs. "bottom-up" development, in the case of Karl was clearly observed that the low-level vorticity did not start increasing until the mid-level vortex developed.

Since this paper mainly focuses on the meso-alpha scale, this aforementioned sensitivity probably will not hurt the conclusions. Nevertheless, it remains interesting to check whether the vertical profiles in this paper will show sensitivity on the size of averaging areas.

We do believe that all the convection within the disturbance plays a role. Therefore, this sort of sensitivity test is not appropriate for this manuscript.

Wang, Zhuo, 2012: Thermodynamic Aspects of Tropical Cyclone Formation. J. Atmos. Sci., 69, 2433–2451.

2. Line 3-5 on Page 18924: Could you offer more details that link the strong stratification with bottom-heavy mass flux? You may want to consider adding a brief but self-contained discussion of Raymond and Sessions (2007) to better illustrate the context. The current discussion of the context seems scattered and inadequately emphasized for readers who are less familiar with topic. Alternatively, a nice scheme figure that illustrates the theory will also be welcome.

Thank you for this suggestion. I consider adding a paragraph in the revision. Raymond and Sessions (2007) did an experiment using a cloud resolving model. They were perturbing moist radiative-convective equilibrium profile and were doing weak temperature gradient simulations with the perturbed profiles. They found that when negative temperature perturbations were applied in the lower troposphere, and positive temperature perturbations in the upper troposphere, the resulting mass flux experienced maximum at lower elevations, and it had larger magnitude.

3. Could you speculate whether the link between stratification and vertical mass flux (as well

as the convergence) works for more mature tropical cyclones? Emanuel (2012) speculates that major properties of tropical cyclones depend on small-scale turbulence in the outflow, which acts to set the thermal stratification of the outflow. Physically, this bears some similarity with the case in the genesis stage.

Emanuel, K., 2012: Self-stratification of tropical cyclone outflow: Part II: Implications for storm intensification. J. Atmos. Sci., 69, 988-996.

There must be a link between the thermodynamic stratification and convective vertical mass flux anywhere in the atmosphere. The question one should ask is how significant is this link in a mature tropical storm that has already asquired large inertial stability. I can't speculate anything regarding this, as I have not done much research with mature storms.

4. Relevant with Comment 3, the vertical temperature profiles (thus the stratification) are modulated by convection and storm dynamics. A possibility is, the driver in the feedbacks may vary with the storm development or the genesis condition, e.g., the environment temperature profiles may dominate the feedbacks when convection is weak, but become a more passive component in the feedbacks given strong convective activity grown from the feedbacks or the impacts of pre-existing convective activity. Therefore, the stratification emphasized in this study seems not necessarily contributed or caused by a mid-level vortex alone.

For the scales we are looking at in this study it is less likely that convection dictates the temperature profiles, even though it probably has some influence. Raymond (2012) did potential vorticity inversion. He used the observed potential vorticity from Nuri (2008) and did potential vorticity inversion to calculate the balanced potential temperature. For storm scales, the calculated ballanced potential teperature was close to the observed potential temperature, which suggests that the meso scale vorticity causes the thermodynamic stratification on these scales.

Raymond, D. J., 2012: Balanced thermal structure of an intensifying tropical cyclone. Tellus-A, 64, 19181, doi.org/10.3402/tellusa.v64i0.19181.