Reply to "Comments on 'Symmetric and Asymmetric Structures of Hurricane Boundary Layer in Coupled Atmosphere–Wave–Ocean Models and Observations'"

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In our original paper Lee and Chen (2012, hereafter LC12) we documented the three-dimensional (3D) structure in Hurricane Frances's (2004) boundary layer using both observations and a coupled atmosphere–wave–ocean model, namely, the University of Miami Coupled Model (UMCM). Zhang et al. (2014, hereafter Z14) raised a few questions mainly on some perceived differences between LC12 and a previous study by Zhang et al. (2011, hereafter Z11). We stand by our original results and conclusions and provide some specific responses to Z14. The following numbers are corresponding to the sections in Z14:

1) Much of the introduction in Z14 is not directly relevant to the questions raised in the comments, but mostly citations of the authors' own work and self-promotion.
2) The question raised by Z14 regarding the analysis of hurricane inflow in LC12 is a moot point. LC12 used $-2\,\mathrm{m\,s^{-1}}$ as a criteria for the top of the inflow layer (Figs. 15 and 16 in LC12), which is about the same as the 10% criteria used in Z11. The azimuthally averaged inflow shown in LC12 is in good agreement with that of Z11, as we stated clearly in LC12, p. 3588. However, the actual 3D inflow field showed a strong asymmetric structure that has a highly variable inflow depth around the storm. The azimuthally averaged (axisymmetric) inflow structures in Z11 and LC12 are consistent. The key difference is that LC12 showed the actual 3D structure of the inflow in both observations and model simulations, whereas Z11 did not.
3) Both LC12 and Z11 are peer-reviewed publications. The two studies showed different aspects of hurricane boundary layer. LC12 simply pointed out the fact that the azimuthally averaged field in Z11 cannot represent highly asymmetric, 3D fields in some hurricanes, which is a fundamental limitation of Z11. We trust that readers can make their own judgments on the peer-reviewed publications.
4) The asymmetry in the mixed-layer depth, especially over the hurricane-induced cold wake, is clearly a coupled phenomenon. LC12 has shown that the observed asymmetry in Hurricane Frances (2004) is reproduced in the coupled atmosphere–ocean model simulations, whereas there is no such asymmetry in the uncoupled atmospheric model. Chen et al. (2013) shows that the asymmetry in surface winds is strongly affected by the asymmetry in the hurricane-induced surface wave and stress fields in Hurricane Frances (2004), which have a direct impact on friction-induced inflow. To our knowledge, there is no existing parameterization in the atmospheric model that can represent the complex asymmetric structure in the upper ocean and surface waves/stress and their influence on hurricanes.
5) Z14 mischaracterized the results in LC12 as from a single storm, a single model, and a single planetary boundary layer (PBL) scheme. The authors of Z14 would have been better served if they had actually read through section 5 in LC12 before making their comments. In fact, in addition to Hurricane Frances (2004), LC12 has also shown the coupled model simulations of Hurricane Floyd (1999) and Typhoon Choiwan (2009). While the two hurricanes (Frances and Floyd) were simulated using the same coupled model [UMCM, coupled with the fifth-generation Pennsylvania State University–National Center for Atmospheric Research Mesoscale Model (MM5), WAVEWATCH III (WW3), and the three-dimensional Price–Weller–Pinkel (3DPWP) upper-ocean model (UMCM-MWP)] with the Blackadar

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PBL scheme, the Typhoon Choiwan simulation was conducted using a different model: the coupled Weather Research and Forecasting–3DPWP model (WRF-3DPWP) with the Yonsei University (YSU) PBL scheme (UMCM-WP; Lee and Chen 2014). Figure 17 in LC12 showed a comparison of all three tropical cyclones. The inflows in all three cases are highly asymmetric and more than 5–10 km in depth in the rear to left quadrants. These results are consistent with observations shown in LC12 and Kepert (2006a,b).

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REFERENCES

Chen, S. S., W. Zhao, M. A. Donelan, and H. L. Tolman, 2013 Directional wind–wave coupling in fully coupled atmosphere–wave–ocean models: Results from CBLAST-Hurricane. *J. Atmos. Sci.,* **70,** 3198–3215, doi:10.1175/JAS-D-12-0157.1.

Kepert, J. D., 2006a: Observed boundary layer wind structure and balance in the hurricane core. Part I: Hurricane Georges. *J. Atmos. Sci.,* **63,** 2169–2193, doi:10.1175/JAS3745.1.

——, 2006b: Observed boundary layer wind structure and balance in the hurricane core. Part II: Hurricane Mitch. *J. Atmos. Sci.,* **63,** 2194–2211, doi:10.1175/JAS3746.1.

Lee, C.-Y., and S. S. Chen, 2012: Symmetric and asymmetric structures of hurricane boundary layer in coupled atmosphere–wave–ocean models and observations. *J. Atmos. Sci.,* **69,** 3576–3549, doi:10.1175/JAS-D-12-046.1.

——, and ——, 2014: Stable boundary layer and its impact on tropical cyclone structure in a coupled atmosphere–ocean model. *Mon. Wea. Rev.,* **142,** 1927–1944, doi:10.1175/MWR-D-13-00122.1.

Zhang, J. A., R. F. Rogers, D. S. Nolan, and F. D. Marks Jr., 2011: On the characteristic height scales of the hurricane boundary layer. *Mon. Wea. Rev.,* **142,** 2523–2535, doi:10.1175/MWR-D-10-05017.1.

——, M. T. Montgomery, F. D. Marks Jr., and R. K. Smith, 2014: Comments on "Symmetric and asymmetric structures of hurricane boundary in coupled atmosphere–wave–ocean models and observations." *J. Atmos. Sci.,* **71,** 2782–2785, doi:10.1175/JAS-D-13-0207.1.