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Composite Analysis on Structure of Tornado-spawning Tropical Cyclones Using CAPE Including the Effects of Entrainment

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Previous statistical studies on tornadoes associated with tropical cyclones show that they occur most frequently in the right-front quadrant of the cyclones, where storm-relative environmental helicity (SREH) is large. However, their occurrences are not necessarily consistent with the distribution of CAPE, which is large in the right-rear quadrant. The present study examines the structure and environment of typhoons that spawned tornadoes in Japan, and shows that CAPE including effects of entrainment explains the tornado occurrences well.

35 tornadic typhoons (TTs) and 199 non-tornadic typhoons (NTs) that had similar strength and geographical locations are selected from the best track data of typhoons and the tornado database of the Japan Meteorological Agency between 1991 and 2012. CAPE and SREH are calculated using the Japanese 55-year Reanalysis and their distributions are composited by superposing typhoon centers with their moving directions aligned. In the calculation of CAPE, effects of entrainment on lifted parcels are considered by the method of Romps and Kuang (2010).

CAPE calculated with no entrainment (hereafter CAPE_{00}) is large on the outer region of the right-rear quadrant of the composited typhoons. This distribution of CAPE_{00} is not consistent with that of observed tornadoes. On the other hand, CAPE calculated with an entrainment rate of ε = 20% km^{-1} (hereafter CAPE_{20}) is large in the right-front quadrant, which is consistent with locations of tornadoes. This occurs because both the high equivalent potential temperature in the boundary layer and abundant moisture in the mid-troposphere contribute to the large CAPE_{20} in the quadrant. Furthermore, CAPE_{20} in the right-front quadrant for TTs is larger than that for NTs, where the difference is statistically significant even at the 1% level according to a Welch's t-test. This difference between TTs and NTs mainly reflects the fact that the temperature at a height of about 5 km in the right-front quadrant for TTs is slightly lower than that for NTs.

If CAPE_{20} instead of CAPE_{00} is used for calculating energy helicity index (hereafter EHI_{20} and EHI_{00}, respectively), the distribution of EHI_{20} is found to give much better agreement with the tornado occurrences than that of EHI_{00} does in the case of TTs. Since both SREH and CAPE_{20} in the right-front quadrant for TTs are larger than those for NTs, EHI_{20} for TTs is much larger than that for NTs. These results imply that a CAPE including effects of entrainment is an appropriate parameter for measuring potential strength of convection in a tropical cyclone environment and a combination of veering shear and thermal instability work together to generate mini-supercells and associated tornadoes.