18–22 September 2017, Pula, Croatia
ECSS2017-106


# Entrainment rate of typhoon-associated supercells estimated by a large eddy simulation

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In Japan, about 20 percent of tornadoes are spawned by typhoons, which are tropical cyclones (TCs) having a maximum wind larger than 17 m $s^{-1}$. Occurrences of TC-spawned tornadoes are known to be concentrated in the northeast quadrant of TCs or the right-front quadrant with respect to their moving direction. Previous climatological studies revealed that the spatial distribution of storm-relative environmental helicity (SREH) around the TC center is consistent with that of tornado occurrences, and thus SREH seems to be a useful parameter for assessing the risk of TC-spawned tornadoes. On the other hand, convective available potential energy (CAPE) generally becomes large in the southeast side of the TC and does not explain the distribution of tornadoes. Recently, our study showed that CAPE including the effects of entrainment of environmental air (entraining CAPE: E-CAPE) well account for the distribution of tornado occurrences and distinguish typhoons that spawn tornadoes and that do not (Sueki and Niino, 2016, *Geophysical Research Letters*), where an entrainment rate of 20% $km^{-1}$ is shown to give the best agreement between the spatial distributions of tornado occurrences and E-CAPE. However, since this entrainment rate is based on indirect evidence, we need to examine the actual entrainment rate for supercells associated with typhoons.

In the present study, we have studied the entrainment rate for a supercell in a typhoon-associated tornado environment using a large eddy simulation (LES). The horizontally-uniform basic state for the LES was taken from an observed sounding in the northeast quadrant of a tornado-spawning typhoon. The LES successfully reproduced a storm which showed typical characteristics of typhoon-associated supercells with cyclic generation of tornado-like vortices. In order to estimate the entrainment rate in the simulated supercell, a steady-state one-dimensional entraining plume model was assumed, where the plume is defined as a continuous updraft region in which vertical velocity exceeds 5 m $s^{-1}$, and the initial concentration of a passive scalar was set to decrease linearly with increasing height. It is found that the entraining plume model with a constant entrainment rate gives a reasonable approximation to the simulated distribution of the passive scalar concentration for levels between the top of the boundary layer and the mid-troposphere. The entrainment rate for these levels is estimated to be about 15–20% $km^{-1}$, which is consistent with the entrainment rate for which the distribution of E-CAPE agrees well with that of the tornado occurrences.