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Recent Simultaneous Aircraft and Satellite Evidence of Cross-tropopause Transport by Convective Storms and Comparison with Model Simulation

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Direct in situ observation of cross-tropopause transport due to thunderstorms is very rare due to the danger and difficulty involved although the mechanism has been proposed for a long time. Most of the evidence available now are mainly from remote sensing data by satellites. But satellite data are hard to interpret as often more than one mechanism can explain the observed radiance pattern. We had performed cloud resolving model simulations of storms previously and found many simulated storm features fit satellite observations so that the satellite observed features can be explained by model physics. However, satellite data lack vertical resolution and consequently there are still ambiguity issues about the deep convective tropopause dynamics remained to be resolved.

A recent rare opportunity occurred to the author who encountered a series of sea breeze thunderstorms coastal China during a flight so that a direct observation of the storm top was realized. The aircraft observation provided the vertical structure information of the storm top processes such that the above ambiguity issues were resolved. The new observation completely confirms the dynamical processes at the storm top proposed by the author previously, namely, the storm updraft causes vigorous internal gravity wave motions at the tropopause level and, at the same time behaves as an obstacle to the ambient flow. This latter effect produces a mountain wave-like phenomenon such that wave breaking occurs somewhere in the downstream region of the storm anvil, in analogy to the wave breaking occurring in the wake of a real mountain. The breaking wave first behaves as a jumping cirrus described by T. T. Fujita (1974) and then elongates to become above anvil cirrus plumes described by Setvak and Doswell (1991) and Levizzani and Setvak (1996).

The author also obtained concurrent Himawari-8 images of the thunderstorms observed so that the satellite data can be compared with the above aircraft observation and cloud model simulations. This will make the satellite data interpretation in the future much more trustworthy and can be used profitably to assess global UTLS dynamical and chemical processes. The implications of this work to the chemistry in the UTLS and the global stratospheric water vapor will be discussed.