Comments on "Three-Dimensional Kinematic and Microphysical Evolution of Florida Cumulonimbus"

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In their introduction Yuter and Houze (1995a) discuss the history of downdrafts in cumulonimbus clouds and refer to *The Thunderstorm Project* (Byers and Braham 1949), in which the only downdrafts noted were in the lower part of the cloud. Yuter and Houze then cite seven recent observations, beginning in 1985, that show the existence in the upper portion of the thundercloud of what Yuter and Houze have chosen to call "upper-level downdrafts."

It is worth recognizing earlier perceptions of convection in cumuli. Lomonosov (1753) was aware of updrafts and downdrafts and suggested that friction between them caused the electrification of clouds. Again convection was proposed as the source of electrical energy, when Grenet (1947) in France published a novel theory of cumulus electrification in which a charge deposited on the upper surface of the cloud by electrical conduction was carried down to lower levels by upper-level downdrafts to accumulate and cause lightning. In the United States, Grenet's convective electrification mechanism was found unacceptable because the findings of *The Thunderstorm Project* showed no evidence at any stage in the thunderstorm's development of the upper-level downdrafts that were of primary importance in the theory.

Though measurements from a glider (Lecolazet 1948) and from an airplane (Malkus 1954) established that upper-level downdrafts exist in cumulus clouds, opinion was divided whether upper-level downdrafts were also present in thunderstorms (Vonnegut 1955; Malkus 1955; Byers and Braham 1955).

Even following observations of downdrafts in the upper part of thunderclouds with a balloon (Moore et al. 1957) and with an airplane (Steiner and Rhyne 1962), there has been little recognition that upper-level downdrafts exist. Influenced by grotesque, early representations of thundercloud dynamics, many articles and textbooks continue to preclude a satisfactory understanding of thunderstorms by providing unrealistic illustrations that fail to include upper-level downdrafts. This is unfortunate because they are undoubtedly present and of great importance in cloud behavior. It is incomprehensible that convective mechanisms of cumulus electrification continue to be rejected on grounds the upper-level downdrafts they require are nonexistent (Mason 1971; Williams 1989; Telford 1995).

The new high-resolution data of Yuter and Houze (1995a,b) confirm earlier observations of upper-level downdrafts and show they are of adequate intensity to carry space charge down from the top of the cloud at the rates required by convective cloud electrification theories. Doubt remains, however, whether the air trajectories are such that they ultimately carry the electrified cloud particles far enough down into the cloud to produce the accumulations of space charge responsible for lightning.

An even more detailed picture of the conglomeration of updrafts and downdrafts in the cloud than is revealed by Yuter and Houze will be required for an adequate understanding of how convective clouds transport energy, momentum, heat, gases, aerosols, and electric charge between the upper and lower atmosphere. It is highly desirable that these excellent investigations be extended. An additional way new information concerning this phenomenon can be obtained is by releasing radar chaff into the penetrative top of a thundercloud and seeing where it goes.

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