Reply

C. WARNER AND J. SIMPSON[1]
University of Virginia, Charlottesville 22903

D. W. MARTIN, D. SUCHMAN AND F. R. MOSHER
University of Wisconsin, Madison 53706

R. F. REINKING
Boundary-Layer Dynamics Group, NOAA/ERL, Boulder, CO 80303

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1. Cloud penetrations by aircraft

Prompted by comments of Dr. LeMone, we have re-examined the 18 cloud penetrations by the DC-6 aircraft reported in our paper (Warner *et al.*, 1979). In all the clouds, the gust probe thermistor recorded large in-cloud temperature deficits, of 1–3°C, relative to the environment. We should have suspected these sooner: Plots of the same penetrations made using the Rosemount temperature showed much warmer in-cloud temperatures. We thank LeMone for drawing attention to this.

Consultations with several experts on the Rosemount probe[2] used on the DC-6 confirms our opinion that particularly in small clouds, the Rosemount is probably sufficiently accurate for useful cloud buoyancy estimations. Florida use of the instrument (for instance, Simpson, 1980, Fig. 3) shows substantial temperature excesses (3°C and more) in growing congestus clouds, with evaporative cooling due to sensor wetting evident only in subsaturated portions and at cloud exit.

Under the assumption that in our 18 clouds the Rosemount probe gave correct in-cloud temperatures, mean virtual temperature anomalies have been calculated. Two computations of each anomaly were made, the first using the dew point as given for the environment, the second adjusting the dew point upward—usually by only a few tenths of a degree—so that its average equalled the average Rosemount temperature in the cloud. Results were essentially the same by both methods. Of the 18 clouds, 10 had virtual temperature excesses $\gtrsim 0.2°C$, with a maximum value of 1.2°, five had little or no anomaly (within ±0.1°), and three had negative anomalies of $\sim 0.2°$. Ten clouds contained temperature excesses. In most cases of temperature deficit, great moisture content yielded positive buoyancy. Clearly, our comment that all these clouds were negatively buoyant was in error, as are the temperatures in Fig. 15. Section 8 of our paper—and the corresponding paragraph in the summary (on pp. 1633–1634)—may be crossed out. In no other parts of the paper are changes desirable.

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[1] Present affiliation: Goddard Laboratory for Atmospheric Sciences, NASA, Greenbelt, MD 20771

[2] Personal communication with R. L. Ruskin, R. I. Sax and personnel of NOAA's Research Facility Center.

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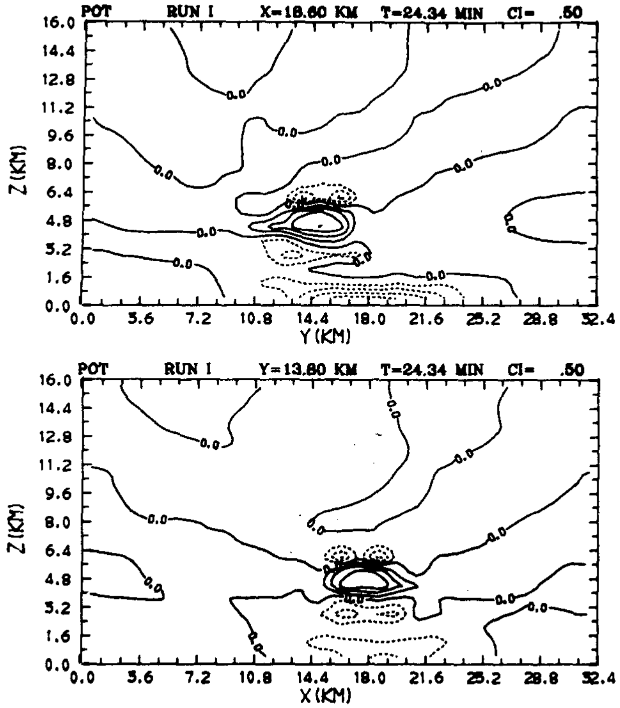

FIG. 1. Vertical sections of potential temperature excess at 24 min into the life of a simulated cumulus congestus on GATE day 261. Contour interval 0.5 K. Dashed lines show negative values. Top: north-south section at distance x = 18.6 km; bottom: east-west section at y = 13.8 km.

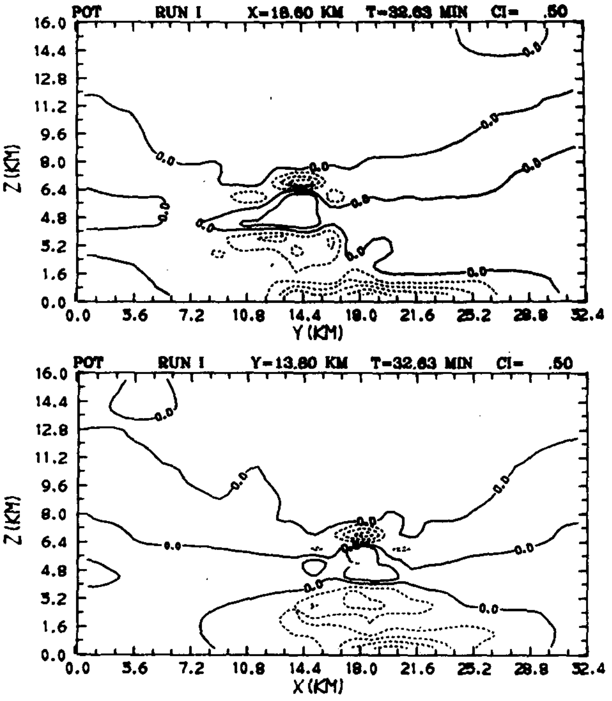

FIG. 2. Vertical sections of potential temperature excess at 33 min into the life of a simulated cumulus congestus on GATE day 261. Details as in Fig. 1.

In this and earlier work, we have found that usually, only clouds which obscure visibility through the aircraft windshield, or nose camera window, cause significant sensor wetting. Most of the 18 clouds sampled by the DC-6 obscured the view through the nose camera window. Sometimes raindrops were seen individually on the window, with the view unimpaired. It appears that in general raindrops strike an exposed thermistor bead only occasionally. In our Fig. 15, the decrease in T' signals cloud entry (I). No such signature occurred with rain (R)—in this or any other penetration on day 261. A multitude of small drops impair temperature measurement—but a small number density of raindrops probably do not.

While LeMone's calculations provide some guidelines, they contain many assumptions, for instance a collision (collision-coalescence) efficiency of 1, and idealizations (the treatment in terms of dr/dt). A small-mesh screen shields the gust probe thermistor from damage by projectiles, so its droplet collision efficiency and the consequent wetting are neither known nor readily calculable. Also, in cases when sensor wetting does occur, droplet shedding at the aircraft speed (100 m s^{-1}) is without doubt an important drying factor.

With respect to the gust probe refractometer, cavity wetting is improbable in clouds with small droplets and low liquid water contents. In-flight visual inspection of the 5.5 cm cube of the cavity from the cockpit of small aircraft indicates that this sensor stays dry in such clouds. When some wetting does occur, droplets are likely to streak across the cavity walls as they do across a side window on the aircraft. Uniform, thorough wetting will occur only in wetter clouds; then the refractive index reading is driven off scale and no measurement is obtained.

The refractometer has been used as a cloud indicator, as well as an indicator of invisible cloud precursors or remnants, because the instrument responds to the saturation-level concentration of water vapor in the air. LeMone's statement to this effect is incomplete and misleading.

We agree with LeMone that in-cloud measurements of temperature and humidity which are accurate enough for flux calculations must be a high-priority goal.

With respect to LeMone's criticism of our Fig. 11, it should be noted that cloud penetrations are indicated by solid black bars—that shading with a letter C indicates flight in an environment containing cumulus clouds. The aircraft were not in cloud for very much of the time. Note that clear air near clouds was cooler and moister than clear air away from the cloud fields—and that in each mesoscale cloudy area this trend was detected by the Electra and DC-6 before the first cloud was encountered. We find that the shallow clouds of day 261 cooled and moistened their surroundings. Were it not that clouds develop negative buoyancy as they mature, they would rise ad infinitum. LeMone is right to criticize Fig. 15, but not Fig. 11 (or the main results of the paper).

2. Three-dimensional cumulus models initialized with GATE data

LeMone's comment that "three-dimensional simulations suggest positive buoyancies in the cloud layer" needs some qualification. Two three-dimensional cumulus models have been used with GATE day 261 data—that of Schlesinger (1975, 1978, 1980) in a paper by Van Helvoirt *et al.* (1980), and that of Steiner (1973) in a paper by Turpeinen and Yau (1980). Figs. 1 and 2 are typical results for a small congestus from the research by Van Helvoirt *et al.* Even in a relatively early stage of the cloud, warm in-cloud temperature anomalies (maximum ~2°C) are confined to a small region of the rising tower. There are negative anomalies beneath the tower associated with downdrafts and negative buoyancy. This bubble-like character of towers, with downdrafts and dissipating cloud under the rising thermal, is typical of the GATE area, and is related to the stability of the lower cloud layer, which is substantially greater than that in the western Atlantic. In that region, Malkus (1958) found that only ~10% of visible cloud matter contained buoyant updraft. Taking these points into consideration, the high fraction of positive virtual temperature anomalies on day 261 (10 of 18) indicates both a preponderance of active cloud tops sampled by the DC-6 aircraft, and an unlikelihood of substantial temperature underestimation by the Rosemount probe in these penetrations.

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