Reply

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The pleasures of working in cloud physics have been considerably enhanced by the constant challenges at every step of Dr. Battan. We aıe happy to substantiate further our previous reasoning regarding seeded cloud 6 on 16 May 1968. Extensive studies of this cloud by photogrammetry, radar and aircraft penetrations have been reported elsewhere (Simpson and Woodley, 1969; Simpson and Wiggert, 1970); these observations all fit together in supporting the picture presented in my note (Simpson, 1970).

The use of a 4 m sec^{-1} downdraft in my calculation was based on measurements; it should not have been presented as an assumption. Fig. 1 shows measured vertical velocity profiles on two DC-6 aircraft penetrations through the cloud at 5.8 km elevation, the first at 4 min before (above) and the second 10 min following

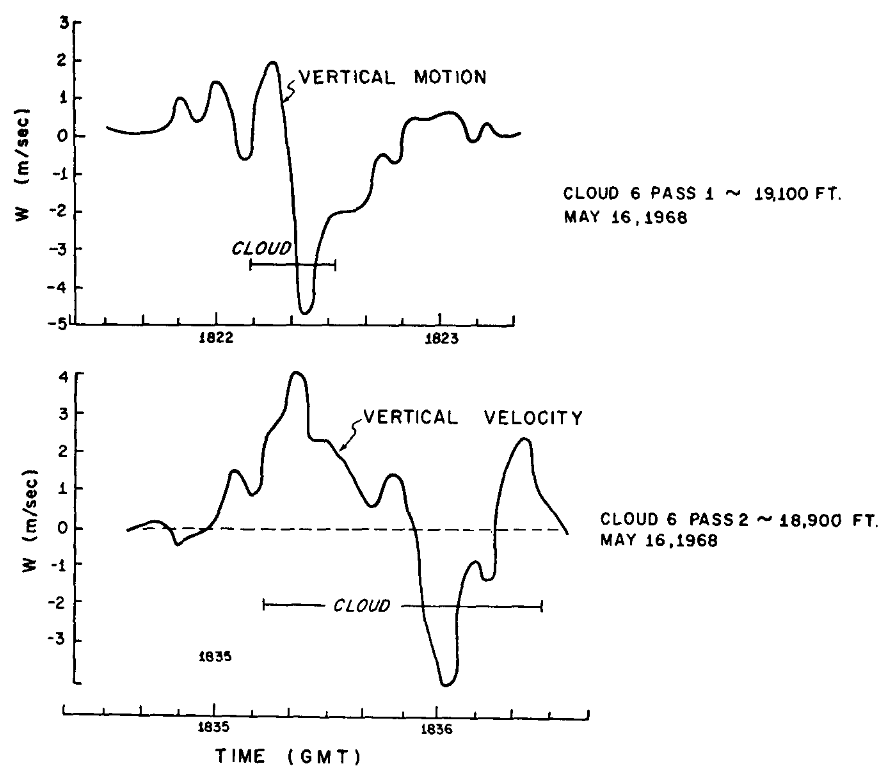

FIG. 1. Draft profiles in seeded cloud 6 of 16 May 1968 showing vertical motion (m sec^{-1}) as a function of time. Seeding occurred at about 1826.

seeding (below). These profiles were constructed by Sheets and Carlson[1] using the radar altimeter and the aircraft attitude, power setting, etc., to calculate its sinking speed.

Since publication of my previous note, the Sheets-Carlson method of draft determination has been placed on a fairly firm footing in a study by Turbulence Consultants, Inc.[2] Their tests consisted of a comparison, on six different cloud penetrations, of drafts as measured by the gust probe system and those measured by the Sheets-Carlson method. Good agreement was obtained in draft locations and magnitudes, particularly in the more vigorous clouds.

In the figure, the before-seeding (upper) penetration was made 700 m below the top of an actively rising tower (Simpson and Woodley, 1969). By the time of the next (lower) penetration, ~10 min after seeding, the cloud top had grown above 11 km, so that there was 5.2 km of cloud above the aircraft. These profiles show that there was a strong persistent downdraft, of the size used in my calculation, during the most actively rising phase of the cloud. The following data show the photogrammetrically measured rise rates of the tower during this period:

Height interval (km)	Measured tower rise rate ($m\ sec^{-1}$)
7–8	6.1
8–9	12.0
9–10	9.7
10–11	6.0
Average	8.5

Our observations show that it is the rule, not the exception, to find downdrafts, comparable in magnitude to the updrafts, on the downshear side of tropical cumuli in the active and vigorously growing portion of their life cycle. Similar results are reported by Telford and Warner (1962).

The next question is whether the downdraft shown in the figure extended down to cloud base. The temperature and accelerometer records of the cloud base aircraft (an S2D of the Naval Research Laboratory) provide nearly definite proof that it did. Of particular interest are base passes made 7 and 13 min after seeding. On the first of these a 250 m wide region of strong negative acceleration was found in the central portion of the cloud, which was 3.5C colder than the surroundings. On the next pass, the negative accelerations were stronger and the temperature deficit (over a somewhat wider region) was 5C. The aircraft observer, Mr. R. Shecter, estimated a sustained downdraft in this region of not less than 800 ft min^{-1}, or ~4 m sec^{-1}. This indication of a penetrative downdraft in an active cloud is supported by previous data. Years of cloud observations at Woods Hole, only a small fraction of which have been published (Malkus, 1954, 1955; Levine, 1965) show that when a tropical cloud begins to precipitate, the downdraft commonly extends to cloud base and is found there in association with the precipitation shaft. Cloud 6 on 16 May 1968 began to precipitate at 1810 GCT or ~16 min before seeding.

Our model of the precipitation growth in a cumulus has been explained quantitatively, using this cloud as an example, in another publication (Simpson and Wiggert, 1970). Briefly, precipitation grows to some extent by autoconversion and collection in the updraft. Updraft air is continually "detrained" (Malkus, 1949, 1954) into the adjacent downshear downdraft where the precipitation particles continue to grow by collection. About 90% of the growth in mass of the precipitation is accreted in the descending portion of its travel. Thus, we expect, and commonly find, that the strongest 10-cm radar echo is found in the downshear, downdraft portion of the cloud.

[1] Personal communication.

[2] Communication on file at the National Hurricane Research Laboratory, Coral Gables, Fla. It will appear in a forthcoming report by Sheets and Carlson.

REFERENCES

Levine, J., 1965: The dynamics of cumulus convection in the trades—a combined theoretical and observational study. Ph.D. dissertation, Dept. of Meteorology, M.I.T., Cambridge, Mass.

Malkus, J. S., 1949: Effects of wind shear on some aspects of convection. *Trans. Amer. Geophys. Union.*, **30**, 19–25.

——, 1954: Some results of a trade cumulus cloud investigation. *J. Meteor.*, **11**, 220–237.

——, 1955: On the formation and structure of downdrafts in cumulus clouds. *J. Meteor.*, **12**, 350–354.

Simpson, J., 1970: On the radar-measured increase in precipitation within ten minutes following seeding. *J. Appl. Meteor.*, **9**, 318–320.

——, and V. Wiggert, 1970: 1968 Florida cumulus seeding experiment: Numerical model results. *Mon. Wea. Rev.* (in press).

——, and W. L. Woodley, 1969: Intensive study of three seeded clouds on May 16, 1968. Tech. Memo. ERLTM-APCL 8, ESSA Research Laboratories, Boulder, Colo., 41 pp.

Telford, J. W., and J. Warner, 1962: On the measurement from an aircraft of buoyancy and vertical air velocity in cloud. *J. Atmos. Sci.*, **19**, 415–423.