Reply

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Moore and Vonnegut's (MV) comments are at least partially a result of Williams et al.'s (WGB) not having made clear that essentially all their lightning echoes were obtained from mature thunderstorms, which formed before moving within radar range. The echoes typically sprang out of the steady background echo of the precipitation as in Fig. 7 of WGB, with no noticeable change in background intensity before or after the flashes. The main changes in intensity of the storms were a result of movement into or out of the fixed beam, as was readily apparent when resetting the antenna angle. Since publication, we have developed a computer method which allows us to check for any so-called rain gush behavior that we may have missed when originally analyzing the data. In the method, the intensity of the background precipitation at the time of the lightning echo is compared with that immediately preceding and following the event. Histograms of the change in background intensity during the minute before and the minute after each lightning echo for approximately 700 events on 29 July 1986 are shown in Figs. 1 and 2 respectively. There appears to be no significant change associated with the lightning.

Another aspect of the observations that seems to have been missed by MV is that the elevation of the antenna was set so that the observing volumes were centered at altitudes of 7 or 8 kilometers, heights where the precipitation is essentially all ice. In that case, 30 dBZ does not signify "relatively weak precipitation." The echo at lower levels was generally considerably stronger. In any case, lightning occurs in areas of widely differing background reflectivity. In fact, we have observed (visually) dozens of lightning strokes occurring largely outside of cloud, with the luminous channels appearing against a background of blue sky, at times even terminating in the clear sky. There is, however, a distinct tendency for the strongest lightning echoes to be associated with the stronger precipitation echoes, as noted in WGB.

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Moore and Vonnegut are, of course, free to question precipitation-based theories for thunderstorm electrification as they choose, but their quote from Williams and Lhermitte (WL) should not be construed as the death knell of such theories. WL made certain assumptions concerning the energy in lightning that indicated that the expected changes in particle velocities would be large enough to be detectable. They now feel that these assumptions were not entirely valid and that the changes would not have been detectable with their radar and that therefore that particular result of their experiment can not be considered definitive.

With regard to Moore's (1965) observations, we can only point out that recent observations with sailplane-mounted field mills and well-calibrated radar indicate that storm reflectivities in New Mexico thunderstorms generally reach the 40 dBZ range before electrification is detected (Dye et al. 1989).

We agree with MV that the surface area afforded by the cloud particles for carrying charge in a thunderstorm is far greater than that of the precipitation. Certainly, identifying the charge carriers in the thunderstorm remains one of the most important unsolved problems in cloud electrification studies. The answer would go a long way towards culling the most important mechanisms among the many proposed to account for cloud electrification. We favor a precipitation-based mechanism for the reasons advanced in WGB and be-

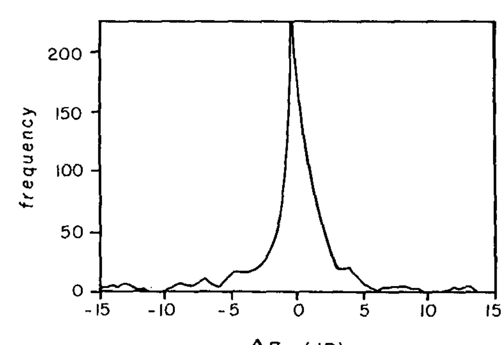

FIG. 1. Changes in intensity of background precipitation from one minute before lightning to the time of lightning.

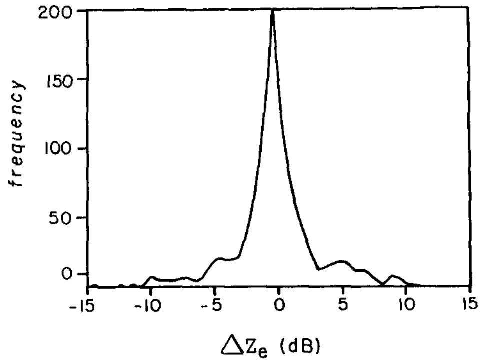

FIG. 2. Changes in intensity of background precipitation from time of lightning to one minute after lightning.

cause some, such as the work based on charge reversal with temperature of Takahashi (1978) and Jayaratne et al. (1983), seem to give promise for explaining the apparent tripole structure of the thunderstorm, and incidentally, the observation by Workman and Reynolds quoted in MV. We recognize, however, that no truly convincing theory exists at this time, for the reasons given by MV and for others. Although we remain skeptical concerning Grenet's (1947) and Vonnegut's (1955) convective theories, we do recognize the importance of convection in cloud electrification, no matter what the mechanism. Our studies here in New England, in the Huntsville area of Alabama, and in the Darwin area of Australia have made it amply clear that the most highly electrified storms are invariably the tallest, most vigorous ones.

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