Reply

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Sevruk (1984) comments that he neglected out-of-levelness errors as well as other errors (Sevruk, 1982) because ". . . they occur in an unpredictable manner or can be kept well under control." Perhaps the major point of Rinehart (1983) was that the effects of out-of-level instruments are very predictable, given knowledge of the wind speed and direction during a precipitation event. Further, the levelness of raingages is not always well controlled as both Sevruk and I show (see my Fig. 11; also see Fig. 5 of Sevruk, 1982). I agree that it would take complete wind and precipitation data to correct for out-of-levelness errors and that prevention is indeed the best protection. Nevertheless, given the rain rate and wind velocity as functions of time and the out of levelness and direction of slope of the orifice of an individual raingage, it should be possible at the very least to determine if the rainfall amount was over- or underestimated and, at best, it may even be possible to correct for the errors introduced by this effect.

In his final paragraph, Sevruk (1984) gives evidence that out-of-level instruments can introduce systematic and significant errors for certain measurements; he said that about 3% of the gages in the experiment he cited were out of level. Evidence for out-of-level gages was that the higher of two paired gages had more rainfall than the ground-level gage. It is entirely possible, however, that out of levelness of one or both of the gages could cause the higher gage to have less rainfall than the lower gage; the experiment cited apparently accepted negative differences as always being correct and attributed these to the known wind effects being studied—but not to out-of-levelness problems. The higher gage having had a smaller amount of rainfall than the lower gage does not insure that out-of-levelness problems were under control. Tilting the higher gage away from the wind would also reduce the amount of precipitation it collected.

To estimate the real effects of out-of-level gages in this study, consider the following. As a first guess, one might estimate that another 3% of all gages could have been out of level in the opposite direction and that still another 3% might be out of level in each of the two orthogonal directions (such that they would neither increase nor decrease the measured rainfall amounts). Thus, a total of up to 12% of all gages in the study quoted by Sevruk could have been out of level. The degree of out of levelness is harder to estimate. Sevruk gives the range of excess rainfall as 1 to 7%. Wind effects should reduce the amount of rainfall collected at all of the elevated gages, not just those that were level. That some gage pairs had more rainfall at the higher than at the lower gage by 1 to 7% suggests that out of levelness really contributed errors of 5 to 11%, i.e., the increases caused by out of levelness were reduced 4% on the average by wind effects. This total error could be accounted for (see Rinehart, 1983, Fig. 10) by 1.5 deg instrument out of levelness and 10 m s^{-1} winds.

Sevruk and I are in agreement that out-of-levelness errors should not exist in well-managed data collection programs. Frequent checking and re-leveling of precipitation-measuring instruments can easily reduce this source of error to acceptable amounts. While I tend to agree with Sevruk that wind effects are the most important source of error in point precipitation measurements, both of us have shown evidence that out-of-levelness instruments can be a significant source of error as well.

While reviewing my paper (Rinehart, 1983) to respond to Sevruk, I discovered that part of a sentence is missing in Section 2. In the last paragraph of this section, the third to the last sentence should conclude: "The number *N* of stones per unit volume (1); the rate *R* at which stones hit a unit area (1.5); the fraction F of all area hit by stones of a given size and smaller per unit time (3.5); the hail content *W* of a unit volume of space, e.g., g m^{-3}, (4); the hailfall rate *H*, e.g., mm h^{-1}, (4.5); the kinetic energy *KE* (5.5); and the radar reflectivity *Z* (7)." The missing portion of the above

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sentence is underlined. These terms are correctly labeled and discussed in Fig. 4 of that paper.

As a final comment, since my paper was published, someone pointed out another paper that deals with certain aspects of the effects of collecting samples with tilted instruments. Griffiths (1975) considered the effects of intentionally tilting disdrometers into the wind to minimize the errors associated with certain sized particles. While the problem being considered was somewhat different than that discussed by Rinehart (1983), the effects are similar and Griffiths should have been referenced.

REFERENCES

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