Effect on Mean Rainfall of Artificially Increased Variance

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In a manuscript recently submitted to the Journal of Applied Meteorology, Adderley and Bethwaite (1965) call attention to an increase in the variance of the rainfall associated with cloud seeding experiments in the New England region of Australia. This observation strikes a responsive chord, not only with respect to the results of several other statistical evaluations with which the undersigned has been concerned, but also with respect to the general impression shared by a number of cloud seeders that seeding is occasionally spectacularly successful, much of the time only slightly effective, and sometimes may have a negative effect.

Heretofore, evaluations of the effectiveness of cloud seeding for increased precipitation have been based upon the assumption that each occurrence of rainfall has an equal probability of being proportionally increased. Such, for example, is the suggestion made by Thom (1957) that seeding increased the scale factor beta of the rainfall distribution normalized by an incomplete gamma-function transformation. The effectiveness of seeding would then be evaluated by testing for a significant change in the mean value of the transformed rain quantities.

On the other hand, if the effect of cloud seeding were to be an increase in the variance of the rainfall distribution, without any change in the median, it is apparent from the skewness of the actual rainfall distribution that an increase in the mean rainfall would result. In a typical instance, where the distribution of monthly rainfall on a target has been normalized by a cube-root transformation and where the normalized distribution has a mean of 1.48 and a variance of 0.09, an estimate of the effect of doubling the variance arrived at by a simple stochastic approximation is shown in the following table of decile values of rainfall.

Decile	Rainfall, $\sigma^2=0.09$	Rainfall, $\sigma^2=0.18$
1	0.94	0.45
2	1.60	1.09
3	2.10	1.68
4	2.53	2.25
5	3.01	2.86
6	3.51	3.65
7	4.10	4.49
8	4.83	5.59
9	5.83	7.30
10	7.76	10.58
Mean	3.62	3.99

In this instance, doubling the variance resulted in an increase in mean rainfall of 10 per cent. The purpose of many rainfall stimulation programs is equally well served by an increase in mean rainfall regardless whether this is accomplished by an increase in the median or by an increase in the variance. If seeding

does increase the variance, then statistical tests based on increase of the median alone underestimate the confidence that can be placed on the practical effectiveness of the seeding. Apparently, further refinement of the evaluation procedure will be necessary if maximum contribution to decision criteria is to be attained.

One is tempted to speculate about the physical basis for an increase in variance. This might, for example, come about if the cloud seeding technique applied in a particular instance had no influence on convective clouds smaller than some critical size, but became increasingly effective as the size of the clouds increased beyond this limit. For instance, it might be that cloud seeding has little or no effect on those clouds that exhaust their positive buoyancy before the formation of precipitation is well under way, while it may have a major influence on those clouds where precipitation formation goes on in regions of high positive buoyancy and where the change of state stimulated by ice-forming nuclei may contribute to maintenance of the positive buoyancy. Such a notion might explain some of the difference between the experimental results of Project Whitetop in Missouri (Braham, 1964), with respect to relatively brief showers from short-lived convective cells, and the results of Project Stormfury (Malkus and Simpson, 1964) with the seeding of larger clouds, which showed a positive response in the form of additional cloud growth. In this event, an increase in the rainfall from the larger clouds would be associated with an increase in over-all level of development of the cloud, and not necessarily with an increase in the proportion of clouds of a given size that contained precipitation. It seems likely, also, that the outcome of a particular program might be considerably influenced by the choice of cloud seeding techniques and the manner of their application to particular weather situations. For example, Elliott and Strickler (1954) have suggested that the effects of air-borne seeding may be quite different from those of seeding from the ground. It is likely, therefore, that statistical indications derived on the basis of one program or another can be considered as applying only to the particular techniques and practices used, and that the application of such indications to cloud seeding in general must be regarded with the greatest caution.

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