NOTES AND CORRESPONDENCE

Comments on "Note on the Potentialities of Cumulonimbus and Hurricane Seeding Experiments"

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In two recent publications Malkus and Simpson (1964a, b) have discussed their work on the seeding of convective clouds and hurricanes. Both articles, though offering notes of caution in the last few paragraphs, have been written in such a fashion as to indicate that they are offering major new hypotheses for thunderstorm and hurricane modification. The tones of the articles are likely to mislead the unknowing reader into believing that their observations have shown that the hypotheses have been proven.

For example, in the article in *Science* (page 547), the authors state, "We believe that the series of control calculations establishes, beyond reasonable doubt, the causal relationship between seeding and the observed explosive cloud growth which followed." What does this statement mean to imply? Many readers are likely to think otherwise, but I do not believe that the authors want the reader to conclude that it has been proven beyond reasonable doubt that their silver-iodide seeding caused "explosive" growth in actual clouds. If this were not the case why say that, "This experiment barely scratched the surface, its repetition with a number of improvements, is mandatory. Selection of clouds for seeding and for control should be randomized."

The article in the *Journal of Applied Meteorology* begins with the statement that, "Two seeding experiments on tropical hurricanes have been successfully executed to date." In later sections they refer to "successfully seeded" clouds (pages 471 and 473). Again, we wonder what the authors mean to imply by the term "successfully seeded." We presume it means that the mechanics of the seeding operation, i.e., the disperal of the AgI and cloud observations, etc., were successful. However, those people who have been close to the cloud modification controversies over the last 15 years would find it hard to deny that for many readers the term "successful seeding" implies not only that the operations were carried out successfully but also that the effects of the seeding were clear cut and conclusive. It appears to me that the results of this work to date, fit into the category of the old medical expression, "The operation was a success but we still don't know about the patient."

From this point of view, these investigations fall into step with other research done on weather modification by many others over the last decade and a half. To say, as is done in *Science* (page 547), "Here meteorology is taking the first small steps towards becoming an experimental science," is not to place this work correctly in its proper historical perspective.

The fundamental hypothesis concerned with the so-called "explosive" growth of convective clouds following ice-nuclei seeding is that the sudden freezing of the supercooled liquid leads to a rapid release of the latent heat of fusion which causes increased buoyancy and strong upwards acceleration. This hypothesis has sufficient merit to recommend it as a fruitful area for further research. However it should be recognized that this is not a new hypothesis. It was first proposed by Kraus and Squires (1947). Their article is listed as reference 11a in the *Science* article but is quickly passed over in the discussion. It is not even mentioned in the article in this *Journal.*

A second pertinent piece of work was carried out by the Project Cirrus group in New Mexico on 21 July 1949. It involved the seeding of a convective cloud which grew to an altitude of 44,000 ft in a rapid and unexpected fashion. Langmuir (1950) has given a detailed discussion of this experiment. Mason (1957) has briefly discussed the hypothesis and given reference to others who have reported rapid cloud growth after seeding.

Thus, the hypothesis of the effects of released latent heat of fusion has been known for almost 15 years and considered by a number of investigators. It is true that the use of a dynamical model which incorporates the effects of buoyancy modified by entrainment, drag and liquid water has advantages over a simple model involving for example, merely a parcel-method approach. Nevertheless, this simple approach will show that a 2C increase of temperature of a buoyant mass of rising air will cause a substantial increase in the height of a

convective cloud. Neither approach yields information on the natural relase of latent heat of fusion and whether or not ice nuclei seeding will cause the rapid release of sufficient heat to cause clouds to grow unexpectedly large. It can surely be said that the authors' theoretical work has improved on past work in this subject but, with reference to the effects of seeding, the improvement has been in detail rather than substance.

The authors appear to be of the opinion that it is easy to select similar cumulonimbi when they state on page 474 that "cumulonimbi are easily and reproducibly isolated." If this were possible it would not, as implied in the *Science* article (page 544), require a very large sample of observations to establish by statistical means that seeding can cause "explosive" growth of convective clouds. However, I have grave doubts that it is possible to select identical cumulonimbi. With available instruments it is possible to pick out clouds which appear to have some similarity but which nevertheless can be quite different. Certainly one or two temperature and liquid-water-content profiles made by means of instruments having a sampling area of no more than a few square centimeters as an airplane flies through a cloud with a diameter of about 2 kilometers can not be said to characterize a cloud. To treat as fact an assumption that one knows the properties of a cloud and how it will behave in the future, certainly can be misleading.

On the basis of a careful study of the articles already cited, as well as more detailed but yet unpublished reports on this subject by Dr. Malkus and her colleagues, it is evident that there are important uncertainties about the following aspects of the convective cloud study: (1) the rate at which latent heat is released by natural processes; (2) the concentration of active silver-iodide ice nuclei at the critical temperatures between −4 and −7C; (3) the temperature and moisture structure of the atmosphere in the immediate vicinity of the test clouds; (4) entrainment rates; and (5) the quantity of retained liquid water in the clouds. In the light of these uncertainties, it appears that the authors, pending additional experiments, should allow for the possibility that the observed cloud behaviors may have been a result of chance.

Finally, lest the authors misunderstand the intent of these comments, it should be noted that they should be commended for devoting their considerable talents to such a difficult but vitally important subject as cloud and weather modification. It is an area of research where there is often more criticism than congratulations, but the consequences of success are so great that it deserves the attention of even more atmospheric scientists. We look forward to the results of additional experiments.

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