"REVIEWED"

HOW MUCH IS ENOUGH!

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For many years attempts have been made to determine whether or not weather modification "works".

Originally there were individuals and groups (there still are a few) who denied that dry ice or silver iodide could have any effect on supercooled clouds or weather systems containing such clouds. After evidence in the laboratory had shown that without question a laboratory cloud could be quickly and spectacularly converted to ice crystals, the skeptics then claimed that the atmosphere was too big or that the seeding materials would be deactivated or that it was not possible to distribute the materials in an effective manner.

It reached the point at a scientific meeting when Dr. Langmuir showed the Project Cirrus "race track" that he suggested that if the "doubters" still felt that such a pattern could occur "naturally" we would cut the G.E. monogram in a supercooled cloud deck!

After it was conceded that supercooled stratus and ground fog could be profoundly modified the skeptics insisted that convective clouds were a different matter and that efforts to prevent hail or increase rain were an idle or worthless effort.

When asked for a procedure to follow that would provide scientific proof of effectiveness of the seeding of convective clouds, the randomization method was proposed wherein "seedable" clouds were identified by certain a priori characteristics and then a randomized decision was made as to whether or not to seed.

In the earlier randomized programs a network of rain gauges were used. More recently a greater amount of confidence has been placed on measuring the intensity, vertical development, location and areal extend of radar echoes.

Despite the complexitites, the variabilities and the poor designs that have plagued a number of programs, the recent Cleveland Report[1] provides a fairly optimistic view of the potential in this area of experimental meteorology.

(NOTE: Despite my general approval of the Cleveland Report I was perplexed to read on Page 28, 5th paragraph, of Part I, that the effect of introducing dry ice into a supercooled cloud is to freeze the water droplets. How such a profound mistake could escape the scrutiny of the distinguished cloud physicists on the Committee is beyond comprehension. While it is true that the supercooled droplets in the cloud are caused to freeze, the dominant effect of dry ice is to cause homogeneous nucleation by dropping the localized temperature colder than -40^{0}C and thus generating effective nuclei concentrations from a billion to a trillion times greater than the concentration of cloud droplets!)

This report seems to conclude that certain of the randomized experiments (which have been carried out at great cost) provide strong evidence of the validity that cloud seeding operations actually increased the amount of precipitation that fell.

The report has been interpreted to provide an optimistic viewpoint but that even greater emphasis must be placed on randomization procedures.

I would like to pose the question: -- WHY?

If evidence is available from the careful work that has been done that the seeding of supercooled convective clouds is feasible and produces measureable effects it seems to me that the time has arrived when the present types of randomization be abandoned and that seeding activities proceed where the need is recognized and that the monies that would be spent in operating a randomization effort be directed toward ascertaining physical reactions which can be directly attributed to the seeding operation.

During the period 1960 to 1971, I led eleven winter expeditions, each lasting a month, to Yellowstone Park -- most of them to the Old Faithful Geyser Basin. The main purpose of the Yellowstone Field Research Expeditions which were funded by the National Science Foundation, was to carry out seeding experiments in the rich and copious supercooled clouds that develop under the nighttime inversion along the Firehold River.

More than fifty atmospheric scientists participated each year in a wide variety of atmospheric research activities. Nightly seminars provided the participants with a review of their colleagues interests and the friendships and collaborations which evolved from these intimate contacts persist to the present day.

It was soon discovered at Yellowstone that the effect of a seeding operation carried out in the vicinity of Old Faithful Geyser could be monitored and measured quantitatively in the vicinity of more than a mile away. Predictions were made on arrival time of the seeding effect, types and concentration of ice crystals, optical effects and cloud dissipation.

Many new types of seeding materials were tested under severe field conditions and evaluated in a semi-quantiative way. Nothing was found that indicated that the new substances could supplant dry ice or silver iodide in effectiveness and ease of production of ice nuclei.

The most impressive result of the many experiments conducted at Yellowstone was the realization that a profound change could be produced in the supercooled clouds which pervaded the basin in the early morning. By suddenly introducing large concentrations of ice nuclei into the all pervasive supercooled clouds at Old Faithful, a profound change was made in the system within a few seconds. By initiating this complete change of phase in the cloud at a specific moment, it was found to be possible to predict within a minute or two the arrival time of the ice crystal cloud several kilometers away. Prior to the arrival of the seeding effect nothing but supercooled water drops could be detected even at temperatures as cold as $-30^{\circ}C$. The arrival of the ice crystal cloud was always spectacular since the crystals were much larger than the water droplets, had a falling velocity of a meter per second

or more, would quickly cover a sheet of black velvet with sparkling crystals and would suddenly produce magnificent optical effects in the sky where previously only the suns disc could be seen.

Of the several hundred dry ice and silver iodide seeding experiments conducted at Yellowstone, not a single one failed to produce remarkable and easily observable effects except when temperatures were within a few degrees of $0^{o}C$ or colder than $-40^{o}C$.

The reason why I feel that randomization projects should be abandoned forthwith is that it should be recognized that by the sudden introduction of seeding elements into a supercooled cloud this action provides a "time zero" base line which can be and should be exploited. Since practically all seeding is now done by aircraft or projectile it is a simple procedure to establish such conditions. With the highly sophisticated instrumentation now available to remotely observe and measure the change in phase of water substance it should be feasible to follow such changes with a precision not possible in our earlier Project Cirrus experiments.

I have great expectations that the Cleveland Report will provide the encouragement and the funding to permit some of the new generation of highly capable atmospheric scientists to tackle the job ahead. I hope they will not be hampered by the naivete of "randomization". If Nature provided reasonably similar storm systems there might be some justification for the randomization procedure. Since every storm is different I see no hope that such an approach will yield the kind of data that will be acceptable to the "doubters". I do believe that a relatively small group of our younger scientists, given adequate equipment, proper incentives and freedome to innovate and to learn by doing in the field and the atmosphere will come up with results which will convince everyone about the possibilities as well as the limitations of weather modification.

I hope this happens!!

REFERENCES

The Management of Weather Resources, Part I. Report to the Secretary of Commerce from the Weather Modification Advisory Board. Harlan Cleveland, Chairman.