SEEDING CLOUDS AT THE SURFACE, CLOUD BASE, AND CLOUD TOP

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INTRODUCTION

This discussion will present a brief summary of various cloud seeding techniques presently used for weather modification efforts. Specifically, it will deal with ground-based, cloud base and cloud top seeding techniques.

However, before these various methods of application are considered, it is worthwhile to evolve the requirements of a delivery system in relation to the desired weather modification goal. We are all too keenly aware of the need to properly define this goal, both in terms of a specific objective and the evaluation or verification of that objective. This need applies equally to the researcher and the field operator.

Once the goal has been defined, it becomes necessary to design a suitable field or laboratory program to achieve this goal. It is at this early stage that the delivery mode comes into consideration.

The operational implementation of the model design concerns itself with the logistics of the field or laboratory program. Here the day-to-day weather modification operations are monitored, along with the support roles, according to the model design. The selection of the delivery technique, such as airborne vs. ground-based platforms, have been made based on considerations including cost-to-benefit of the endeavour, previous experience or understanding to meet the desired ends, and operational limits in terms of manpower or equipment.

From the design stage onward, the problems of targeting the material have had to be considered. The vital questions of where this material is needed, when it is needed, how much is needed, and, for completeness sake, just what is needed, must at least be addressed, if not answered.

In considering this question of material targeting, there appear to be two specific problem areas. The first area deals with the field logistics of operating the delivery platform. Consider, just as an example, the seeding of orographic wintertime clouds. Terrain difficulties will dictate the serviceability of ground-based generators, as well as aircraft delivery platforms. Likewise, the meteorology of the phenomenon, such as the occurrence of hurricanes or the formation of airport-shrouding fogs, will also delimit the selection of certain delivery techniques.

As if that wasn't enough to put a damper on our efforts, there remains the other targeting problem. This is the material transport problem, or, just what does that material do from the time it leaves its delivery platform until it reaches its pre-selected target? The transport distance may be relatively short, such as direct injection from an in-cloud generator, to considerable distances when considering ground-based sources for convective clouds.

Since the design of the weather modification activity called for a specific seeding target, i.e., a temperature level or zone, and some estimation of the required material, the operator must be cognizant of processes which might deplete the material during its transport. Thus, lateral dispersion might spread the material over a region greater than the specific target. Photo-chemical reactions or entry into solution might neutralize the nucleating potential of the material. Even the very transport mechanism that is anticipated must be examined to ensure that the material could reach the desired target.

You can see, then, that difficult questions arise for those of us involved in the operational aspects of weather modification.

CLOUD SEEDING TECHNIQUES

Now that some of these considerations have been briefly mentioned, it is worthwhile to look at various operational cloud seeding techniques. The easiest way to treat these techniques is to consider the weather modification goals and comment on the techniques used therein.

1. Fog Dispersion

Supercooled fog dissipation techniques have been demonstrated for several years now, and actual operational programs are presently under way at several major airports. Both airborne seeding with dry ice and ground-based seeding using propane are used in these field programs. In addition, there are several research programs involving thermal dissipation techniques, and the use of helicopter downwash to clear warm fog.

The airborne dry ice seeding technique normally requires the seeding aircraft to fly a rectangular grid just above the fog layer, and 30 minutes or more upwind of the airport. The resultant homogeneous ice nucleation of the supercooled droplets hopefully leads to an increase in the visibility to above aircraft landing minima. The optimum seeding rate is approximately 8 lbs/mile^{-1}. Savings to the airline industry, both in direct costs and in passenger convenience, have demonstrated a very high cost-to-benefit.

The use of ground-based propane dispensers have been used for several years at Fairchild AFB, Washington, and at Orly Airport, Paris, France. Vertically-pointed spray nozzles are arranged along upwind arcs of the approach end of the runways. Seeding is accomplished by turning on selected spray nozzles up to an hour prior to the desired time for fog-clearance.

Warm fog clearing techniques are as yet in the testing stages. Experiments using helicopter rotorwash to mix in dry air, seeding with hygroscopic chemicals, and the exhaust heat from jet engines attest to the variety of experiments.

2. Orographic Cloud Seeding

Theoretical and field studies have shown that under certain favorable conditions, snowpack augmentation is practicable along certain orographic barriers. Cloud temperature and cloud depth appear to be significant to the modification efforts.

The early studies conducted by Colorado State University used AgI generators located in upwind valley sites. The synoptic flow, lifted up over the barrier, provided the transport of the nuclei into the orographic cloud. These studies did reveal an increase in precipitation following a seeding event, under certain conditions. The generators produced 4×10^{15} active ice nuclei, effective at $-20^{\circ}C$, as tested in the CSU isothermal chamber.

A similar study by Montana State University, focused on the Bridger Range, used a modified Skyfire AgI generator. Results tended to suggest that precipitation increases were found when cloud top temperatures were colder than $-20^{\circ}C$, but no precipitation increases at warmer temperatures.

Both airborne and ground-based generators were used by Utah State University to seed winter orographic clouds in the Wasatch Range. Precipitation increases were found following tests with either system.

Results of other studies, principally using ground-based generators, tend to verify a cloud seeding "temperature window". Given the increases of 5-30 percent, depending on the study, do suggest the feasibility of fully operational programs. The stationarity of both the cloud systems and the ground-based generators, plus the operational problems of operating aircraft in mountainous terrain, appear to favour the fixed ground-generator.

3. Cumulus Cloud Seeding

Precipitation augmentation effort from cumulus cloud structures have utilized all three forms of cloud seeding cited in the title. Those are ground-based sources, aircraft seeding at cloud base, and the seeding of cloud tops. The seeding of warm clouds ($T\ 0^{\circ}C$ throughout) has been an attempt to enhance the coalescence growth mechanism. One of the main hygroscopic materials used is sodium chloride ground into powdered form. This material is normally released by aircraft into the cloud system, although there was a recent study in India involving seeding with large salt particles released from a ground source. Results from seeding warm rain clouds have not been conclusive.

Supercooled cumulus cloud seeding involving AgI, or other ice nucleants, is much more common, particularly in the mid-latitudes. The attempt is to freeze supercooled water droplets in order to increase the precipitation efficiency of the cloud. The ice crystals will grow at the expense of the water droplets, and subsequently fall out as rain or snow.

Cumulus seeding for precipitation augmentation has been global in scope, and has involved variations of all three seeding techniques. For example, Montana State University has conducted plume tracking studies, using AgI released from ground level, for convective seeding. The South Dakota School of Mines and Technology has been involved for many years in evaluating cloud base seeding with both AgI and salt.

An operational ground-based rain increase program in Oklahoma has been going on for a number of years.

The Experimental Meteorology Laboratory in Florida has been very active in developing and testing a droppable AgI source into the tops of cumulus towers.

4. Hail Suppression

The early successes quoted from the USSR have led to several investigations of hail suppression in other parts of the world. For example, there are studies presently conducted in the U.S., Canada, France and South Africa. These various programs, either research or operational, have included all three techniques of cloud seeding, while the hail program in the Soviet Union used rocket and artillery systems for the delivery platforms.

Studies were conducted in Switzerland and France using ground-based generators, and in Italy using a cloud top seeding technique. The NHRE in Colorado has looked at both cloud base fusee generators and vertically pointed rockets released from cloud base.

The Alberta Hail Project has used both cloud base and cloud top techniques for three years, and is also in the process of evaluating the potential for ground-level generators.

WRAP-UP

The purpose for this discussion has been to comment on various cloud seeding techniques as they apply to certain weather modification endeavours. There certainly are differing approaches to a common goal, which will only serve to improve our model of the seeding target.