Silver Iodide Cloud Seeding Rates and Corresponding Precipitation

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Abstract. Contrasting signatures as the apparent effect of different AgI-amounts used for seeding clouds with the goal to enhance precipitation have been observed over a period from 1955 through 1997: (1) In general, good precipitation from lightly-seeded slow-growing cumulus congestus, and (2) Little or no precipitation from rapidly-growing cumulus congestus heavily seeded, which reach cumulonimbus stage with cirrus densus.

1. INTRODUCTION

Over a period of 42 years, two very different signatures have been observed during and after cloud seeding operations (ground based as well as airborne ones): (1) cumulus congestus growing slowly to twice or even three times their initial size over an extended period of time with good precipitation to ground, and (2) cumulus congestus growing violently into cumulonimbus with extended anvils which often spread into large cirrus densus, and with the result of little or nonexistent precipitation reaching the ground. The former situation tends to follow 'light' applications of seeding agent, while the latter tends to result from 'heavy' application of seeding agent. The appearance of cirrus densus has been observed after cumulus congestus were heavily seeded with AgI.

2. BACKGROUND AND EXAMPLE CASES

A cloud seeding operation was carried out in Florida from July through September, 1981; the suggested amounts of AgI to be used were such as to "enhance the dynamics" of the seeded clouds instead of "working with the dynamics" of the seeded clouds – that is, clouds were heavily seeded. These clouds grew quickly into well developed "cumulus mushroomulus" (cumulonimbus) which spread rapidly into extensive cirrus densus, with resulting rainfall to ground nonexistent or less than expected. These operations were observed over the southern Kissimmee Valley and in the vicinity of Lake Okeechobee.

In contrast, good precipitation reached the ground over the northern Kissimmee drainage area from cumulus congestus that were seeded with small amounts of AgI. During most seeding operations the AgI amounts dispensed into clouds over the northern Kissimmee drainage area were one to two 20-gram flares per cloud or cell; the AgI amounts dispensed over the southern Kissimmee drainage area and in the vicinity of Lake Okeechobee were one 20-gram flare per second in strong updrafts.

On July 31, 1997, large "cumulus mushroomulus" were observed from the northwest corner of the High Plains Underground Water Conservation Districts cloud seeding area in Texas looking toward the south and southeast. The anvils of those clouds became extensive cirrus densus over a large portion of the project area. On August 1, 1997, it was learned that only about 1/2 to 1 inch of rainfall had reached the ground in the Hereford, TX, area, and south of there, large areas had no precipitation observed or measured. Furthermore, it was learned that a relatively large number of 20 gram AgI flares were dispensed during the seeding operation on July 31, 1997 over the operations area (about 40+ flares). This was done apparently in accordance with the AgI amounts suggested by the Rosenfeld/Woodley Cold Cloud Conceptual Seeding Model which applies to the seeding technique for that program.

Dr. Edwin Kessler, of the University of Oklahoma, mentioned low and even insignificant precipitation amounts as the result of seeding clouds over the Great Plains (Kessler 1998). He also discussed some West Texas field experiments during the years 1987 through 1989 including the application of the Rosenfeld/Woodley Cold Cloud Conceptual Seeding Model. Apparently these experiments showed unimpressive rainfall results, and are contrary to results commonly reported, especially from "operational" programs. For example:

- Gagin and Neumann (1981) reported a sustained long-year average increase in precipitation for the cloud seeding program carried out in Israel from 1961 through 1975 of +18% resulting from a low AgI seeding rate of 62 g/km/h.

- Hsu (1981) reported an average increase in rainfall from a cloud seeding program carried out in Taiwan from 1952 through 1979 of +42%; the seeding rate was also a low one with about 100 g/h being used.
- From 1972 through 1976, Krick (1975) reported a 50% increase in precipitation for a program carried out in Central Michigan, having used 0.5 and 2.0 g/h/gen, respectively.
- Walser (1982) reported on a cloud seeding program carried out for 12 counties in Eastern Georgia with a 20% increase in rainfall comparing target and control areas, and having used AgI in the amounts of 20 g/cloud.
- Howell (1981) reported an obtained 23% increase in rainfall by seeding clouds for precipitation enhancement for the City of New York, using 2 generators each having a burning rate of 10 grams per hour.
- W.E. Howell Associates in the 1951-52 season obtained an increase in precipitation of 63% in the Rio Chicama program in Northern Peru (Howell 1965). We also find there reported rainfall increases of 30% for the 1952-53 season for the same program, 42% for the 1953-54 season, 31% for the 1954-55 season, and increases in rainfall of 20% and 15% for the 1955-56 and 1956-57 seasons respectively. Howell also reports an average rainfall increase for the Peruvian theater in the Rio Chicama watershed of 25% and an average runoff increase of 55% for the years of 1951 through 1959, having used AgI in the amounts of 4 g/h/generator. In the three river drainages of the Rios Moche, Chicama, and Jequetepeque only 29 ground-based AgI generators were installed. This program in Northern Peru lasted through 1969, and the significance of the evaluation is mentioned as $p \leq .0001$.

It is of special interest to note that the above mentioned increase figures for the Peruvian theater were supported by a reported 60% increase in "acreage under irrigation" at the sponsor's plantations – this without changing the technique of irrigation, and converting sponsor-owned desert lands. It is also of interest to note that three years after the termination of the Peruvian program in the Rio Chicama watershed this extra and extremely productive "acreage under irrigation" had become desert again!

Howell was severely criticized that he compared the seeding results against the "increase in acreage under irrigation". The question arises: What better comparison could he have used?

It was observed from 1955 through 1969 that basically no cirrus densus had formed over the Rio Chicama watershed program area. The seeding there was basically carried out on cumulus congestus with 4 g/h/gen and was initiated shortly after onset of convection (when irrigation water was requested by the sponsor). The seeded cumulus congestus clouds basically grew to twice and sometimes to as much as three times their initial sizes while the seeding continued, and maintained precipitation for several hours. During a test "to increase rainfall to even higher amounts when seeding", one specially prepared generator was used on six occasions to seed cumulus congestus clouds experimentally above a separate valley in the Rio Chicama drainage area burning 3.3 g/min (200 g/h) directly into the inflow of the clouds. These grew extremely fast into cumulonimbus with large anvils, produced only small amounts of precipitation or none at all, as they developed into an upper level cloud deck and convection dissipated. These tests were discontinued.

After severe drought conditions three years prior to 1977, Weather Modification Inc. (Schnell, personal notes, 1977) operated a cloud seeding program from mid June through mid September 1977 in Northern California that was cut short before its planned termination due to the fact that heavy precipitation had reached the ground during and shortly after seedings. There was heavy snow on Mount Shasta in August, and one seeding contributed towards the extinction of a large forest fire in the Siskiyou Mountains. The decision to shorten the program was initiated by politicians who – besides other reasons they gave – were afraid that seeding related rainfall increases would reach the nut plantations shortly before harvest time. Unfortunately, and against the strongly-voiced wishes of the farmers within the projects area, the program was cut short anyway. The seeding rate there was mostly 20 to 40 g of AgI/cloud or developing cell.

During the year-round Popeye cloud seeding program from 1966 through 1972, over the Laos Panhandle, carried out by the U.S. Air Force in cooperation with the U.S. Navy and the U.S. Marine Corps, AgI pyrodrops were used in drastically reduced amounts after initially heavy to very heavy amounts of seeding material per cloud did not result in rainfall increases but instead showed considerable precipitation decreases. The operation continued using seeding amounts even smaller and copious amounts of precipitation resulted, often exceeding several hundred percent over expected rainfall

amounts (Saint-Amand, 1999, private communication).

Most successful operators like Court, Davis, Elliot, Henderson, Howell, Krick, Simpson, and Walser, among many others, obtained and reported good precipitation increases by using small amounts of seeding agent to influence the dynamics of the clouds, not by using large amounts of seeding agent to violently increase them. Joanne Simpson obtained increases of 500%, using only 60 g of AgI per cloud on large maritime cumulus congestus over Florida (Todd and Howell, 1985). The seeding signatures reported by all these successful operators consisted of measured or recorded increases in "rainfall water reaching the ground", for which, in the opinion of many clients, there is no substitute! Almost always, those operators used AgI seeding rates which were in general much smaller than those suggested by the Rosenfeld/Woodley Cold Cloud Conceptual Seeding Model.

It would be of interest to document the seeding of cumulus congestus clouds with modest AgI amounts in such a way that the dynamics of the seeded clouds be enhanced slowly and over a period of time; the desired result being additional production of rain water to ground without the clouds reaching the cumulonimbus stage with large anvils or even cirrus densus over extended areas.

3. SUGGESTION

In conclusion, I would not hesitate to recommend adequate documentation of future observations on cloud development before, during, and after treatments with either the smaller or the larger silver iodide amounts, and it is furthermore suggested to test the Rosenfeld/Woodley Cold Cloud Conceptual Seeding Model during one or more future El Niño seasons by treating large clouds and cloud systems offshore of the coast of California with a goal of reducing flood potential.

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