EVIDENCE OF EFFECTIVENESS OF HYGROSCOPIC COLLECTOR EMBRYOS

Albert H. Schnell
AIRAO Enterprises
Pagosa Springs, CO

Wallace E. Howell
Certified Consulting Meteorologist
Del Mar, CA

ABSTRACT: Faced with insufficient rainfall, the Cabildo (Municipality) of Grand Canary has experimented with cloud seeding as well as expanding its use of desalinated sea water. Its natural rainfall comes almost entirely from maritime clouds blown against the windward side of the island during disturbed weather, too warm for glaciogenic seeding. The lifetime of these clouds is usually too short for full growth of natural collector drops to produce rain. The cloud seeding program, carried out for eight winter seasons 1983-84 to 1990-91 by AIRAO Enterprises, a Colorado company, dispersed 20 μm diameter hygroscopic droplets as collector embryos in updrafts at cloud base which were capable of shortening the time required for appearance of collectors and production of rain. The material used was a highly-concentrated eutectic solution of urea and ammonium nitrate in distilled water. Evaluation of the rainfall results is being reported elsewhere. Here we present cloud droplet collector impact samples and raindrop impact samples, indicating substantial effects of the seeding in increasing the population of collector drops that fell as rain within the time available. These results are consistent with the theory that underlay the operational design.

1. INTRODUCTION

Observations are reported of the results of seeding low-level shallow warm maritime clouds with hygroscopic collector embryos to induce increased rainfall.

During the rainfall seasons of 1952 to 1957 in Cuba, one of us (WEH) conducted hygroscopic cloud seeding experiments with NaCl in wild clouds (Howell, 1960). The term wild is used here to mean clouds in their natural state, subject to the whole array of natural influences, as distinct from clouds captured and confined in computer models. In these early observations of cloud seeding with finely ground salt, the smallest tradewind clouds apparently dissipated faster, middling clouds around 4000 ft deep showed no effect, and larger ones developed rain more frequently than similar unseeded wild clouds nearby.

This and other information led us to the paradigm of a cloud into which large hygroscopic nuclei were introduced as the embryos of drops that would become collectors of wild cloud droplets sooner than in unseeded clouds, thus speeding the onset of rainfall, the consequent gravitational unloading of the cloud, and the imbedding in it of heat released by condensation of the unloaded water. That leads us to present a small sample of pictures of droplet and drop impacts found in rainfalls from unseeded and seeded clouds.

2. THE CONTEXT

The Canary Islands lie at the southeastern end of the Atlantic subtropical high where polar air tends to subside under Coriolis effects, producing dry air aloft over a relatively shallow, cool marine layer. Most of the island's rainfall occurs when winter disturbances deepen the marine layer and drive clouds up the island's windward slope. The result is often a close call between time required for rain formation in a cloud and the time available before the cloud passes the crest and starts downslope. The aim of the seeding was to shorten the time required by furnishing a population of effective collector embryos that would grow quickly by condensation, then by collision with wild cloud droplets, and become very effective collector drops and soon raindrops within the time available.

The seeding material used was a nearly eutectic solution of ammonium nitrate and urea in distilled water. This material was sprayed into updrafts at cloud base, using 50 No. 66000 stainless steel nozzles supplied by Mee Industries, Inc., at a pressure of 700 pounds per square inch. They discharged the solution at a rate of about 70 $ml \cdot s^{-1}$ in droplets with a volume median diameter close to 20 μm. This seeding material hydrolizes in successive steps, maintaining a lower equilibrium vapor pressure than if it hydrolized in a single jump. St.-Amand (1970 & personal communication, 1995) states that "this solution of urea and ammonium nitrate is a eutectic with those two phases, with each other and with water. The material is present as an un-ionized complex that includes the water, and this alone gives a water vapor suppression to about 25% of that over pure water. As the material is diluted by picking up water from air, the eutectic breaks down to some extent and the ammonium nitrate component of the mixture then acts separately and ionizes. This gives ions of NO_3- and NH_3+. Each of these two ions now contributes to the vapor pressure lowering as dilution increases. The urea does not ionize, but it does contribute to suppress the vapor pressure also, and this contributes to effective vapor pick-up at dilutions well beyond what other substances give and at much smaller droplet sizes for the solution. There is little doubt that the material chosen is about the best that could be found in terms of its effectiveness and of its beneficial effects on the terrain." He adds, "The undiluted agent has a vapor pressure of 7.9 mm Hg at 25.8°C." The relative humidity is then 25%. Thus it is by far the most efficient agent so far reported in operational use.

3. THE OBSERVATIONS

The observations were made by a technique introduced by V. J. Schaefer, exposing a small slide of very thin aluminum foil out the window of the airplane into the windstream ahead of one of the propellers, exposing it for one second to impact of droplets and drops, using an instrument on loan from the University of Wyoming. A total of 84 droplet and drop impact samples was obtained during the last six of eight winter seasons 1985-91 over Grand Canary when AIRAO Enterprises of Pagosa Springs, Colorado, carried out hygroscopic seeding at Grand Canary.

Figure 1, which was used as operational guidance, shows at the lower right the average air volume in which typical seedable clouds having depths of between 700 and 1300 m were mostly found, and also the air volume in which collector drops resulting from the seeding are expected. Further explanation of this figure is found in the *Handbook of Applied Meteorology* (Houghton, 1985) at page 1084 *et seq.*

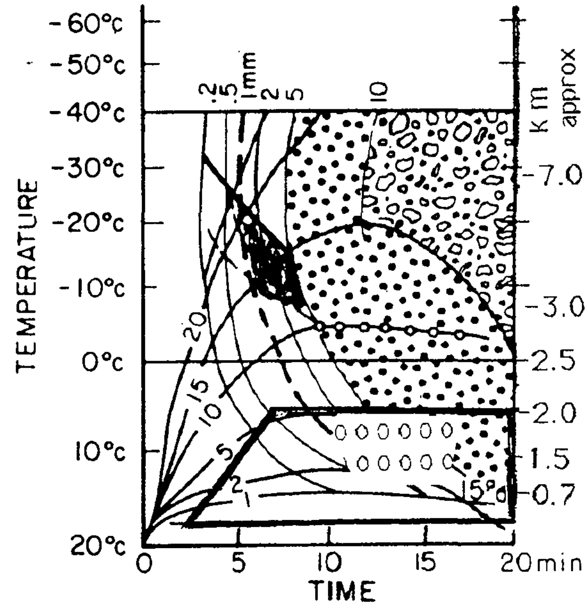

Figure 1. Average cloud conditions under which seedable clouds of 700 to 1300 m depth were found, and approximate level where hygroscopic collector embryos(ooooo) became effective collectors. Adopted from Houghton (1985) p 1087. Fig. 38.15.

Figure 2 is a sample of collector drops taken near the top of a cloud at 1515 m altitude that had been seeded at cloud base and had developed potential collector drops not found in the tops of unseeded clouds. Table 1 gives details. Figures 3 through 8 show paired samples taken in or near the bases of unseeded and seeded clouds, showing in the seeded cases raindrops capable of reaching the ground. The unseeded samples were made shortly before seeding began, and the others shortly after it had ended. All illustrations are reproduced on a scale of 1:1.

It is of interest that effective collectors were not found in clouds which were not seeded and that they did not produce rainfall even though their depths mostly exceeded 1000 m and often reached to about 1500 m.

Figure 3 shows, on the left side, droplet impacts within the lower portion of the seeded cloud. There had been no rainfall before seeding. The right side shows raindrops falling below cloud base from a

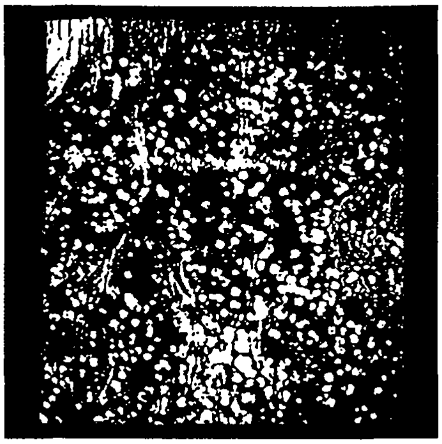

Figure 2. Illustrative of collector droplets sampled at the location listed in Table 1.

general rainfall falling from the seeded cloud volume that had moved over the island.

Figures 4 through 8 show, to the left, raindrop impacts from clouds before seeding, and, to the right, raindrop impacts after these same clouds were seeded. It is of interest that all the samples exhibit a nearly uniform five-fold larger average drop volume and three-fold greater population for raindrops from seeded clouds over unseeded. Table 1 gives additional information on the impacts from Figures 2 through 8.

4. DISCUSSION

The Grand Canary seeding was an operational project, not an academic experiment. Any scientific work, including that here reported, had to be piggybacked on operations as opportunities arose. Yet the pressure to present an academic-style evaluation for a final report was unavoidable. Randomized no-seed comparison events were out of the question; the best we could do was to call "ghost" missions when weather was appropriate for seeding but it could not be done for some reason not associated with the rain, such as a pilot being unavailable, flight clearance refused, or, in one case, a crosswind too strong for take-off. There were also occasional demands from the Cabildo to stop a seeding in progress or to suspend seeding for other reasons, including too much rain. It will be no surprise that the evaluation presented to the Cabildo would not meet the standards of the National Academy of Science for credibility.

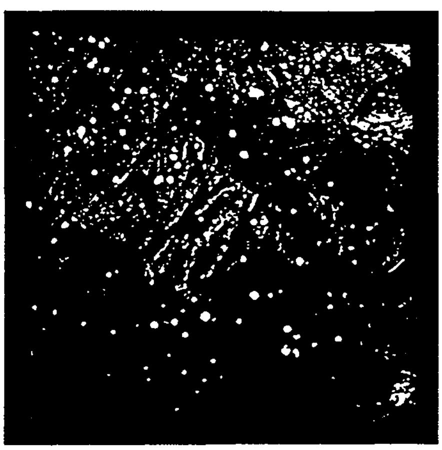

Figure 3 left. See Table 1.

Figure 3 right. See Table 1.

Figure 4 left. See Table 1.

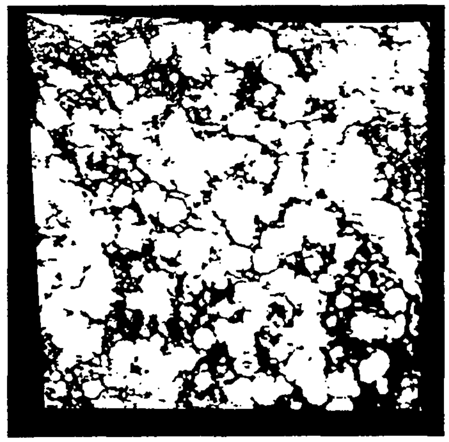

Figure 4 right. See Table 1.

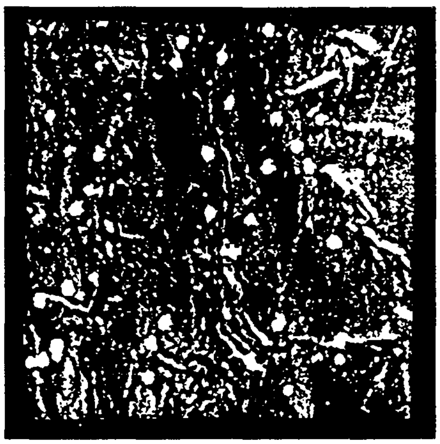

Figure 5 left. See Table 1.

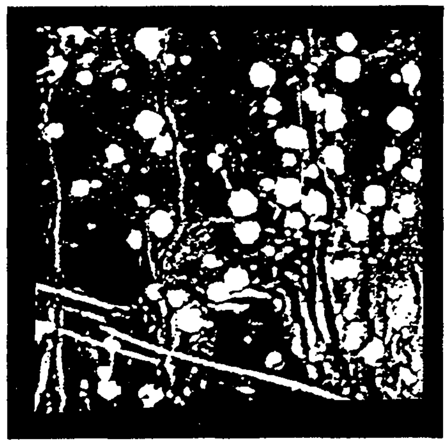

Figure 5 right. See Table 1.

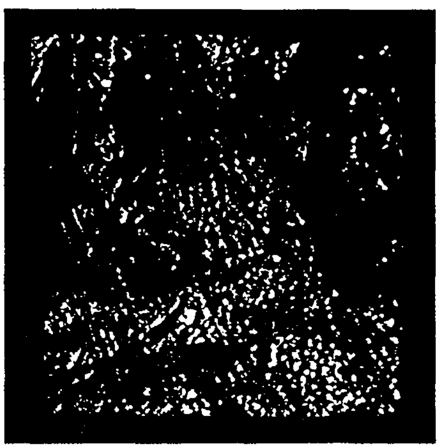

Figure 6 left. See Table 1.

Figure 6 right. See Table 1.

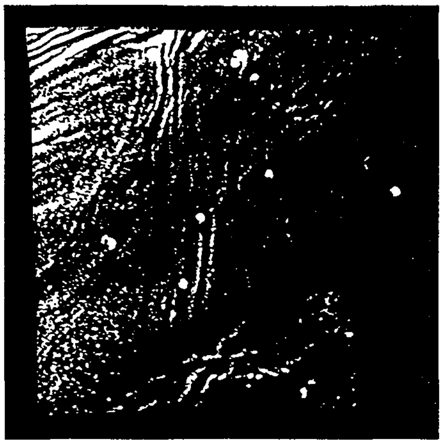

Figure 7 left. See Table 1.

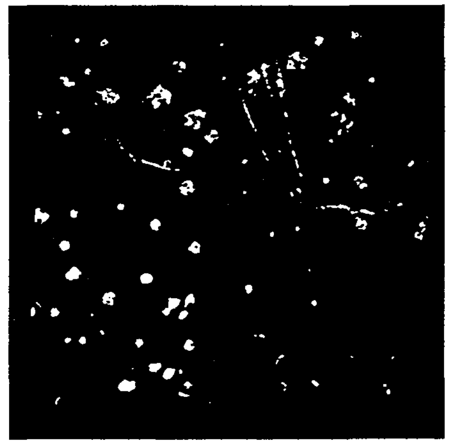

Figure 7 right. See Table 1.

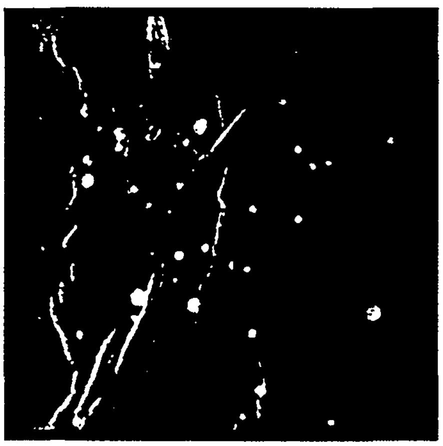

Figure 8 left. See Table 1.

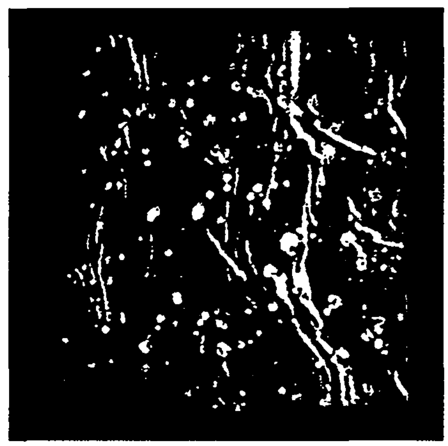

Figure 8 right. See Table 1.

The best we can state is that we probed for evidence wherever we could, and that all we were able to find supported but did not prove the elements of the paradigm. The above is the result of one of those probes.

One reason for calling attention to the Canary Island setting is that it presents an exceptional opportunity for a random cross-over between Grand Canary and Tenerife. These islands have similar rainfall regimes and both islands are currently paying a very stiff rate for alternative water from desalination.

5. CONCLUSION

The evidence presented here is compatible with the conceptual model of hygroscopic cloud seeding presented by Todd and Howell (1985) as applied to relatively shallow, warm maritime clouds where the difference between time available for cloud passage across a narrowly-defined orographic target and time required for collector drops to form and become raindrops was critical to the formation of rain. Hygroscopic seeding in these clouds was associated with more and larger collector drops and raindrops in seeded clouds compared with similar unseeded clouds nearby. These changes were attributed to seeding with hygroscopic droplets of a eutectic

Table 1. Additional information on figures 2 to 8

Figure	Date	Time: GMT	Seeded?	Cloud base, m	T_c °C	LWC gm^{-3}	Updraft ms^{-1}	Position, heading and DME from VOR, nm	Sampling altitude m
2	010887	1400	Yes	450	10.0	0.6	0	300°, 8.0 GDV	1515
	Sample taken near cloud top; cloud top at 1650 m measured with T_c = 4.0°C, LWC at sample altitude = 0.8 gm^{-3}, updrafts at sample altitude and top = 0 ms^{-1}.								
3L	010887	1331	During	424	17.0	0.1 to 0.2	0.5	325°, 8.0 GDV	636
3R	010887	1417	Yes					190°, 6.5 GDV	330
	Measured cloud thickness = 1200 m								
4L	120187	1638	No	575	22.2	0.2 to 0.6	>0.5	118°, 43.3 TFS	575
4R	120187	1709	Yes			>2.0	0.5 to 2.0	110°, 42.0 TFS	470
	Estimated cloud thickness during seeding = 900 variable to 1100 m								
5L	012888	0848	No	303	14.0	0.2	>0.5	170°, 7.5 GDV	303
5R	012888	0932	Yes	773	11.0	0.2	>0.5	310°, 11.4 GDV	773
	Estimated cloud thickness before seeding = 900 variable to 1000 m								
6L	010889	1503	No	242	18.6	0.03	0.3	180°, 7.5 GDV	242
6R	010889	1649	Yes	394	16.2	0.06	0.3	115°, 48.5 TFS	394
	Estimated cloud thickness during seeding = 1000 m								
7L	021891	0904	No	303	9.0	0.05	0.5	170°, 2.0 GDV	303
7R	021891	1001	Yes	1061	4.3	0.03	0.5	330°, 7.7 GDV	1061
	Estimated cloud thickness during seeding = 1100 m								
8L	030791	1145	No	546	11.3	0.03	2.5	285°, 21.0 GDV	546
8R	030791	1226	During	318	11.9	0.07	3.0	310°, 19.0 GDV	318
	Estimated cloud thickness during seeding = >1500 m; seeding operation interrupted on sponsor's demand due to a Meteorological Service forecast of possible flooding.								
Note:	GDV = Gando VOR, TFS = Tenerife South VOR, DME distances are nautical miles from the VOR-station. Most samples obtained near shore line, except for samples in Fig. 2, 8L and 8R, which were obtained off shore, sample 3R was taken over land before landing but still flying below the seeded cloud mass. T_c measured at cloud base. Updrafts determined by aircraft variometer. None of the clouds sampled as in figures 2 through 8R extended above the freezing level.								

solution of ammonium nitrate and urea of around 20 μm diameter in quantities of about 20 l per seeding run. This material appears to be the most efficient available in terms of the amount of water condensed into collector droplets in proportion to quantity of seeding material.

Acknowledgements

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6. REFERENCES

Howell, W. E., 1960: Seeding of Clouds in Tropical Climates. Jour Irrig & Drainage Div, Proc Amer Soc of Civil Eng, Mar 1960, pp 55-77.

St.-Amand, P.: Atmospheric Applications of Hygroscopic Agents. Naval Weapons Center, China Lake, NWC TP 5190, 26 pp.

Todd, C. J., and W. E. Howell, 1985: Weather Modification. In Handbook of Applied Meteorology, D. D. Hougton, Ed. John Wiley & Sons.