1948—1949 Trials of the Schaefer-Langmuir Cloud-Seeding Technique in Hawaii[1]

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Abstract

Fifteen tests during 1948—49 involving thirty-seven individual cloud inoculations over the islands of Lanai and Molokai are described. With regard to the rôle of the dry ice in causing the observed rainfall, the tests are too few in number to be considered conclusive, but the large rainfall values associated with seeded clouds are of particular interest. The largest rains seem to be associated with clouds where cloud top temperatures are slightly colder than 0° C and such clouds are also relatively thick. The relative importance of cloud thickness and temperature cannot be determined from the available data.

There exists at the time of this writing divergence of opinion concerning the efficacy of seeding clouds with dry ice for the production of rain.

The current status of the problem was succinctly stated by BERGERON (1949). "The question . . . is . . . no longer whether precipitation can be released artificially, but rather whether such a release can produce an appreciable amount of rainfall, and when and where this could be done."

The early experiments in Hawaii have already been reported (LEOPOLD and HALSTEAD 1948) and the present paper presents the results of further seeding experiments conducted in a more or less comparable manner. The consistent location of seeded clouds from day to day, the large number of rain gages, and high elevation of the freezing level make the Hawaiian experiments of some interest, though both the earlier and the current sets of data suffer the disadvantage of no observations with radar.

In all but one of the trials discussed here, the dry ice was ground to a size resembling granulated sugar. The plane was a twin-engined Beechcraft in which 400—500 pounds of dry ice were carried on a given flight. The dry ice was dispersed from a hopper having a sliding door, and from which 150 pounds of the granulated material could be dropped out in a time period of five to seven seconds. Flying at a speed of 140 mph the seeding rate was approximately 12.5 pounds per 100 feet of horizontal flight. The cloud towers seeded were ordinarily of such a width horizontally, about one-quarter mile, that the six seconds during which the dry ice was dropped was approximately the flight time across or through the top of the tower. For a seeding run the plane was flown just through or just over the cloud top.

The clouds seeded were those which occur over the central part of the Island of Lanai or over the Maunaloa area of the Western part of the Island of Molokai. These clouds on test days were cumulus congestus associated with the cloud line formed by the interaction of tradewind and sea breeze. These clouds have been described in detail in another paper (LEOPOLD 1949). The cloud type is important in considering the results because the convergence in the lower levels where the op-

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posing winds meet provides a source of vertical motion in the upper cloud which is not found in the common air mass cumuli. It is possible, then, that these clouds possess the prolonged "path of fall" of droplets referred to by BERGERON (1949, p. 34), even though the total cloud thickness seldom exceeded 12,000 feet at the time of seeding.

It can be stated with some certainty that when the cumulus clouds are capped by a temperature inversion of 1° C or more as is the normal case in Hawaii, seeding with dry ice either produces a partial dissipation of the cloud or no noticeable effect; the clouds do not increase in height and the rain, if any, is of insignificant amount. This is based on a large number of observations during the 1947—1948 tests including not only tests made by the authors but many others run independently by various companies in Hawaii. The conclusion was sufficiently well established during the first year that all later tests reported here were conducted on days when the Honolulu 1500 Z (0500 LST) radiosonde indicated the absence of the tradewind subsidence inversion or that the inversion was less than 1° C. Changes in the strength of the subsidence inversion occur rapidly in the Hawaiian area. On several occasions the 0500 LST raob showed no inversion, on the basis of which a seeding flight was made. However, by 1000 LST, after the flight had already begun a definite inversion had formed, as could be seen by the concordance of cloud tops and by temperature measurements taken in flight.

Our experience, furthermore, indicates that large horizontal wind shear through the levels between base and top of cloud tends to blow off the top of the cloud, and rain will not result.

An initial depression of the cloud top immediately following seeding has been observed by nearly all experimenters. Experience in Hawaii indicates that the cloud will recover from this initial depression and will grow even higher than its pre-seeding condition only if the cloud was actively growing in height at the time of seeding. Growing clouds over Hawaii usually have "harder", more well-defined tops than those not in the process of growing which tend to be wispy-edged. The wispy edges, the authors believe to be either a dissipating phenomenon or a result of ice-crystal formation in the clouds.

It is typical for moisture values to be moderately large below the subsidence inversion, decreasing sharply above. On days when the inversion is absent, moisture occurs through a much thicker layer, and experience points toward large values through a deep layer as a feature conducive to rain from a seeded cloud.

The Hawaiian experiments share with many others the difficulty of defining a practical and definite control against which the results of seeding can be compared. The tests reported here were all made on days of small or no temperature inversion. On such days, all clouds in the area tend to be thicker than usual. The same conditions promote the growth of the sea-breeze clouds. For these reasons, it is obvious that the days chosen for test are the days on which natural rainfall is most likely to occur on the test islands, Molokai and Lanai.

On the other hand, it is a fact widely known in Hawaii that even on such days, when unusual build-up of cumulus clouds can be seen everywhere, dark threatening sea-breeze clouds remain nearly all day over the Islands of Molokai, Lanai and certain other areas, but seldom does more than a light shower occur. One reason for this undoubtedly lies in the fact that such a cloud, whose appearance suggests imminent rain, often extends nearly to the freezing level but seldom into it. The freezing level over Hawaii usually lies between 14,000 and 18,000 feet, while the cloud tops on days of no inversion generally lie between 10,000 and 13,000 feet. On such a day a few cumulonimbus usually can be seen somewhere in the Territory. It appears, then, that these conditions are unusually favorable for the use of dry ice as an agent to start the rain process which is potentially near but whose unaided initiation is relatively infrequent.

Result of tests

In the 1948—1949 series, tests made on 6 days over the Island of Lanai and 9 days over the Island of Molokai include adequate data. Certain additional tests are omitted because necessary data are not available or because circumstances made the conditions of test sufficiently different from the standard that the tests cannot be considered comparable. For example, some clouds were seeded which lay entirely over the ocean and though rain was observed, it could not be measured. In certain others, wind and temperature conditions changed so rapidly during the test that the Honolulu upper-air data were considered completely unrepresentative of the test area.

On a given day of test, one to five seeding runs were made. Data on individual runs, including summaries of cloud changes observed, are included in Table 3 appended to this report. The rainfall quantities measured are summarized in Table 1. These data represent the arithmetic mean rainfall in five gages except where indicated.[1]

Table 1. Summary of all Hawaiian experiments, 1947—1949.

Number of Test Days: 27.

Cases of Cloud Tops Warmer than 0 °C		Cases of Cloud Tops Colder than 0 °C	
No. of Cases	Rain at Ground or Other Notes	No. of Cases	Rain at Ground or Other Notes
1	1.25[1]	1	2.18[2]
1	0.03	1	1.95[2]
6	Trace	1	1.88 M
			0.78 L
2	Virga	1	0.60[2]
3	Cloud dissipated	1	0.50
6	No change observed	1	0.25[2]
19		1	Trace
		1	Cloud dissipated
		8	

[1] Cloud went above freezing level after seeding and during rain.

[2] Mean of 5 gages in seeded area; rainfall figures without superscript are for an individual gage under seeded cloud.

M Molokai; L Lanai.

It will be noted that the rainfall quantities measured in association with the experiments reported here are considerably larger than those reported by ORR et al. (1950), COONS et al. (1948 a) and most other workers. In the Lanai test of June 28, 1948, 1.75 inches fell in 45 minutes at Lanai City at the outer edge of the cloud. A total of 3.40 inches fell in the Palawai Basin directly beneath the seeded cloud. This rain began 19 minutes following seeding. It is the largest rainfall on any day in June in a 45-year record on that island.

[1] Gages used in this analysis: Lanai gage numbers 671, 672, 674, 681, 683; Molokai gage numbers 513, 514, 518, 519, 522. Locations indicated by maps of LEOPOLD, BURN, STIDD (1948).

The interpretation of the data shown in the table will be facilitated by a discussion of certain problems which will immediately occur to the reader.

Did any rain precede seeding, and was rain occurring in the general area?

This question was stressed by COONS, GENTRY and GUNN (1948 c) who noted in a particular test that radar echoes from snow were existing or were forming in the immediate vicinity at the time of seeding. "Without the facilities utilized . . ., especially the radar, it probably would have been concluded that the one inch of snow was definitely a result of the cloud-seeding operation (p. 18)."

Theirs is a cogent argument. From the standpoint of agriculture, however, it is not necessary to prove that dry ice can precipitate rain when no rain would have fallen. The question is rather: was the amount or timing of rainfall affected by seeding?

The Hawaiian experiments were all run on days of unusually high probability of natural rainfall, and rain usually did occur in the area near or at the time of rain from the seeded cloud. However, rainfall amounts under the test clouds were generally larger than those in the vicinity.

As mentioned earlier, it is difficult to define a practical and definite control by which we may compare the results of seeding against circumstances which might have occurred had no seeding taken place. As a step in this direction, results for the 8 experiments where clouds colder than freezing were seeded are presented in Table 2 and compared with rain-

Table 2. Mean rainfall amounts measured by specific rain gages on days of test and similar days of no test.

Rainfall	0—.01	.01—.09	.10—.99	> 1.00	Total
	(Rainfall values are average of 5 gages, Lanai)				
Non-seeded days:					
No. of days	26	25	21	5	77
% of total days	34	32	27	7	
Seeded Days:					
No. of days	3	2	1	2	8
% of total days	37	25	12	25	

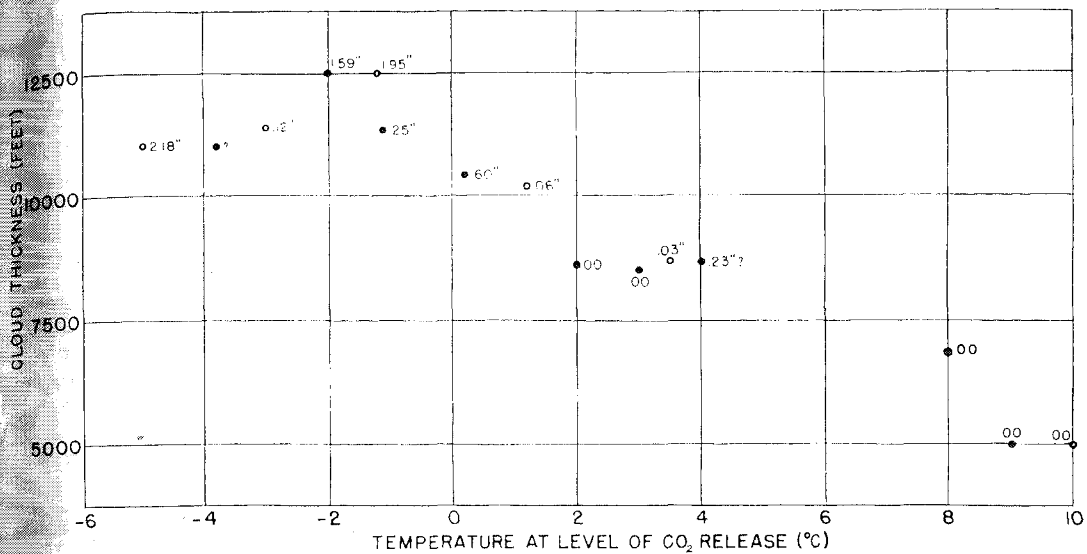

Fig. 1. Rainfall amounts associated with seeded clouds of given temperature and thickness. Temperature given are at the level of CO_2 release, approximately at the top of the cloud.

fall amounts occurring on days where no seeding was done and similar upper-air and cloud conditions existed.

Because there are only 8 such cases, a statistical test for significant differences in the rainfall frequency distributions on these days versus non-seeded days will not yield a significant result. The results are nevertheless of interest even if definite conclusions cannot be reached.

In what ways did rain occurring after seeding appear to be related to seeding?

As previously mentioned, rainfall in each case followed the seeding by only a short interval of time or rain intensity increased. In most instances, rain endured for less than an hour. In the case of Test 1 L and 5 L, however, rainfall continued for approximately three hours. The heaviest rainfall intensity in both of these instances occurred between 15 and 30 minutes following seeding. Clouds having hard or well-defined edges at the top were chosen for seeding with the idea that rain in such clouds had not yet developed. Lacking radar this was the best evidence concerning the state of the moisture droplets in the cloud. Other experimenters equipped with radar equipment have indicated that this feature is indicative of the lack of formation of ice crystals within the cloud (ORR et al. 1950).

What Was the Relation between Rain Cloud and 0° C Isotherm?

Data plotted in fig. 1 indicate that for the 15 days of experiments in 1948—1949 reported here, a difference in the rainfall amounts exists between those where the cloud-top temperature was warmer than freezing and those where the cloud-top temperature was colder than freezing. Since the freezing level in Hawaii tends to be at roughly a uniform height, this represents, as indicated in fig. 1, not only colder temperatures but also greater cloud thickness. A correlation of cloud thickness with observed rainfall was indicated by the previous Hawaiian experiments (LEOPOLD and HALSTEAD 1948), and its importance has been stressed by VIERHOUT (1950). Since even the coldest temperatures observed at the cloud tops were only — 5° C, it is difficult to evaluate the relative importance of temperature and cloud thickness.

Conclusions

No definite conclusions can be drawn from these data owing to the small number of

Table 3 a. CO_2 Tests
Island

No. & Date	Data from 1500 Z Sounding Honolulu Inversion			Times of Drop LST	Quantity of CO_2	Height and Thickness	
	Pressure At Base	Strength[1]	Pressure & Altitude at Moisture Break			Base	Top
				(Began 3 min. scatter			
1 M 6/28/48	701 mb	0.4	700 mb	13: 53 LST)	100 lbs	3,000 ft	15,500 ft
	9,800 ft		9,850 ft	14: 03	100	3,000	15,500
2 M 6/29/48	730 mb	0.3	730 mb	12: 00	150	3,000	8,000
	8,775 ft		8,775 ft	14: 20	150	3,000	8,000
3 M 7/9/48	680 mb	1.5	700 mb	13: 17	100	2,900	11,000
	10,600 ft		10,500 ft	13: 30	100	2,900	12,100
				13: 36	50	2,900	11,300
				15: 34	100	2,900	8,000
				15: 39	50	2,900	8,300
4 M 8/3/48	632 mb	0.8	755 mb	14: 22	100	2,500	9,500
	12,450 ft		7,900 ft	14: 32	100	2,500	10,000
				14: 45	100	2,500	10,500
5 M 9/22/48	659 mb	1.4	631 mb	13: 02	100	4,000	11,500
	11,425 ft		12,950 ft	13: 19	100	4,000	12,500
				13: 29	100	4,000	13,000
6 M 9/24/48	525 mb	0.7	525 mb	12: 35	75	2,500	13,800
	17,100 ft		17,100 ft	12: 47	75	2,500	14,500
				12: 55	150	2,500	14,800
7 M 11/9/48	608 mb	0.7	610 mb	13: 19	150	2,000	8,160
	13,425 ft		13,375 ft				
8 M 11/27/48	850 mb	0.3	None	14: 33[2]	150	2,000	14,000
			None	15: 04[3]	150	2,000	13,100
9 M 6/13/49	585 mb	0.5	573 mb	13: 55	100	2,500	12,900
	14,400 ft		14,900 ft				

[1] Figures given are approximately $\frac{\Theta_E \text{ Top} - \Theta_E \text{ Base}}{4}$ °K.

[2] Fine granules.

[3] Coarse granules.

in 1948—1949.
of Molokai.

of Cloud	Alt. & Temp. at Level Ice Release		Remarks on Cloud and Rainfall	Mean Rainfall 5 Gagess
Thickness	Alt.	Temp. from Honolulu Sonding		
12,500 ft	14,300 ft	— 2.0 °C	12:00 LST weather report from Molokai indicated rain showers. Rain was not visible to pilot at altitude. Ice formed on plane while seeding. Heavy rain was seen from plane at 14:33 LST under seeded towers.	1.59 in.
12,500	14,000	— 1.2		
5,000	8,000	+ 9.0	No rain.	0.00
5,000	8,000	+ 9.0		
8,100	10,700	+ 5.5	Light showers began at 13:10 LST from cloud seeded at 13:17 LST. A sudden increase in rain could be seen at 13:18 LST by observers on Lanai (shown in photographs). At 13:47 LST a further increase of rain was noted. At 13:56 LST rain covered most of West Molokai as seen from Lanai.	0.23
9,200	12,100	+ 4.0		
8,400	11,500	+ 5.2		
5,100	8,000 ·	+ 8.0		
5,400	8,300	+ 8.2		
7,000	9,500	+ 5.5	Cloud dissipated in 2 minutes after final seeding. No rain associated with seeded cloud. Clouds in vicinity showed wind shear with tops and bases separating.	0.00
7,500	10,000	+ 4.5		
8,000	10,500	+ 3.0		
7,200	11,300	+ 2.1	No rain. Cloud dissipated.	0.00
8,200	12,100	+ 2.0		
8,700	12,400	+ 2.0		
11,300	13,500	— 1.1	Rain was falling from cloud at time of seeding. At time coincident with first seeding, observer on Lanai noted darkening of cloud and a second shaft of rain from base of cloud. At 12:43 LST rain covered 10 times the area prior to seeding. Rain activity decreased at 12:55 LST and a new shower began at 13:04 LST. Cloud tops flattened out beginning at 13:04 LST.	0.25
12,000	14,000	— 2.0		
12,300	14,300	— 2.5		
6,160	8,000	+ 8.0	Cloud dissipated rapidly.	0.00
12,000	14,500	— 3.8	Rain at time of seeding. Cloud tops lowered after first seeding (14:40 LST); at 15:05 LST rapid dissipation of cloud could be seen from Lanai.	0.00
11,100	12,800	— 0.1		
10,400	12,500	+ 0.2	Showers over seeded area at 12:15 LST. Of short duration and small amount. Heavy rain observed from plane under seeded cloud at 14:10 LST.	0.60

in 1948—1949.

of Lanai.

of Cloud	Alt. & Temp. at Level Ice Release		Remarks on Cloud and Rainfall	Mean Rainfall 5 Gages
Thickness	Alt.	Temp. from Honolulu Sounding		
12,500 ft 11,500 11,500	13,800 ft 14,000 14,000	− 1.0 °C − 1.2	Between 1 and 2 in. fell previous day. Cloud built rapidly in 2 min. following ice but 14 min. after seeding, top of cloud was 1,000 ft. lower. Rain at Lanai City began at 13:15 LST and in Palawai Basin (seeded area) about 13:15 LST.	1.95 in.
10,200	12,000	+ 1.2	Rain had occurred in hour previous to test. Tops of CU were flattened into As at 7,000 ft. At 13:53 LST plane flew under seeded area and encountered light rain and moderate turbulence.	0.06
8,500 8,600 8,500	10,500 10,600 10,000	+ 3.5 + 3.2 + 3.5	Cloud top dropped 500 ft 4 minutes after 14:27 LST. Large central portion of cloud dissipated. At 15:00 LST rain was observed from plane and ground directly below seeded cloud. No other rain on Lanai or Molokai. Stopped raining at 15:30 LST.	0.03
	6,900 6,700	+ 9.8 +10.2	No rain.	0.00
11,000 11,000 9,000 9,000	14,000 14,000 12,000 12,000	− 5.0 − 5.0 − 3.0 − 3.0	Small showers fell in morning but were not associated with CO_2 drop in A. M. Cloud seeded was not highest cloud in area but was in formative process with well defined hard tops. Cloud was small in area. Rain began as a single shaft directly below point where plane was seen to emerge from cloud (700 ft below top of cloud). Rain rapidly spread over wide area.	2.18
11,400 11,400	14,400 14,400	− 3.2 − 3.2	No indication of rising cloud tops after seeding. Top of cloud dissipated after second seeding and became separated from lower portion. Tops became 8,000 ft by 13:25 LST. Moderate rain was observed at 13:30 LST when plane flew under seeded cloud.	0.12

tests and the lack of suitable control. Nevertheless, it is important that all pertinent data on the subject of cloud inoculation be added to the literature. The present experiments are of particular interest because of the large rainfalls which were experienced under the seeded clouds and very possibly related to the inoculation.

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