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WEATHER MODIFICATION ACTIVITIES IN TAIWAN, 1951-1978

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Abstract. Weather modification in Taiwan has been going on for more than 20 years, which makes it one of the longest continuously running operation projects in the world. The three goals of the program are enhancement of precipitation for hydroelectricity, agriculture, and drought-relief. Evaluation efforts using simple least squares regression indicate a 44% increase. Recent aircraft seedings to relieve short droughts aroused considerable public interest.

1. INTRODUCTION

The first modern effort to modify weather in Taiwan occurred on the 22nd of January, 1951, when the Taiwan Power Co. (TPC) began experiments using aircraft to dispense dry ice and a colloidal silver iodide solution into clouds to increase the rainfall over the Sun Moon Lake area, the largest reservoir for hydroelectric power generation in Taiwan. In April, 1952 the Rain Stimulation Research Institute of Taiwan (RSRIT) was established under the auspicies of TPC, with support from the Chinese Petroleum Corporation and the Central Weather Bureau. Since then RSRIT has been the major organization responsible for conducting weather modification activities in Taiwan.

Ground generators were the major delivery systems from the winter of 1952 to 1978, except in 1951-1952 when only aircraft were used for seeding experiments (22 flights), and in 1977-1978 when aircraft were used to relieve drought spells temporarily. Balloons carrying dry ice into clouds were used in the springs and summers of 1956, 1959-1967, and 1970 along the western coast, mainly at Tainan (Fig. 1), for a total of 113 station days. Four hundred forty kg of dry ice were used. Ground generators were operated by local people, usually ranchers or power lines maintenance personnel, through telephone or telegraphic instructions from operation head quarters according to the weather conditions. On the average, generators were operated for a duration of 2.0-2.7 hours (Shieh, 1956; Tau, 1958; Lin, 1961; Lin, 1962; Lu, 1966; Lu, 1972; Lu, 1978).

Charcoal impregnated with 1% silver iodide was burned at the rate of 2.5-3.0 kg per hour. The decision to use impregnated charcoal was based on laboratory studies (Shieh, 1956), which compared the effectiveness of various silver iodide and lead iodide in charcoal, acetone solution, colloidal solution and water solution. The original generator was first modified in the spring of 1963, the result being that the smoke outlet was moved from the top to the middle of the three sides so as to reduce the outlet temperature. In 1966, the outlet was placed back on top, this time using better materials (Lu, 1966).

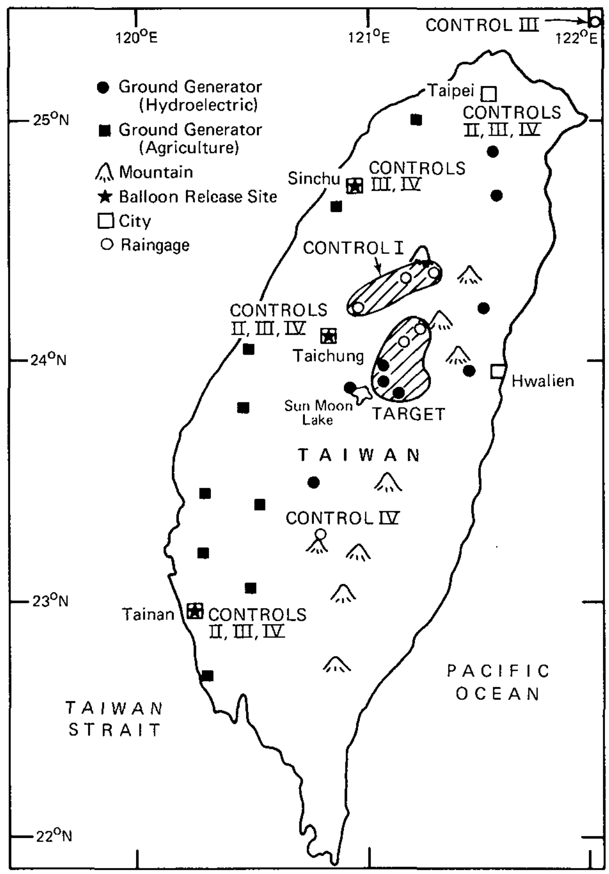

Figure 1. Locations of the Target and Control areas in evaluating the rainfall enhancement project around the Sun Moon Lake area.

2. THREE GOALS

The main goal of weather modification activities in Taiwan has been to increase precipitation for three subgoals: The first and the main thrust has been to increase the rainfall on the upstream areas of rivers which supply the water for generating hydroelectricity. Cloud seeding has been conducted mainly in the upstream areas of the Ta Chia and Cho Suay Rivers, both in central Taiwan, in the winters (November to March) of 1952-1959 and in all seasons from 1960 to 1979. After 1963, the beginning of the major "operational" phase of weather modification caused a substantial increase in generator operation time (Fig. 2).

The second subgoal has been to increase rainfall for agricultural usage, usually initiated by the Taiwan (Provincial) Food Bureau and conducted by RSRIT. The Taiwan Food Bureau is the main organization in Taiwan responsible for overseeing the production and distribution of grains and rice and has a keen interest in the supply of irrigation water. Ground generators in the western coastal plains (Fig. 1) operated mostly in the spring and summer from 1959 onward. The agriculturally oriented generator operations in this period are also shown in Figure 2. In addition, seeding experiments using balloons to carry dry ice into convective clouds were implemented along the western coast (Fig. 1).

The third subgoal has been to relieve short drought spells, partly for agricultural irrigation water and partly for municipal water supply. The effort devoted to the achievement of this subgoal was relatively sparse, occurring mainly in the spring of 1977 and the summer of 1978. Aircraft were used to deliver dry ice and saturated salt water into clouds from cloud top levels.

3. GEOGRAPHY AND CLIMATE

The island of Taiwan is 200 km southeast of mainland China and 1200 km southwest of Japan. It is inside the rectangle (120°E, 122°E) x (22°N, 26°N) and has an area of 36,000 km^2. About 80 mountains with altitudes over 3,000 m spreading from north to south along the Central Mountain Range exert substantial influence on the movement of weather systems and on local weather conditions. Major rivers flow westward into the Taiwan Strait. The island is surrounded by the Pacific Ocean, East China Sea, and South China Sea, which have tremendous impacts on the climate. The majority of the population resides along a strip of plains on the western coast, where most of the agricultural activities are conducted.

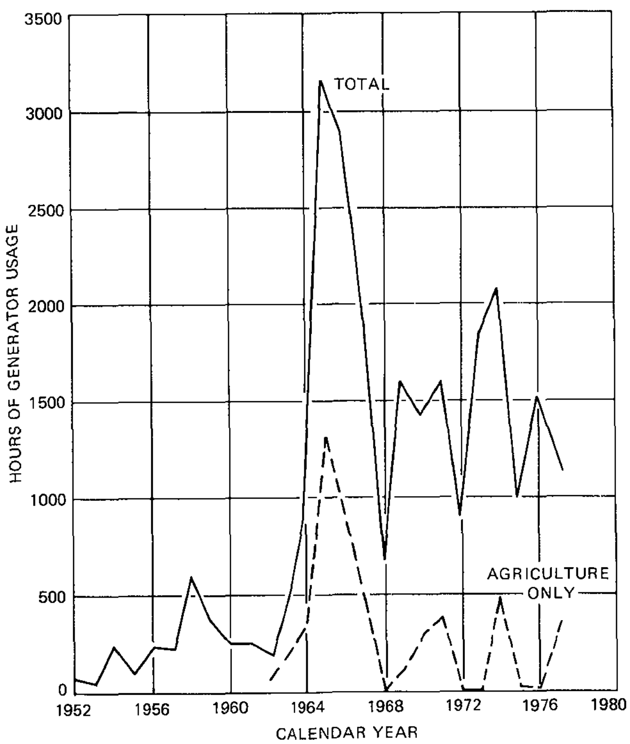

Figure 2. Yearly generator usage (in hours).

In general, the winter season (November to April) in Taiwan is relatively dry. Nearly continuous light rains fall in the northeastern part of the island, while rainfall on the western coast, where most power plants' reservoirs are located, can be best described as sparse. Steep slopes and the very short lengths of rivers further restrict the available water supply in winter. This dryness is reflected in the typically very low levels of reservoirs maintained by hydroelectric power plants.

When the dominant Mongolian high in the winter moves southeast toward Taiwan, it is intercepted by the Central Mountain Range. Upper air wind direction of this high is forced to switch from northwest to west. The moisture picked up when passing over the oceans is also forced to rise, thus creating favorable conditions for seeding using ground generators in the mountains. Seedings were carried out mainly when high pressure prevailed over mainland China, and when this high's front or upper trough approached Taiwan. The winter average freezing level aloft is 3,700 m (Lu, 1978). Most precipitation is in the form of rain, although the peaks get some snow.

Rainfall brought by typhoons becomes a major source of water supply in July, August, and September, so the need for cloud seeding in summer is not as urgent as in winter. Weather conditions in May and June are rather favorable for seeding, moisture is ample, and wind direction is usually from the southwest; thus, more seedings occurred in May than in any other month, except those of winter. The agricultural need for water in spring for planting and seedling developments also justifies cloud seeding to improve weather conditions.

4. EVALUATION EFFORTS

Efforts to evaluate winter cloud seeding activities by RSRIT from 1952 to 1977 were summarized in eight reports. The aircraft seeding project conducted in 1977 was reported by Lu (1978), Liu (1977), and Chu (1978).

The evaluation effort by RSRIT used a historical target-control approach. The technique used was simple regression, and the statistic used was difference/predicted ratio (see below). For each month, January to December, mean areal rainfalls were calculated for a chosen target in the mountain area (3 stations) and four control areas (3, 3, 5, and 5 stations) (Fig. 1). However, only seeding efforts related to hydroelectric reservoirs were evaluated. Agriculturally oriented seeding efforts (including balloon experiments) in the western coastal plains, due to lack of appropriate control areas, were not evaluated.

Simple regression equations were fitted by least squares to each target-control pair for each of the 12 months in 1923-1944. Out of 12 monthly regression equations, five (November to March) were selected in the evaluation effort for the hydroelectric subgoal. The multiple correlation, R, of the 20 regressions ranged from .616 to .966, with the better fits in February and March. For each of these five months, historical regression of each target-control pair was used to compute a predicted rainfall value for the target area, PT, during seeding years. This predicted value was then compared to the observed target rainfall, OT, as in the following difference/predicted ratio:

$$D = 100(OT - PT)/PT.$$

Table 1 shows the 5-month average of D for each year using matching of Target vs. Control I, and Target vs. Control IV. Control I is north of the target and at a similar altitude. Controls II to IV consist of stations widely spread over the western coast, at lower altitudes than the Target. Because Controls II, III, and IV overlap, it is not appropriate to average D values using all four Controls as in the RSRIT reports. Instead, only Control I and Control IV were used, for the following two reasons: First, coefficients of determination, R^2, of the historical regressions for Control IV are consistently larger than those of Controls II and III in each winter month. Second, R^2 of the historical regressions for Control IV are larger than those of Control I in December, January, and February.

Table 1. Difference/Predicted Ratios for Target vs. Control Rainfall Comparisons.

Year	Control Area I	Control Area IV	Avg.
1951-1952	-11	12	1
1952-1953	101	2	52
1953-1954	-9	-7	-8
1954-1955	188	62	125
1955-1956	13	-12	1
1956-1957	22	-1	11
1957-1958	66	5	36
1958-1959	-27	-62	-45
1959-1960	-26	200	87
1960-1961	36	-20	8
1961-1962	-31	-44	-38
1962-1963	28	58	43
1963-1964	25	-23	1
1964-1965	2	30	16
1965-1966	78	12	45
1966-1967	66	11	39
1967-1968	63	53	58
1968-1969	-39	15	-12
1969-1970	4	-42	-19
1970-1971	45	-21	12
1971-1972	41	-24	9
1972-1973	53	-15	19
1973-1974	28	7	18
1974-1975	349	83	216
1975-1976	21	5	13
1976-1977	56	-46	5
Mean	44	12	28

The 26 years of seeding activities reported here have 20 positive and 6 negative D values, using comparison with Control I. The mean seeding effect indicates a positive 44% increase in rainfall, the significance level corresponding to the Wilcoxon signed rank test is .000. The individual seeding effects vary from -39% to 349%. On the other hand, 14 positive and 12 negative D values result from the Control IV comparison. The mean seeding effect indicates a positive 12% increase, the corresponding significance level of Wilcoxon signed rank test is .406, and the variation ranges from -62% to 200%. The combined (averaged) D values offset a few negative values (only 5 negative values are left), and the range of variation is reduced to -45% to 216%, with an average effect of +28%, and significance level .002.

The Target and Control I have similar geographic and climatological features, are closer together, and the areas covered by the stations are more nearly equal than those of Target and Control IV. If no contamination can be safely assumed, Control I offers a better comparison than Control IV.

5. AIRCRAFT SEEDING

Severe drought occurred in western and northern Taiwan during March-May of 1977 and the summer of 1978. Urgent needs for irrigation and municipal water supplies led to cooperative efforts between the staff of RSRIT and the Chinese Air Force to seed clouds. The Central Weather Bureau provided weather forecasts for suitable clouds and synoptic weather conditions. Two C-119 aircraft were used to deliver dry ice and saturated salt water at levels between 3500-4500 m, very close to 0°C. Crushed dry ice particles, mostly 1-2 cm in diameter, were shoveled into a funnel-shaped aluminum cylinder and dispensed through the gate (Chu, 1978). Salt water was dispensed using funnel and tube. No precise dispersing rate was available; however, approximate rates were estimated at 100 kg/min for dry ice and 80 liters/min for saturated salt water.

Seeding efforts took place on five occasions (9 flights), mostly in the afternoon -- March 24, April 18, May 7-8, May 13 in 1977 and August 5 in 1978. Total dry ice dispensed was 640, 1000, 3000, 1000, and 1000 kg, respectively; total salt water dispensed was 400, 400, 800, 800, and 800 liters, respectively. Cloudtop heights from 00Z radiosondes closest to seeding for the first four occasions were respectively 3500, 4300,4600 (3400), and 4300 m; cloudtop temperatures were respectively 0, 1, -3.5 (6.5) and -1°C (Chu, 1978). Reporters from newspapers, as well as from radio and television stations, were aboard seeding aircraft on some occasions and gave the public a rather interesting account of the seeding operations.

There has been no evaluation effort for aircraft seeding comparable to that of the winter seeding. On one occasion, May 7-8, visual observations from the aircraft did show considerable growth of seeded cloudtops to 10,000 m; ground stations also reported a noticeable increase in precipitation. However, cause and effect were not established. The inflow rate of water into Shih Men Reservoir in northern Taiwan increased from 4 to 5 m^3s^{-1} after seeding, and the water level of the city reservoir of Taipei increased from 7 m to 22 m (Chu, 1978). Liu (1977) also reported that, on this occasion, a rain increase of 19% was observed in a northern station inside the target area. However, no statistical evaluation was pursued. The cost for the seeding on 6 August 1978 was estimated to be near $4,000 (Central Daily News, 6 August 1978, Taipei). Six mm of rainfall was observed near a reservoir which provides water to the city of Taipei.

6. CONCLUSIONS

The lack of reference to these Taiwanese seeding projects in the literature indicates that few scientists are aware of this large scale program. It represents an interesting mix of government, weather service and power company involvement to address water needs for hydroelectric power generation and agriculture. The governmental statistical evaluation suggests precipitation increases in 20 of the 26 years. Interestingly, this project represents one of the longest, continuously operated weather modification projects in the world. More thorough physical and statistical evaluation could provide very useful information on the effectiveness of ground-based silver iodide seeding of winter orographic precipitation.

7. ACKNOWLEDGMENTS

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