"REVIEWED"

CLOUD SEEDING AND ATMOSPHERIC TRACER PROGRAM CONDUCTED IN THE TSENGWEN RESERVOIR AREA OF TAIWAN DURING THE 1992 MEI-YU SEASON

By

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ABSTRACT

North American Weather Consultants (NAWC) of Salt Lake City, Utah, U.S.A. was contracted by the Taiwan Central Weather Bureau (CWB) to assist in the design, operation and analysis of a cloud seeding and atmospheric tracer program. This program was conducted from April 22 to June 23, 1992. The area of interest was the Tsengwen River drainage located in south central Taiwan. The program was conducted during a portion of the Mei-Yu season which is the transition period between the northeast and southwest monsoon seasons.

A network of 15 ground based silver iodide (AgI) generators was utilized to conduct the cloud seeding program. A tracer gas, sulfur hexafluoride (SF_6), was also released at one of the silver iodide generator sites on some of the operational days. The SF_6 was tracked by an instrumented van on some of these tests. The SF_6 was tracked on one test with instrumentation carried on-board a C-130 cargo aircraft. The goal of this tracer work was to attempt to document the vertical transport of SF_6 and by inference AgI. The question being considered was whether the use of AgI ground generators in Taiwan offers an effective means of seeding clouds in Taiwan.

1.0 INTRODUCTION

Drier than normal conditions occurred in portions of Taiwan during the normally wet typhoon season in the summer of 1991. Representatives of the Central Weather Bureau (CWB) of Taiwan, Republic of China contacted North American Weather Consultants (NAWC) in December 1991 to discuss the potential application of cloud seeding to alleviate some of the negative impacts of the drought conditions. NAWC personnel performed an assessment of the potential application of cloud seeding in Taiwan. The main recommendation of this assessment was that the application of cloud seeding technology appeared to be suitable for application in Taiwan.

A two month operational cloud seeding program with an associated transport and dispersion research component was conducted. This program was conducted during the Mei-Yu season in Taiwan which marks the transition from the winter (northeast) monsoon to the summer (southwest) monsoon. It is during this season (April to June) that southern Taiwan receives approximately three-fourths of its annual precipitation (Chen and Kuo, 1991). The target area for the two month program was the Tsengwen River drainage located in south-central Taiwan.

2.0 PROGRAM DESIGN

An operations center was established at the Tsengwen Dam complex. NAWC and CWB personnel operated from this facility. A network of 15 ground based silver iodide generators was established to be operated during the two month period (April 22 to June 23, 1992). This ground seeding mode was selected on the basis of a long-term cloud seeding program which had been conducted in central Taiwan in the years of 1951 to 1978. An evaluation of this program had indicated precipitation increases in the target area (Chin-Fei Hsu, 1981). NAWC recommended that a tracer gas capability be added to this ground based design in an attempt to verify the vertical transport of the silver iodide nuclei. To be effective, the silver iodide nuclei would need to reach at least the -5°C level, approximately 5.5 to 6.0 km in Taiwan. A real-time gas analyzer (Benner and Lamb, 1985) was installed in a van and later in an aircraft to track sulfur hexafluoride (SF_6) released from one of the silver iodide generator sites. The CWB arranged for special rawinsonde observations in support of the program. Figure 1 provides the location of the target area and associated features.

3.0 OPERATIONS

Only three different seeding events were attempted due to a number of program suspensions related to concerns about heavy rainfall and/or impacts on orchard areas in the foothill regions adjacent to the target area.

A total of seven SF_6 tracer studies were conducted. Five of these studies involved surface sampling and two involved airborne sampling. The airborne sampling was accomplished in a rather unique manner which involved driving the van equipped with the SF_6 real-time analyzer into a Taiwanese Air Force C-130 cargo aircraft.

4.0 RESULTS

Visual observations classified days into potentially seedable and non-seedable primarily based upon the presence of convective clouds observed over the target area. Of the 52 days, 22 were considered to present some seeding potential. Of these 22 days 13 were classified as associated with frontal systems and 9 as airmass events. Table 1 summarizes some statistics from the project rawinsonde data for these 22 days.

The tracer van was able to detect the SF_6 plume released from a single location at the surface on three different experimental days. In essence the detection of SF_6 at the surface implies that at least a portion of the ground released silver iodide was not being transported above the surface of the earth. There is therefore some question about the effectiveness of ground based seeding during these experiments.

Two aircraft tracer missions were flown near the end of the operational period. The first mission was aborted early due to mechanical problems. The SF_6 plume released from a single surface location was, however, encountered three times before the mission was terminated. These plumes were detected at approximately 900 m above ground level.

The second aircraft mission was more successful. SF_6 was released from a surface location (near sea level) at a rate of 75 kg/hr. A special project rawinsonde, taken from Tainan near the SF_6 release point, is provided in Figure 2. The SF_6 plume was encountered 17 different times on this flight with observed concentrations varying from 20 to 800 parts-per-trillion (ppt). The SF_6 plume was observed quite close to the release site at altitudes from .9 km to 2.4 km. The highest level at which the SF_6 plume was observed corresponded well with a slight inversion as observed on the special rawinsonde observation (Figure 2). Of interest was the fact that the SF_6 plume was encountered in several small cumulus clouds which developed during the experiment. Of note is the fact that the top of the plume only rose to a minimum temperature of +12°C, far above the temperature activation threshold of approximately -6°C for silver iodide to serve as an ice nucleant.

The data collected from this experiment can be utilized to calculate the potential maximum number of ice crystals that could be produced from a ground release of silver iodide. The following factors are important in such a calculation: 1) the SF_6 release rate was 75 kg/hr or 20.81 g/s, 2) a silver iodide release rate from one of NAWC's manual generators would have been 13 g/hr or .0036 g/s, 3) 1 $\mu g/m^3$ of SF_6 = 167 ppt at standard temperature and pressure, 4) the average observed concentration of SF_6 at the highest detected plume height (2.4 km) was 31 ppt, 5) the C-130 aircraft was pressurized to sea level, 6) the NAWC silver iodide generator in a recent cloud chamber test at Colorado State University yielded an average 9 x 10^{14} ice crystals per gram of silver iodide consumed with a supercooled water content of 0.5 g/m^3 (DeMott, 1994).

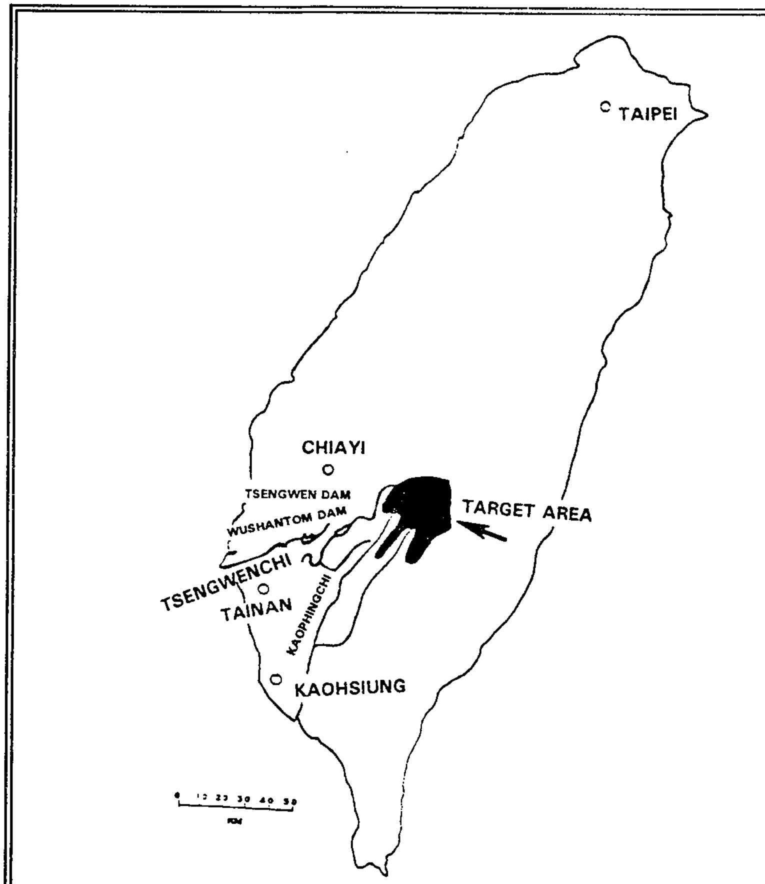

Figure 1 Tsengwen Basin Target Area and Related Features

Table 1 Sounding Climatology for Seedable Cases

	0°C Level MB	-5°C Level MB	-10°C Level MB	K Index	TT Index	850 MB Temp °C	850 MB DP °C	700 MB Temp °C	700 MB DP °C	500 MB Temp °C
SEEDABLE CASES (BOTH FRONTAL AND AIR MASS - 44 SOUNDINGS)										
MEAN	577	508	457	34	43	16.9	14.5	8.3	5.2	-5.8
MINIMUM	536	475	420	22	36	11.8	8.2	2.4	-3.6	-8.9
MAXIMUM	638	560	491	41	49	21.6	18.7	11.2	10.2	-1.3
SEEDABLE CASES (FRONTAL ONLY - 26 SOUNDINGS)										
MEAN	575	506	454	34	42	16.8	14.5	8.5	5.5	-5.5
MINIMUM	547	475	420	22	36	13.8	8.8	6.0	-2.6	-8.7
MAXIMUM	609	534	491	39	47	19.0	17.2	11.2	10.2	-1.3
SEEDABLE CASES (AIR MASS ONLY - 18 SOUNDINGS)										
MEAN	580	512	461	34	44	17.1	14.4	8.0	4.7	-6.1
MINIMUM	536	488	440	23	38	11.8	8.2	2.4	-3.6	-8.9
MAXIMUM	638	560	488	41	49	21.6	18.7	11.0	9.0	-3.7

Using this information, the expected concentration of silver iodide at 2.4 km can be calculated from the following equation:

$$\chi\ AgI = \frac{\chi\ SF_6 \bullet Q\ AgI}{Q\ SF_6}$$

Where:

χAgI = silver iodide concentration

χSF_6 = sulfur hexafluoride concentration

$QAgI$ = release rate of silver iodide

QSF_6 = release rate of sulfur hexafluoride

$$\chi\ \mathbf{AgI} = \frac{(2.3 \times 10^{-4}\ \mu g/l)(.0036\ g/s)}{20.81\ g/s}$$

$$\chi\ \mathbf{AgI} = 3.98 \times 10^{-14}\ g/l$$

If this concentration had been observed at -10°C in a cloud with 0.5 g/m³ supercooled liquid water content and all of the silver iodide nuclei reacted in a short period of time (i.e., $\leq$ 1 minute), the calculated AgI concentration would yield (3.98 x 10^{-14} g/l x 9.0 x 10^{14} crystals/g) 36 ice crystals/l in the cloud at -10°C. Since the average SF_6 concentration was, however, observed at 2.4 km (+12°C) an adjustment in the SF_6 concentration was necessary. If it is assumed that the SF_6 would disperse at the same rate in going from sea level to 2.4 km as it would from 2.4 km to 6.1 km (-10°C) then this calculation would yield approximately 14 crystals/l at -10°C. This concentration is slightly above the 1 to 10 crystals/l range often cited as the desired number of crystals in a cloud to be produced from a cloud seeding program.

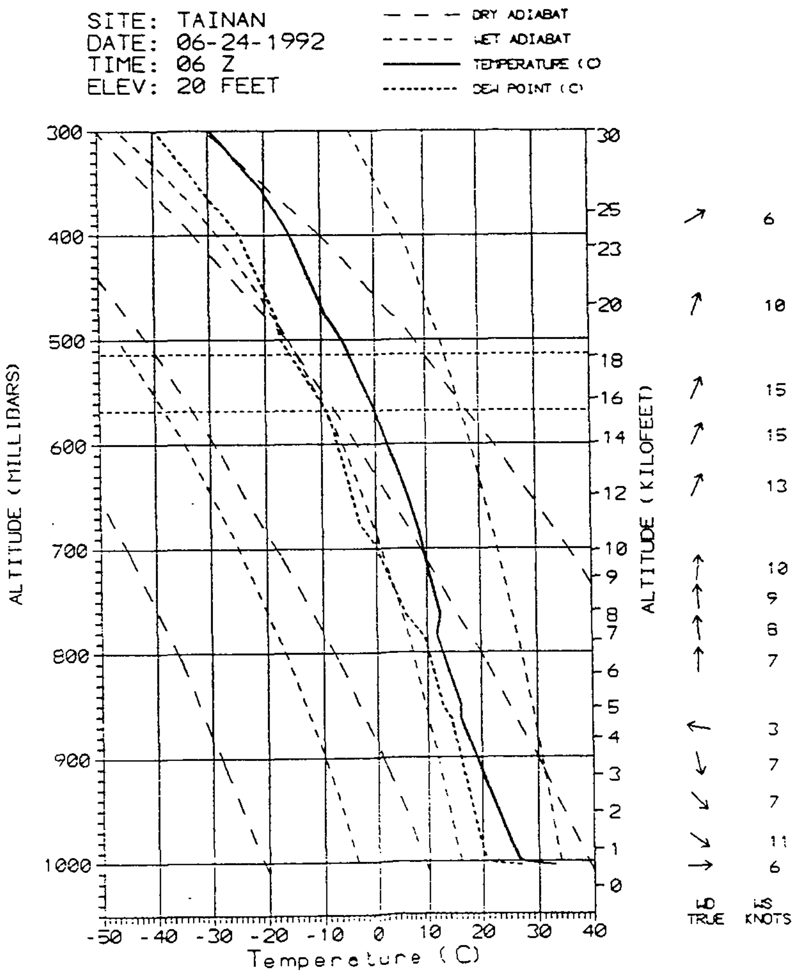

Figure 2 June 24, 1992 - 06Z Project Sounding

There are obviously several assumptions in these calculations. It would be highly desirable to continue the tracer research in an attempt to document SF_6 transport in adequate concentrations to the -10°C level in towering cumulus clouds. This SF_6 tracer research could be refined by concurrently measuring ambient ice particle concentrations in and outside the SF_6 plume to investigate the potential silver iodide seeding signatures.

5.0 CONCLUSIONS

Several conclusions were reached regarding this program. Those conclusions are as follows:

- The Mei-Yu season appears to produce sufficiently frequent opportunity for precipitation increase via cloud seeding to warrant inclusion of that season in an overall cloud seeding program design for southern Taiwan.

- Mei-Yu season cloud seeding opportunities in southern Taiwan occur in two basic categories, organized frontal systems and airmass thunderstorms.

- Ground-based seeding releases appear to have some promise during the Mei-Yu season in certain circumstances in southern Taiwan, primarily with frontal systems having organized low level wind flow. This concept is supported by the frequency of deep convective cloud occurrence, combined with rawinsonde indications of trapping inversions often being overcome when well-organized low level south-southwest flow is established. Limited airborne tracer plume tracking efforts also suggest that vertical displacement of seeding material released from the surface can occur in some cases. The ground-based seeding effectiveness question requires additional investigation.

- Given frequent convective cloud base heights in the vicinity of 1.5 km, and 850 mb temperatures in the seedable situations averaging nearly 10°C, the dynamic seeding approach utilizing aircraft would seem to be well worth serious consideration in deep convective situations with low/warm cloud bases.

- The real-time tracer plume tracking capability provided valuable information regarding the ground-based seeding issue.

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