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Cloud seeding operations 2019 began over South Texas Weather Modification Association target area in May. This annual report serves as a summary of results. A total of **124 clouds** were seeded and identified by TITAN in **40 operational days**. Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **May 3rd, 2019**
Last operational day: **October 24th, 2019**

Number of operational days: 40 (plus an exploratory day on August 25th)
(Seven in May, seven in June, six in July, seven in August, eleven in September, and two in October)

According to the daily reports operational days were qualified as:

Seventeen with excellent performance
Fifteen with very good performance
Four with good performance
Four without proper data

Number of seeded clouds: 124
(67 small seeded clouds, 16 large seeded clouds, 41 type B seeded clouds)

Flares used: 1089 AgI-BIP plus 11 HYG

Missed Opportunities: five (with lifetime longer than 1 hour): ~ 3.9 % of resources

July 2: # 422 over Uvalde County (18:48 - 20:00 Z)

August 5: # 587 over Uvalde County (21:08 - 22:28 Z)
637 over Bandera, Medina, and Uvalde Counties (22:08 - 00:32 Z)

August 24: # 2216 over Medina and Bexar Counties (21:08 - 23:30 Z)

October 24: # 747 over Atascosa, Wilson and Bexar Counties (21:24 - 23:14 Z)

Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 67 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (67 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	40 min	1.63	63 (48)
Area	79.7 km ²	42.4 km ²	1.88	88 (57)
Volume	233.3 km ³	115.0 km ³	2.03	103 (73)
Top Height	7.7 km	7.2 km	1.07	7 (3)
Max dBz	52.4	51.0	1.03	3 (1)
Top Height of max dBz	3.7 km	3.7 km	1.00	0 (-2)
Volume				
Above 6 km	40.7 km ³	14.5 km ³	2.81	181 (108)
Prec.Flux	663.4 m ³ /s	302.2 m ³ /s	2.20	120 (79)
Prec.Mass	3530.4 kton	929.5 kton	4.26	326 (131)
CloudMass	225.4 kton	101.8 kton	2.21	121 (75)
η	15.7	8.1	1.94	94 (33)

Bold values in parentheses are modeled values, whereas **η** is defined as the quotient of Precipitation Mass divided by Cloud Mass, and is interpreted as efficiency. A total of **429 AgI-BIP and 7 Hygroscopic flares** were used in this sub-sample with a very good timing (**83 %**) for an average effective silver iodide dose of about **95 ice-nuclei per liter**. The seeding operation for small clouds lasted about **5.4 minutes** on average. An excellent increase of 131 % in precipitation mass together with an increase of 75 % in cloud mass illustrates that the seeded clouds grew at expenses of the environmental moisture (they are open systems) and used only a fraction of this moisture for their own maintenance. The increases in lifetime (48 %), in area (57 %), in volume (73 %), in volume above 6 km (108 %), and in precipitation flux (79 %) are

notable. There were slight increases in top height (3 %) and in maximum reflectivity (1 %). The seeded sub-sample was 33 % more efficient than the control sub-sample. Results are evaluated as **excellent** for this subsample.

An increase of 131 % in precipitation mass for a control value of 929.5 kton in 67 cases means:

$$\Delta 1 = 67 \times 1.31 \times 929.5 \text{ kton} \approx 72\,805 \text{ kton} \approx 59\,045 \text{ ac-f (layer: 13.6 mm} \approx 0.54 \text{ in)}$$

Large Clouds

The sub-sample of 16 large seeded clouds received a synergetic analysis. On average, the seeding operations on these large clouds affected 67 % of their whole volume with a perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of **192 AgI-BIP and 2 Hygroscopic flares** were used in this sub-sample for an average effective silver iodide dose of about **95 ice-nuclei per liter**.

Also on average, large clouds were 35 minutes old when the operations took place; the operation lasted about 11.2 minutes, and the large seeded clouds lived 155 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (16 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	155 min	130 min	1.19	19
Area	270 km ²	205 km ²	1.32	32
Volume	807 km ³	579 km ³	1.39	39
Volume Above 6 km	127 km ³	83 km ³	1.53	53
Prec.Flux	2232 m ³ /s	1572 m ³ /s	1.42	42
Prec.Mass	26 268 kton	16 287 kton	1.61	61

An increase of 61 % in precipitation mass for a control value of 16 287 kton in 16 cases may mean:

$$\Delta 2 = 16 \times 0.61 \times 16\,287 \text{ kton} \approx 158\,961 \text{ kton} \approx 128\,917 \text{ ac-f (layer: 36.8 mm} \approx 1.45 \text{ in)}$$

Type B Clouds

The sub-sample of 41 type B seeded clouds also received a synergetic analysis. On average, the seeding operations on these type B clouds affected 17 % of their whole volume with a good timing (79 % of the material went to the clouds in their first half-lifetime). A total of **468 AgI-BIP and 2 Hygroscopic flares** were used in this sub-sample for an average effective silver iodide dose of about **80 ice-nuclei per liter**.

Also on average, type B clouds were 150 minutes old when the operations took place; the operation lasted about 15 minutes, and the type B seeded clouds lived 250 minutes.

Table 4 shows the results:

Table 4: Type B Seeded Sample versus Virtual Control Sample (41 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	250 min	235 min	1.06	6
Area	610 km ²	572 km ²	1.07	7
Volume	2262 km ³	2100 km ³	1.08	8
Volume Above 6 km	647 km ³	590 km ³	1.10	10
Prec.Flux	5884 m ³ /s	5443 m ³ /s	1.08	8
Prec.Mass	176 715 kton	159 678 kton	1.11	11

An increase of 11 % in precipitation mass for a control value of 159 678 kton in 41 cases may mean:

$$\Delta 3 = 41 \times 0.11 \times 159\,678 \text{ kton} \approx 720\,148 \text{ kton} \approx 584\,040 \text{ ac-f}$$

(layer: 28.8 mm \approx 1.13 in)

$$\text{The total increase: } \Delta 1 + \Delta 2 + \Delta 3 = 772\,002 \text{ ac-f}$$

(~ 881 ac-f per small, 8 057 ac-f per large, 14 245 ac-f per type B)

Micro-regionalization

Increases in precipitation mass were analyzed county by county in an attempt to better describe the performance and corresponding results. **Table 5** below offers the details for operations (season: May to October):

County Seeding	Initial Seeding	Extended (increase)	Acre-feet (increase)	Inches (increase)	Rain Gage (season value*)	% (increase)
Uvalde	19	20	122 800	1.46	7.38 in	19.8
Bandera	17	21	59 400	1.62	15.79 in	10.3
Medina	11	16	50 400	0.67	9.10 in	7.4
Bexar	3	7	41 000	0.61	20.81 in	2.9
Frío	6	8	31 700	0.58	9.10 in	6.4
Atascosa	23	27	114 900	1.72	11.12 in	15.5
McMullen	8	12	72 300	1.22	8.97 in	13.6
Wilson	7	12	50 400	1.19	14.84 in	8.0
Karnes	9	13	96 300	2.42	12.61 in	19.2
Bee	21	22	122 500	2.61	13.37 in	19.5
Outside		2	7 400 (~ 0.1 % of total)			
Total	124	160	771 300			
Average				1.41	12.31 in	11.5

(**Initial seeding** means the counties where the operations began, whereas **extended seeding** means the counties favored by seeding after the initial operations took place).

* Seasonal precipitation values: May-October 2019

Final Comments

- Results are evaluated as **excellent**; average timing: 84 %, average dose: 90 icn/L; missed opportunities: less than 5 % of resources.
- The micro-regionalization analysis showed increases per county; different zones received downwind benefits; the average increase in precipitation, referred to rain gage seasonal value (May-October), was about 11.5 %.
- Radar estimations of precipitation should be considered as measurements of trend. Clearly, seeding operations improved the dynamics of seeded clouds.
- In 2019, the total increase in the region, estimated in about 0.77 million acre-feet, should be considered as a great help to fresh water natural resources.
- Dual seeding was of limited use during the 2019 campaign. Only 11 hygroscopic flares were used in the analyzed samples.