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Cloud seeding operations 2021 began over the EAA target area in June. This annual report serves as a summary of results. A total of **25 clouds** were seeded and identified by TITAN in **19 operational days**. Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **June 3rd, 2021**
Last operational day: **September 1st, 2021**

Number of operational days: 19
(Seven in June, five in July, six in August, and one in September)

According to the daily reports operational days were qualified as:

Fifteen with excellent performance
Three with very good performance
One with good performance

Eight with technical problems (no TITAN data due to internet problems)

Number of seeded and identified clouds: 25
(16 small-seeded clouds, 6 large-seeded clouds, 3 type B seeded clouds)

Missed Opportunities: one (with lifetime longer than 1 hour)

July 22nd: **# 729 over Medina County** (18:00 – 20:30 UTC)

Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 16 small-seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (16 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	40 min	1.63	63 (75)
Area	70.3 km ²	69.0 km ²	1.02	2 (29)
Volume	206.4 km ³	153.5 km ³	1.34	34 (38)
Top Height	7.6 km	6.7 km	1.13	13 (5)
Max dBz	51.4	50.0	1.03	3 (2)
Top Height of max dBz	3.5 km	3.3 km	1.06	6 (0)
Volume Above 6 km	34.0 km ³	6.6 km ³	5.15	415 (90)
Prec.Flux	500.0 m ³ /s	337.7 m ³ /s	1.48	48 (79)
Prec.Mass	2434.2 kton	1154.4 kton	2.11	111 (120)
CloudMass	180.6 kton	120.2 kton	1.50	50 (52)
η	13.5	9.6	1.41	41 (45)

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 120 AgI-BIP and 6 hygroscopic flares were used in this sub-sample with a very good timing (**89 %**) for an average effective silver iodide dose about **70 ice-nuclei per liter**. The seeding operations lasted on average about 6 minutes. An excellent increase of **120 %** in precipitation mass, together with a **52 %** increase 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 (75 %), area (29 %), volume (38 %), volume above 6 km (90 %), and precipitation

flux (79 %) are noticeable. There were small increases in maximum reflectivity (2 %) and in top height (5 %). The seeded sub-sample seemed 45 % more efficient than the control sub-sample. Results are evaluated as **excellent**.

An increase of **120 %** in precipitation mass for a control value of 1771.5 kton in 30 cases means:

$$\Delta^1 = 16 \times 1.20 \times 1154.4 \text{ kton} \approx 22\,164 \text{ kton} \approx 17\,975 \text{ ac-f (layer: 19.7 mm} \approx 0.78 \text{ in)}$$

Large Clouds

The sub-sample of 6 large-seeded clouds received a synergetic analysis. On average, the seeding operations on these large clouds affected 49 % of their whole volume with a perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of 70 AgI-BIP and 4 hygroscopic flares used in this sub-sample for an effective glaciogenic dose about **70 ice-nuclei per liter**.

Also, on average, large clouds were 35 minutes old when the operations took place; the operation lasted about 8 minutes, and the large-seeded clouds lived 185 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (6 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	185 min	155 min	1.19	19
Area	489 km ²	434 km ²	1.13	13
Prec.Mass	59 960 kton	43 607 kton	1.38	38

An increase of 38 % in precipitation mass for a control value of 43 607 kton in 6 cases may mean:

$$\Delta^2 = 6 \times 0.38 \times 43\,607 \text{ kton} \approx 99\,424 \text{ kton} \approx 80\,632 \text{ ac-f}$$

(Layer: 33.0 mm $\approx$ 1.30 in)

Type B Clouds

Three type B clouds were initially seeded over EAA target area during the season. On average, the seeding operations on these type B clouds affected 15 % of their whole volume with a perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of 12 AgI-BIP flares and 4 hygroscopic flares were used in this sub-sample for an effective dose about **40 ice-nuclei per liter**.

Also, on average, these type B clouds were 65 minutes old when the operations took place; the operation lasted about 5 minutes, and the B seeded clouds lived 270 minutes.

Table 4: Type B Seeded Sample versus Virtual Control Sample (3 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	300 min	290 min	1.03	3
Area	1664 km ²	1615 km ²	1.03	3
Prec.Mass	380 410 kton	345 827 kton	1.11	11

$$\Delta^3 = 3 \times 0.11 \times 345\,827 \text{ kton} \approx 114\,122 \text{ kton} \approx 92\,554 \text{ ac-f}$$

(Layer: 22.9 mm $\approx$ 0.9 in)

$$\text{The total increase: } \Delta = \Delta^1 + \Delta^2 + \Delta^3 = 191\,161 \text{ ac-f}$$

(1123 ac-f/small, 13 439 ac-f/large, 30 851 ac-f/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:

County Seeding	Initial Seeding	Extended (increase)	Acre-feet (increase)	Inches (increase)	Rain gage (season value)	% (increase)
Uvalde	12	13	62 300	0.74	13.54 in	5.5
Bandera	6	8	25 500	0.69	22.00 in	3.1
Medina	8	12	52 600	0.70	19.68 in	3.6
Bexar	1	2	24 300	0.36	24.60 in	1.2
Outside			~ 26 400			
Total (inside)	25	35	164 700			
Average				0.62 in	19.96 in	3.4 %

(**Initial seeding** means the number of clouds seeded when the operations began; whereas **extended seeding** means the counties favored by seeding after the initial operations took place.

Final Comments

- Results are evaluated as **excellent**.
- The micro-regionalization analysis showed increases per county; different zones received downwind benefits; the average increase in precipitation, referred to rain gage seasonal value, is about **3.4 %**
- Radar estimations of precipitation should be considered as measurements of trend. Nevertheless, seeding operations improved the dynamics of the seeded storms.
- In 2021, the total increase in the region, estimated in 0.16 million acre-feet, should be considered a great help to the fresh water natural resources.

Note: TITAN data were missed in 8 operational days (internet connection problems). It is estimated that about 25 seeded clouds were not evaluated which might have produced an additional increase of about 140 000 acre-feet over the target area.

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