ANNUAL EVALUATION REPORT 2023 EAA

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Cloud seeding operations in 2023 began over the EAA target area in May. This annual report serves as a summary of the results. A total of **16 clouds** were seeded and identified by TITAN in **8 operational days**. Table 1 on page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **May 15th, 2023**
Last operational day: **September 26th, 2023**

Number of operational days: 8
(One in May, two in June, two in July, one in August, and two in September)

According to the daily reports, operational days were qualified as:

Five with excellent performance
Two with very good performance
One with good performance

Number of seeded and identified clouds: 16
(10 small-seeded clouds,2 large-seeded clouds, 4 type B-seeded clouds)

Missed Opportunities: one (with a lifetime longer than 1 hour) ~ 6 % of resources

Storm # 6 on September 10th over Bandera, Medina, and Uvalde Counties
(22:16-23:20 Z)

Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 10 small-seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (10 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	55 min	40 min	1.38	38 (**25**)
Area	65.3 km^2	45.2 km^2	1.44	44 (**20**)
Volume	242.6 km^3	129.5 km^3	1.87	87 (**41**)
Top Height	9.1 km	8.2 km	1.11	11 (**3**)
Max dBz	53.3	51.2	1.04	4 (**1**)
Top Height of max dBz	3.7 km	3.9 km	0.95	-5 (**- 3**)
Volume Above 6 km	76.7 km^3	23.8 km^3	3.22	222 (**59**)
Prec.Flux	568.3 m^3/s	315.5 m^3/s	1.80	80 (**35**)
Prec.Mass	1897.1 kton	859.2 kton	2.21	121 (**85**)
CloudMass	235.6 kton	110.7 kton	2.13	113 (**50**)
η	8.1	7.8	1.04	4 (**25**)

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 72 AgI-BIP were used in this sub-sample with good timing (**78 %)** for an average effective silver iodide dose of about **50 ice-nuclei per liter**. The seeding operations lasted on average about 8 minutes. A very good increase of **85 %** in precipitation mass, together with a **50 %** increase in cloud mass illustrates that the seeded clouds grew at expense of the environmental moisture (they are open systems) and used only a fraction of this moisture for their own maintenance. The increases in lifetime (25 %), area (20 %), volume (41 %), volume above 6 km (59%), and precipitation flux (35 %) are noticeable. There were small increases in maximum reflectivity (1 %) and in top height (3 %). The seeded sub-sample

seemed 25 % more efficient than the control sub-sample. Results are evaluated as **very good for this sample**.

An increase of **85 %** in precipitation mass for a control value of 859.2 kilotons in 10 cases means:

Δ_1 **= 10 x 0.85 x 859.2 ktons ≈ 7 303 ktons ≈ 5 923 ac-f (layer: 11.2 mm ≈ 0.44 in)**

Large Clouds

The sub-sample of 2 large-seeded clouds received a synergetic analysis. On average, the seeding operations on these large clouds affected 50 % of their whole volume with perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of 12 AgI-BIP flares were used in this sub-sample for an effective glaciogenic dose of about **20 ice nuclei per liter**.

Also, on average, large clouds were 30 minutes old when the operations took place; the operation lasted about 10 minutes, and the large-seeded clouds lived 225 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (2 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	225 min	205 min	1.10	10
Area	1081 km^2	991 km^2	1.09	9
Prec.Mass	126 277 kton	97 267 kton	1.30	30

An increase of 30 % in precipitation mass for a control value of 97 267 kton in 2 cases may mean:

Δ_2 **= 2 x 0.30 x 97 267 ktons ≈ 58 360 ktons ≈ 47 330 ac-f**
(Layer: 27.0 mm ≈ 1.1 in)

Type B Clouds

Four type B clouds were initially seeded over EAA target area during the season. On average, the seeding operations on these type B clouds affected 18 % of their whole volume with excellent timing (95 % of the material went to the clouds in their first half-lifetime). A total of 44 AgI-BIP flares were used in this sub-sample for an effective dose of about **45 ice nuclei per liter**.

Also, on average, these type B clouds were 100 minutes old when the operations took place; the operation lasted about 15 minutes, and the B-seeded clouds lived 275 minutes.

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

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	275 min	260 min	1.06	5
Area	239 km^2	230 km^2	1.04	4
Prec.Mass	40 977 kton	37 588 kton	1.09	9

Δ_3 **= 4 x 0.09 x 37 588 ktons ≈ 13 522 kton ≈ 10 974 ac-f**

(Layer: 14.2 mm ≈ 0.56 in)

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ **= 64 227 ac-f**

(592 ac-f/small, 23 665 ac-f/large, 2 744 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	**5**	**6**	**14 600**	**0.17**	**11.46 in**	**1.5**
Bandera	**3**	**3**	**16 100**	**0.44**	**14.99 in**	**2.9**
Medina	**9**	**11**	**14 100**	**0.19**	**14.73 in**	**1.3**
Bexar		**1**	**1 600**	**0.02**	**13.79 in**	**0.1**
Subtotal			**46 400**			
Outside (downwind effects)			~ 17 900			
Total			**64 300**			
Average				**0.21 in**	**13.74 in**	**1.5 %**

(**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.

*** Seasonal precipitation values: April-September 2023**

Final Comments

- Results are evaluated as **very good**.
  average timing: **78 %**, average dose: **45 icn/L**; missed opp.: **1**

- The micro-regionalization analysis showed increases per county; different zones received downwind benefits; the average increase in precipitation, referred to as rain gauge seasonal value, is about **2 %**

- Radar estimations of precipitation should be considered as measurements of trend. Nevertheless, seeding operations improved the dynamics of the seeded storms.

- In 2023, the total increase in the region, estimated in 0.046 million acre-feet, should be considered a great help to the freshwater natural resources.

Note: In 2023, well-done operations struggled with very limited seedable resources.