ANNUAL EVALUATION REPORT 2022 WTWMA (San Angelo)

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Cloud seeding operations 2022 began over the West Texas Weather Modification Association target area on March 21st. This annual report serves as a summary of results.

A total of **54 clouds** were seeded and identified by TITAN in **26 operational days**. Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **March 21st, 2022**
Last operational day: **September 25th, 2022**

Number of operational days: 26
(One in March, two in April, three in May, five in June, five in July, six in August, and four in September)

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

Sixteen with excellent performance

Four with very good performance

Two with good performance

Four did not get proper TITAN files (May 23rd, June 28th, September 3rd, and September 25th)

Number of seeded clouds: 54 (23 small storms, 15 large storms, 16 type B storms)

Missed Opportunities: two with lifetime longer than 1 hour,
(~ 4 % of resources)

August 6th: Storm # 216 over Schleicher and Crockett Counties (21:40-23:16 Z)
August 11th : Storm # 716 over Schleicher County (17:44-19:32 Z)

Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 23 small-seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (23 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	80 min	55 min	1.45	45 (**33**)
Area	76.1 km^2	32.2 km^2	2.36	136 (**40**)
Volume	262.6 km^3	95.5 km^3	2.75	175 (**48**)
Top Height	9.2 km	8.0 km	1.15	115 (**5**)
Max dBz	51.5	47.8	1.08	8 (**4**)
Top Height of max dBz	3.7 km	3.6 km	1.03	3(**-2**)
Volume Above 6 km	67.6 km^3	18.5 km^3	3.65	265 (**63**)
Prec.Flux	461.0 m^3/s	143.3 m^3/s	3.22	222 (**60**)
Prec.Mass	2663.2 kton	622.5 kton	4.28	328 (**130**)
CloudMass	169.9 kton	51.2 kton	3.32	232 (**45**)
η	15.7	12.2	1.29	29 (**59**)

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 138 AgI-flares, and 6 hygroscopic flares were used in this sub-sample with excellent timing (**90 %)** for an effective AgI average dose of about **60 ice-nuclei per liter**. The seeding operation for small clouds lasted slightly over **7 minutes** on average. An excellent increase of **130 %** in precipitation mass together with an increase of 45 % 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 modeled increases in lifetime (33 %), area (40 %), volume (48 %), volume above 6 km (63 %), and precipitation flux (60 %) are notable. There was a slight increase in top height (5 %) and in maximum reflectivity (4 %).

The seeded sub-sample seemed 59 % more efficient than the control sub-sample. Results are evaluated as **excellent** for this subsample.

An increase of 130 % in precipitation mass for a control value of 622.5 kton in 23 cases means:

Δ_1 = 23 x 1.30 x 622.5 kton ≈ 18 613 kton ≈ 15 095 ac-f (layer: 10.6 mm ≈ 0.42 in)

Large Clouds

The sub-sample of 15 large-seeded clouds received a synergetic analysis. On average, the seeding operations on these large clouds affected 56 % of their whole volume with perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of 377 AgI-flares and 22 hygroscopic flares were used in this sub-sample for an effective AgI average dose of about **50 ice-nuclei per liter**.

Also, on average, large clouds were 25 minutes old when the operations took place; the operation lasted about 22 minutes, and the large-seeded clouds lived 250 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (15 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	250 min	220 min	1.14	14
Area	1104 km^2	927 km^2	1.19	19
Volume	4259 km^3	3485 km^3	1.22	22
Volume Above 6 km	1469 km^3	1151 km^3	1.28	28
Prec.Flux	6376 m^3/s	5037 m^3/s	1.27	27
Prec.Mass	134 374 kton	92 037 kton	1.46	46

An increase of 46 % in precipitation mass for a control value of 130 690 kton in 15 cases may mean:

Δ_2 = 15 x 0.46 x 92 037 kton = 635 055 kton ≈ 515 030 ac-f (layer: 38.3 mm ≈ 1.51 in)

Type B Clouds

The sub-sample of 16 type B seeded clouds received a synergetic analysis. On average, the seeding operations on the type B clouds affected 13 % of their whole volume with a very good timing (84 % of the material went to the clouds in their first half-lifetime). A total of 248 AgI-flares and 23 hygroscopic flares were used in this sub-sample for an effective AgI average dose of about **70 ice-nuclei per liter**.

Also, on average, type B clouds were 120 minutes old when the operations took place; the operation lasted about 21 minutes, and the type B seeded clouds lived 300 minutes.

Table 4 shows the results:

Table 4: Type B Seeded Sample versus Virtual Control Sample (16 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	300 min	290 min	1.03	3
Area	1344 km^2	1294 km^2	1.04	4
Volume	5437 km^3	5208 km^3	1.04	4
Volume Above 6 km	1724 km^3	1637 km^3	1.05	5
Prec.Flux	6990 m^3/s	6650 m^3/s	1.05	5
Prec.Mass	148 906 kton	137 876 kton	1.08	8

An increase of 8 % in precipitation mass for a control value of 137 876 kton in 16 cases may mean:

Δ_3 = 16 x 0.08 x 137 876 kton ≈ 176 481 kton ≈ 143 126 ac-f (layer: 8.2 mm ≈ 0.32 in)

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 673 251 ac-f

(~ 656 ac-f per small storm; ~ 34 335 ac-f per large storm; ~ 8 945 ac-f per B storm)

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	Initial Seeding	Extended Seeding	Acre-feet (increase)	Inches (increase)	Rain (season value)	% (increase)
Sterling	**7**	**11**	**96 200**	**1.20**	**7.35 in**	**16.3 %**
Reagan	**3**	**4**	**29 400**	**0.46**	**5.43 in**	**8.5 %**
Irion	**7**	**13**	**99 300**	**1.76**	**8.72 in**	**20.2 %**
Tom Green	**6**	**9**	**65 200**	**1.59**	**8.26 in**	**19.3 %**
Crocket	**8**	**15**	**124 100**	**0.83**	**4.85 in**	**17.1 %**
Schleicher	**12**	**18**	**98 500**	**1.47**	**7.50 in**	**19.6 %**
Sutton	**11**	**17**	**95 000**	**1.76**	**8.81 in**	**20.0 %**
Outside TA		9	~ 65 500	(~ 10 % of the total amount)		
Total	**54**	**96**	**673 200 ac-f**			
Average (only for the bold values)				**1.30**	**7.27 in**	**17.3 %**

Season: March-September 2022, 214 days

(**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 value of precipitation does not include April since no seeding operations took place during that month).

Final Comments

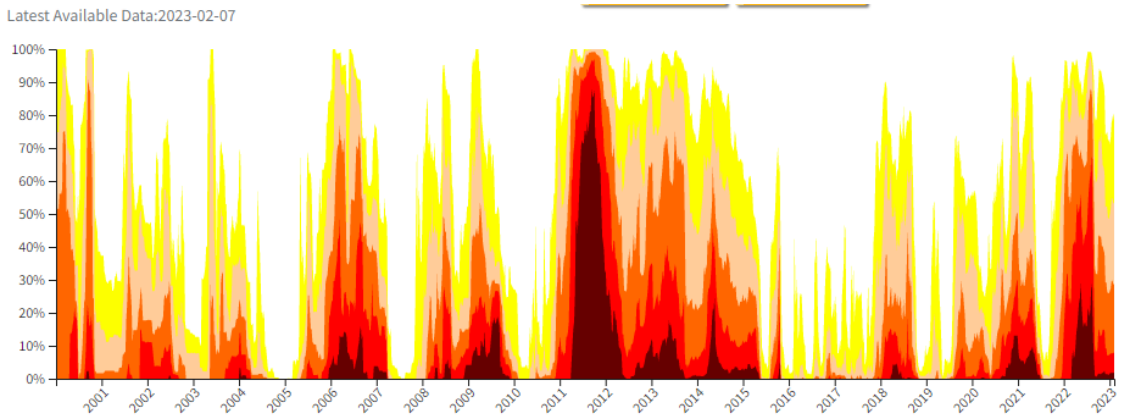
1) Results are evaluated as **excellent**. Average timing: 91 %; average AgI dose: 60 ice-nuclei per liter; two missed opportunities. The use of hygroscopic material during the operations was appropriate.

2) The micro-regionalization analysis showed increases per county; the average increase in precipitation, referred to the seasonal value, is slightly over 17 **%.** Noticeable relative increases in precipitation were detected in all the counties although the southern and central parts of the target area appear to receive the larger increases.

3) Radar estimations of precipitation should be considered as measurements of trend. Nevertheless, according to the results on this report's tables, **seeding operations clearly improved the dynamics of seeded clouds. Notice that the 2022 campaign was implemented under notable drought conditions.**

Addendum: A brief comparison between the last five campaigns

Year	seeded storms	operational days	increases (million ac-f)	%	season precipitation.
2018	54	21	0.96	12.4	15.49 in
2019	61	31	1.07	17.7	10.23 in
2020	56	27	1.06	19.9	10.41 in
2021	62	33	1.17	14.0	15.79 in
2022	**54**	**26**	**0.67**	**17.3**	**7.27 in**



https://www.drought.gov/states/texas