ANNUAL EVALUATION REPORT 2020 WTWMA (San Angelo)

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Cloud seeding operations 2020 began over the West Texas Weather Modification Association target area on April 11th. This annual report serves as a summary of results.

A total of **56 clouds** were seeded and identified by TITAN in **27 operational days**. Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **April 11th, 2020**
Last operational day: **September 16th, 2020**

Number of operational days: 27
(Two in April, eight in May, four in June, four in July, six in August, and three in September)

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

Nineteen with excellent performance

Six with very good performance

One with good performance

Number of seeded clouds: 56 (27 small storms, 12 large storms, 17 type B storms)

Missed Opportunities: none with lifetime longer than 1 hour.

Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 27 small-seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (27 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	40 min	1.63	63 (**48**)
Area	85.6 km^2	60.4 km^2	1.42	42 (**20**)
Volume	312.7 km^3	212.1 km^3	1.47	47 (**24**)
Top Height	9.5 km	8.8 km	1.08	8 (**4**)
Max dBz	52.1	49.1	1.06	6 (**1**)
Top Height of max dBz	4.0 km	4.1 km	0.98	- 2 (**-1**)
Volume Above 6 km	115.6 km^3	65.0 km^3	1.78	78 (**47**)
Prec.Flux	600.1 m^3/s	294.2 m^3/s	2.04	104 (**41**)
Prec.Mass	2873.0 kton	1074.9 kton	2.67	167 (**120**)
CloudMass	209.6 kton	121.4 kton	1.73	73 (**34**)
η	13.7	8.9	1.54	54 (**65**)

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 210 AgI-flares, and 19 hygroscopic flares were used in this sub-sample with a very good timing (**86 %)** for an effective AgI average dose of about **50 ice-nuclei per liter**. The seeding operation for small clouds lasted about **8.3 minutes** on average. An excellent increase of **120 %** in precipitation mass together with an increase of 34 % 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 (48 %), area (20 %), volume (24 %), volume above 6 km (47 %), and precipitation flux (41 %) are notable. There was a slight increase in top height (4 %) and in maximum reflectivity (1 %).

The seeded sub-sample seemed 65 % more efficient than the control sub-sample. Results are evaluated as **excellent**.

An increase of 120 % in precipitation mass for a control value of 1074.9 kton in 27 cases means:

Δ_1 = 27 x 1.20 x 1074.9 kton ≈ 34 827 kton ≈ 28 245 ac-f (layer: 15.1 mm ≈ 0.59 in)

Large Clouds

The sub-sample of 12 large-seeded clouds received a synergetic analysis. On average, the seeding operations on these large clouds affected 55 % of their whole volume with a perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of 260 AgI-flares and 32 hygroscopic flares were used in this sub-sample for an effective AgI average dose of about **70 ice-nuclei per liter**.

Also, on average, large clouds were 30 minutes old when the operations took place; the operation lasted about 27 minutes, and the large-seeded clouds lived 295 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (12 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	295 min	250 min	1.18	18
Area	1966 km^2	1786 km^2	1.10	10
Volume	8731 km^3	7802 km^3	1.12	12
Volume Above 6 km	3704 km^3	3053 km^3	1.21	21
Prec.Flux	14 833 m^3/s	12 461 m^3/s	1.19	19
Prec.Mass	204 472 kton	142 987 kton	1.43	43

An increase of 43 % in precipitation mass for a control value of 142 987 kton in 12 cases may mean:

Δ_2 = 12 x 0.43 x 142 987 kton = 737 813 kton ≈ 598 366 ac-f (layer: 31.3 mm ≈ 1.23 in)

Type B Clouds

The sub-sample of 17 type B seeded clouds received a synergetic analysis. On average, the seeding operations on the type B clouds affected 15 % of their whole volume with a very good timing (85 % of the material went to the clouds in their first half-lifetime). A total of 289 AgI-flares and 38 hygroscopic flares were used in this sub-sample for an effective AgI average dose of about **60 ice-nuclei per liter**.

Also, on average, type B clouds were 120 minutes old when the operations took place; the operation lasted about 19 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 (17 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	300 min	290 min	1.03	3
Area	4186 km^2	4081 km^2	1.03	3
Volume	17233 km^3	16732 km^3	1.03	3
Volume Above 6 km	6861 km^3	6532 km^3	1.05	5
Prec.Flux	26 802 m^3/s	25 633 m^3/s	1.05	5
Prec.Mass	390 981 kton	358 698 kton	1.09	9

An increase of 9 % in precipitation mass for a control value of 358 698 kton in 17 cases may mean:

Δ_3 = 17 x 0.09 x 358 698 kton ≈ 548 808 kton ≈ 445 083 ac-f (layer: 7.7 mm ≈ 0.30 in)

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 1 071 694 ac-f

(~ 1046 ac-f per small storm; ~ 49 864 ac-f per large storm; ~ 26 181 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	**9**	**12**	**105 600**	**1.32**	**7.52 in**	**17.6 %**
Reagan	**13**	**15**	**114 100**	**1.80**	**8.42 in**	**21.4 %**
Irion	**7**	**17**	**159 000**	**2.82**	**13.21 in**	**21.3 %**
Tom Green	**2**	**12**	**94 200**	**2.30**	**12.58 in**	**18.3 %**
Crocket	**7**	**11**	**204 800**	**1.36**	**7.16 in**	**19.0 %**
Schleicher	**9**	**17**	**195 000**	**2.93**	**15.91 in**	**18.4 %**
Sutton	**8**	**13**	**119 100**	**2.21**	**9.58 in**	**23.1 %**
Outside TA	1	3	~ 72 000	(~ 7 % of the total amount)		
Total	**56**	**100**	**1 063 800 ac-f**			
Average (only for the bold values)				**2.11**	**10.41 in**	**19.9 %**

Season: April-September 2020, 183 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: 89 %; average AgI dose: 60 ice-nuclei per liter; no missed opportunities. The use of hygroscopic material during the operations increased in about 35 % in comparison with the previous season.

2) The micro-regionalization analysis showed increases per county; the average increase in precipitation, referred to the seasonal value, is about **20 %.** Noticeable relative increases in precipitation were detected in all the counties.

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.

N.B. Despite of The Pandemic, the 2020 WTWMA Cloud Seeding Campaign was a successful one. Congratulations to everyone involved.