ANNUAL EVALUATION REPORT 2017 WTWMA (San Angelo)

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Cloud seeding operations 2017 began over the West Texas Weather Modification Association target area in March. This annual report serves as a summary of results.

A total of **73 clouds** were seeded and identified by TITAN in **24 operational days**.
Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **March 21st, 2017**
Last operational day: **September 20th , 2017**

Number of operational days: 24
(Two in March, none in April, one in May, six in June, nine in July, five in August, and one in September)

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

Seventeen with excellent performance

Five with very good performance

Two with good performance

Number of seeded clouds: 73 (39 small, 25 large, 9 type B)

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 39 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (39 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	45 min	1.44	44 (**36**)
Area	62.2 km^2	41.4 km^2	1.50	50 (**40**)
Volume	218.3 km^3	132.1 km^3	1.65	65 (**47**)
Top Height	9.8 km	9.0 km	1.09	9 (**2**)
Max dBz	51.1	49.4	1.03	3 (**1**)
Top Height of max dBz	3.8 km	3.8 km	1.00	0 (**- 1**)
Volume Above 6 km	50.2 km^3	27.5 km^3	1.82	82 (**49**)
Prec.Flux	315.8 m^3/s	217.4 m^3/s	1.45	45 (**48**)
Prec.Mass	1755.0 kton	656.1 kton	2.67	167 (**115**)
CloudMass	150.1 kton	82.5 kton	1.82	82 (**50**)
η	11.7	8.0	1.46	46 (**43**)

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 213 AgI-flares and 3 hygroscopic flares were used in this sub-sample with an excellent timing (**94 %)** for an effective AgI average dose about **50 ice-nuclei per liter**. The seeding operation for small clouds lasted about **6 minutes** in average. An excellent increase of **115 %** in precipitation mass together with an increase of 50 % 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 (36 %), area (40 %), volume (47 %), volume above 6 km (49 %), and precipitation flux (48 %) are notable. There was a slight increase in top height (2 %) and in maximum reflectivity (1 %).

The seeded sub-sample seemed 43 % more efficient than the control sub-sample. Results are evaluated as **excellent**.

An increase of 115 % in precipitation mass for a control value of 656.1 kton in 39 cases means:

Δ_1 = 39 x 1.15 x 656.1 kton ≈ 29 426 kton ≈ 23 865 ac-f (layer: 12.1 mm ≈ 0.48 in)

Large Clouds

The sub-sample of 25 large seeded clouds received a synergetic analysis. In average, the seeding operations on these large clouds affected 83 % of their whole volume with a perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of 597 AgI-flares and 31 hygroscopic flares were used in this sub-sample for an effective AgI average dose about **100 ice-nuclei per liter**.

Also in average, large clouds were 23 minutes old when the operations took place; the operation lasted about 50 minutes, and the large seeded clouds lived 250 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (25 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	255 min	195 min	1.31	31
Area	758 km^2	557 km^2	1.36	36
Volume	3481 km^3	2434 km^3	1.43	43
Volume Above 6 km	1535 km^3	1137 km^3	1.35	35
Prec.Flux	9279 m^3/s	7138 m^3/s	1.30	30
Prec.Mass	93 370 kton	66 478 kton	1.40	40

An increase of 40 % in precipitation mass for a control value of 66 478 kton in 25 cases may mean:

Δ_2 = 25 x 0.40 x 66 478 kton = 664 780 kton ≈ 539 137 ac-f (layer: 35.1 mm ≈ 1.38 in)

Type B Clouds

The sub-sample of 9 type B seeded clouds received a synergetic analysis. In average, the seeding operations on the type B clouds affected 15 % of their whole volume with a very good timing (89 % of the material went to the clouds in their first half-lifetime). A total of 149 AgI-flares and 17 hygroscopic flares were used in this sub-sample for an effective AgI average dose of about **105 ice-nuclei per liter**.

Also in average, type B clouds were 125 minutes old when the operations took place; the operation lasted about 40 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 (9 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	300 min	290 min	1.03	3
Area	2069 km^2	1971 km^2	1.05	5
Volume	8943 km^3	8517 km^3	1.05	5
Volume Above 6 km	3195 km^3	3043 km^3	1.05	5
Prec.Flux	14 558 m^3/s	13864 m^3/s	1.05	5
Prec.Mass	151 285 kton	140 079 kton	1.08	8

An increase of 8 % in precipitation mass for a control value of 140 079 kton in 9 cases may mean:

Δ_3 = 9 x 0.08 x 140 079 kton ≈ 100 857 kton ≈ 81 795 ac-f (layer: 5.4 mm ≈ 0.21 in)

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 644 797 ac-f

(~ 612 ac-f per small storm; ~ 21 565 ac-f per large storm; ~ 9 089 per B storms)

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	**18**	**20**	**133 400**	**1.67**	**16.10 in**	**10.4 %**
Reagan	**10**	**15**	**85 500**	**1.35**	**12.00 in**	**11.3 %**
Irion	**17**	**21**	**124 300**	**2.21**	**14.77 in**	**15.0 %**
Tom Green	**10**	**18**	**97 500**	**2.39**	**13.42 in**	**17.8 %**
Crocket	**6**	**9**	**78 300**	**0.52**	**11.20 in**	**4.6 %**
Schleicher	**11**	**13**	**93 000**	**1.33**	**14.77 in**	**9.0 %**
Sutton	**9**	**10**	**34 300**	**0.45**	**14.22 in**	**3.2 %**
Outside TA			~ 7 600	(~ 1.2 % of the total amount)		
Total	**73**	**109**	**653 900 ac-f**			
Average (only for the bold values)				**1.42**	**13.78 in**	**10.3 %**

(**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**.

2) The micro-regionalization analysis showed increases per county; 2017 seedable conditions were less frequent than in previous years; the average increase in precipitation, referred to the seasonal value, is about **10 %.** Maximum relative increases in precipitation were located on the central and northern regions (Reagan-Irion-Tom Green-Sterling Counties) where about 75 % of the seeding operations were made;

3) Radar estimations of precipitation should be considered as measurements of trend. Nevertheless, according to the results on this report's tables, seeding operations improved the dynamics of seeded clouds;

The results obtained for the seeded small clouds reinforce the evidence that there is a strong synergy between the hygroscopic and the glaciogenic actions. The following table illustrates how the dual seeding was applied:

Type of storm	AgI-flares used	Hygroscopic flares used
Small	213 (~ 5.5 per storm)	3 (~ 0.08 per storm)
Large	597 (~ 23.9 per storm)	31 (~ 1.2 per storm)
Type B	149 (~ 16.6 per storm)	17 (~ 1.9 per storm)