ANNUAL EVALUATION REPORT 2019 **WTWMA (San Angelo)**

Dr. Arquímedes Ruiz-Columbié
Active Influence & Scientific Management

Cloud seeding operations 2019 began over the West Texas Weather Modification Association target area on the last day of April. This annual report serves as a summary of results.

A total of **61 clouds** were seeded and identified by TITAN in **31 operational days**.
Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **April 30th, 2019**
Last operational day: **October 6th, 2019**

Number of operational days: 31
(One in April, six in May, nine in June, four in July, six in August, four in September, and one in October)

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

Twenty with excellent performance

Six with very good performance

Three with good performance

One with fair performance

One of experimental character (May 1st)

Number of seeded clouds: 61 (28 small, 16 large, 17 type B)

Missed Opportunities: three, with lifetime longer than 1 hour (less than 5 % of resources)

July 8th: Storm # 2492 over Crocket County (19:40-21:16 UTC)
September 1st: Storm # 1392 over Crocket County (20:00 – 22:00 UTC)
September 22nd: Storm # 1743 over Sterling and Tom Green Counties (21:00 – 02:00 UTC)

Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 28 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (28 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	70 min	50 min	1.40	40 (**27**)
Area	76.5 km^2	56.6 km^2	1.35	35 (**21**)
Volume	272.0 km^3	182.5 km^3	1.49	49 (**27**)
Top Height	9.8 km	8.7 km	1.13	13 (**3**)
Max dBz	53.7	51.5	1.04	4 (**0**)
Top Height of max dBz	4.1 km	4.0 km	1.03	3 (**-5**)
Volume Above 6 km	91.5 km^3	55.1 km^3	1.66	66 (**21**)
Prec.Flux	597.1 m^3/s	366.8 m^3/s	1.63	63 (**26**)
Prec.Mass	2798.9 kton	1251.4 kton	2.23	123 (**105**)
CloudMass	197.0 kton	115.6 kton	1.70	70 (**32**)
η	14.2	10.8	1.31	31 (**54**)

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 174 AgI-flares, 8 hygroscopic flares, and 16.32 gallons of water were used in this sub-sample with an excellent timing (**91 %)** for an effective AgI average dose of about **60 ice-nuclei per liter**. The seeding operation for small clouds lasted about **8 minutes** on average. An excellent increase of **105 %** in precipitation mass together with an increase of 32 % 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 (27 %), area (21 %),

volume (27 %), volume above 6 km (21 %), and precipitation flux (26 %) are notable. There was a slight increase in top height (3 %) and no increase in maximum reflectivity. The seeded sub-sample seemed 54 % more efficient than the control sub-sample. Results are evaluated as **excellent**.

An increase of 105 % in precipitation mass for a control value of 1251.4 kton in 28 cases means:

Δ_1 = 28 x 1.05 x 1251.4 kton ≈ 36 791 kton ≈ 29 838 ac-f (layer: 17.2 mm ≈ 0.68 in)

Large Clouds

The sub-sample of 16 large seeded clouds received a synergetic analysis. On average, the seeding operations on these large clouds affected 76 % of their whole volume with an excellent timing (96 % of the material went to the clouds in their first half-lifetime). A total of 423 AgI-flares and 39 hygroscopic flares were used in this sub-sample for an effective AgI average dose of about **55 ice-nuclei per liter**.

Also on average, large clouds were 35 minutes old when the operations took place; the operation lasted about 26 minutes, and the large seeded clouds lived 270 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (16 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	270 min	230 min	1.17	17
Area	958 km^2	832 km^2	1.15	15
Volume	4292 km^3	3599 km^3	1.19	19
Volume Above 6 km	1762 km^3	1530 km^3	1.15	15
Prec.Flux	8978 m^3/s	7570 m^3/s	1.19	19
Prec.Mass	109 861 kton	66 988 kton	1.64	64

An increase of 64 % in precipitation mass for a control value of 66 988 kton in 16 cases may mean:

Δ_2 = 16 x 0.64 x 66 988 kton = 685 957 kton ≈ 556 311 ac-f (layer: 44.75 mm ≈ 1.76 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 12 % of their whole volume with a good timing (70 % of the material went to the clouds in their first half-lifetime). A total of 324 AgI-flares and 19 hygroscopic flares were used in this sub-sample for an effective AgI average dose of about **45 ice-nuclei per liter**.

Also on average, type B clouds were 145 minutes old when the operations took place; the operation lasted about 28 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	2520 km^2	2468 km^2	1.02	2
Volume	10582 km^3	10312 km^3	1.03	3
Volume Above 6 km	4244 km^3	4156 km^3	1.02	2
Prec.Flux	21 622 m^3/s	21 087 m^3/s	1.03	3
Prec.Mass	537 175 kton	504 158 kton	1.07	7

An increase of 7 % in precipitation mass for a control value of 504 158 kton in 17 cases may mean:

Δ_3 = 17 x 0.07 x 504 158 kton ≈ 599 948 kton ≈ 486 558 ac-f (layer: 14.00 mm ≈ 0.55 in)

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 1 072 307 ac-f

(~ 1066 ac-f per small storm; ~ 34 770 ac-f per large storm; ~ 28 621 ac-f 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	**9**	**10**	**102 600**	**1.28**	**8.33 in**	**15.4 %**
Reagan	**7**	**11**	**70 900**	**1.12**	**8.41 in**	**13.3 %**
Irion	**9**	**14**	**122 300**	**2.17**	**10.26 in**	**21.1 %**
Tom Green	**6**	**13**	**56 400**	**1.38**	**11.39 in**	**12.1 %**
Crocket	**14**	**19**	**338 900**	**2.25**	**10.64 in**	**21.2 %**
Schleicher	**8**	**16**	**157 000**	**2.36**	**12.98 in**	**18.1 %**
Sutton	**7**	**18**	**117 900**	**2.19**	**9.60 in**	**22.8 %**
Outside TA	1	3	~ 105 800	(~ 10 % of the total amount)		
Total	**61**	**104**	**1 071 900 ac-f**			
Average (only for the bold values)				**1.82**	**10.23 in**	**17.7 %**

(**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; the average increase in precipitation, referred to the seasonal value, is about **18 %.** Noticeable relative increases in precipitation were detected in all the counties, although the Irion and the southern region got the maximum impact (~ 64 % of extended resources);

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.