ANNUAL EVALUATION REPORT 2018 **WTWMA (San Angelo)**

Dr. Arquímedes Ruiz-Columbié
Active Influence & Scientific Management

Cloud seeding operations 2018 began over the West Texas Weather Modification Association target area in May. This annual report serves as a summary of results.

A total of **54 clouds** were seeded and identified by TITAN in **21 operational days**.
Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **May 2nd, 2018**
Last operational day: **September 3rd , 2018**

Number of operational days: 21
(Four in May, four in June, eight in July, three in August, and two in September)

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

Sixteen with excellent performance

Two with very good performance

Three with good performance

Number of seeded clouds: 54 (23 small, 10 large, 21 type B)

Missed Opportunities: one with lifetime longer than 1 hour (less than 2 % of resources)
July 6th: Storm # 466 over Irion and Crocket Counties 15:16-19:00 UTC

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	70 min	40 min	1.75	75 (**56**)
Area	87.8 km^2	58.5 km^2	1.50	50 (**49**)
Volume	311.0 km^3	165.7 km^3	1.88	88 (**79**)
Top Height	9.1 km	8.3 km	1.10	10 (**4**)
Max dBz	53.8	48.9	1.10	10 (**3**)
Top Height of max dBz	4.1 km	4.3 km	0.95	-5 (**2**)
Volume Above 6 km	91.3 km^3	30.9 km^3	2.95	195 (**137**)
Prec.Flux	683.2 m^3/s	286.6 m^3/s	2.38	138 (**71**)
Prec.Mass	2860.1 kton	871.6 kton	3.28	228 (**150**)
CloudMass	226.7 kton	90.5 kton	2.50	150 (**87**)
η	12.6	9.6	1.31	31 (**34**)

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 178 AgI-flares and 20 hygroscopic flares were used in this sub-sample with a very good timing (**84 %)** for an effective AgI average dose of about **55 ice-nuclei per liter**. The seeding operation for small clouds lasted about **9 minutes** on average. An excellent increase of **150 %** in precipitation mass together with an increase of 87 % 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 (56 %), area (49 %), volume (79 %), volume above 6 km (137 %), and precipitation flux (71 %) are notable. There were slight increases in top height (4 %) and in maximum reflectivity (3 %).

The seeded sub-sample seemed 34 % more efficient than the control sub-sample. Results are evaluated as **excellent** (although timing might have been better).

An increase of 150 % in precipitation mass for a control value of 871.6 kton in 23 cases means:

Δ_1 = 23 x 1.50 x 871.6 kton ≈ 39 468 kton ≈ 32 009 ac-f (layer: 19.5 mm ≈ 0.77 in)

Large Clouds

The sub-sample of 10 large seeded clouds received a synergetic analysis. On average, the seeding operations on these large clouds affected 74 % of their whole volume with a perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of 126 AgI-flares and 2 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 20 minutes old when the operations took place; the operation lasted about 23 minutes, and the large seeded clouds lived 220 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (10 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	220 min	165 min	1.33	33
Area	1149 km^2	870 km^2	1.32	32
Volume	4717 km^3	3181 km^3	1.48	48
Volume Above 6 km	1808 km^3	1037 km^3	1.74	74
Prec.Flux	9997 m^3/s	6934 m^3/s	1.44	44
Prec.Mass	131 960 kton	73 720 kton	1.79	79

An increase of 79 % in precipitation mass for a control value of 73 720 kton in 10 cases may mean:

Δ_2 = 10 x 0.79 x 73 720 kton = 589 760 kton ≈ 478 295 ac-f (layer: 50.7 mm ≈ 2.0 in)

Type B Clouds

The sub-sample of 21 type B seeded clouds received a synergetic analysis. On average, the seeding operations on the type B clouds affected 27 % 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 426 AgI-flares and 16 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 22 minutes, and the type B seeded clouds lived 250 minutes.

Table 4 shows the results:

Table 4: Type B Seeded Sample versus Virtual Control Sample (21 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	250 min	235 min	1.06	6
Area	3528 km^2	3221 km^2	1.10	10
Volume	14917 km^3	13173 km^3	1.13	13
Volume Above 6 km	5503 km^3	4660 km^3	1.19	19
Prec.Flux	23 555 m^3/s	20 963 m^3/s	1.12	12
Prec.Mass	167 901 kton	141 093 kton	1.19	19

An increase of 19 % in precipitation mass for a control value of 141 093 kton in 21 cases may mean:

Δ_3 = 21 x 0.19 x 141 093 kton ≈ 562 961 kton ≈ 456 561 ac-f (layer: 7.60 mm ≈ 0.30 in)

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 966 865 ac-f

(~ 1392 ac-f per small storm; ~ 47 830 ac-f per large storm; ~ 21 741 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**	**11**	**139 100**	**1.74**	**13.37 in**	**13.0 %**
Reagan	**4**	**10**	**63 700**	**1.01**	**11.65 in**	**8.7 %**
Irion	**8**	**15**	**123 200**	**2.19**	**12.63 in**	**17.3 %**
Tom Green	**8**	**15**	**146 200**	**3.58**	**17.66 in**	**20.3 %**
Crocket	**9**	**16**	**204 800**	**1.36**	**11.93 in**	**11.4 %**
Schleicher	**10**	**13**	**168 000**	**2.53**	**20.71 in**	**12.2 %**
Sutton	**5**	**6**	**47 300**	**0.88**	**20.75 in**	**4.2 %**
Outside TA	1	2	~ 66 800	(~ 7 % of the total amount)		
Total	**54**	**88**	**959 100 ac-f**			
Average (only for the bold values)				**1.90**	**15.49 in**	**12.4 %**

(**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 **12 %.** Noticeable relative increases in precipitation were more distributed than in previous campaigns, although the central region (Irion and Tom Green Counties) got the maximum impact (~ 30 % of 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 improved the dynamics of seeded clouds.