ANNUAL EVALUATION REPORT 2015 WTWMA (San Angelo)

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Cloud seeding operations 2015 began over the West Texas Weather Modification Association target area in March. This annual report serves as a summary of results.

A total of **88 clouds** were seeded and identified by TITAN in **38 operational days**.
Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **March 31st, 2015**
Last operational day: **September 19th , 2015**

Number of operational days: 38
(One in March, seven in April, ten in May, four in June, three in July, ten in August, and three in September)

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

Twenty-eight with excellent performance

Four with very good performance

Four with good performance

One with fair performance (June 30th)

One with no TITAN data (July 8th)

Number of seeded clouds: 88 (49 small, 10 large, 29 type B)

Missed Opportunities: none with lifetime longer than 45 minutes

Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 49 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (49 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	70 min	45 min	1.56	56 (**48**)
Area	70.2 km^2	44.7 km^2	1.57	57 (**50**)
Volume	236.3 km^3	143.9 km^3	1.64	64 (**53**)
Top Height	8.8 km	8.4 km	1.05	5 (**2**)
Max dBz	51.5	50.1	1.02	2 (**0**)
Top Height of max dBz	4.0 km	3.9 km	1.03	3 (**- 2**)
Volume Above 6 km	63.0 km^3	34.6 km^3	1.82	82 (**48**)
Prec.Flux	420.5 m^3/s	254.0 m^3/s	1.66	66 (**41**)
Prec.Mass	2016.0 kton	777.5 kton	2.59	159 (**135**)
CloudMass	148.2 kton	91.8 kton	1.61	61 (**40**)
η	13.6	8.5	1.60	60 (**68**)

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 499 AgI-flares and 24 hygroscopic flares were used in this sub-sample with an excellent timing (**98 %)** for an effective AgI average dose about **50 ice-nuclei per liter**. The seeding operation for small clouds lasted about **7 minutes** in average. An excellent increase of **135 %** in precipitation mass together with an increase of 40 % 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 increases in lifetime (48 %), area (50 %), volume (53 %), volume above 6 km (48 %), and precipitation flux (41 %) are remarkable. There was a slight increase in top height (2 %) and no increase in maximum reflectivity (0 %).

The seeded sub-sample seemed 68 % more efficient than the control sub-sample. Results are evaluated as **excellent**.

An increase of 135 % in precipitation mass for a control value of 777.5 kton in 49 cases means:

Δ_1 = 49 x 1.35 x 777.5 kton ≈ 51 432 kton ≈ 41 711 ac-f (layer: 14.95 mm ≈ 0.59 in)

Large Clouds

The sub-sample of 10 large seeded clouds received a synergetic analysis. In average, the seeding operations on these large clouds affected 82 % of their whole volume with a perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of 283 AgI-flares and 23 hygroscopic flares were used in this sub-sample for an effective AgI average dose about **120 ice-nuclei per liter**.

Also in average, large clouds were 25 minutes old when the operations took place; the operation lasted about 58 minutes, and the large seeded clouds lived 205 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	205 min	155 min	1.32	32
Area	525 km^2	382 km^2	1.37	37
Volume	2483 km^3	1778 km^3	1.40	40
Volume Above 6 km	1098 km^3	806 km^3	1.36	36
Prec.Flux	10444 m^3/s	7954 m^3/s	1.31	31
Prec.Mass	66 701 kton	35 292 kton	1.89	89

An increase of 89 % in precipitation mass for a control value of 34 288 kton in 10 cases may mean:

Δ_2 = 10 x 0.89 x 35 292 kton = 314 099 kton ≈ 254 734 ac-f (layer: 59.8 mm ≈ 2.36 in)

Type B Clouds

The sub-sample of 29 type B seeded clouds received a synergetic analysis. In average, the seeding operations on the type B clouds affected 16 % of their whole volume with a very good timing (83 % of the material went to the clouds in their first half-lifetime). A total of 628 AgI-flares and 70 hygroscopic flares were used in this sub-sample for an effective AgI average dose of about **95 ice-nuclei per liter**.

Also in average, type B clouds were 140 minutes old when the operations took place; the operation lasted about 41 minutes, and the type B seeded clouds lived 350 minutes.

Table 4 shows the results:

Table 4: Type B Seeded Sample versus Virtual Control Sample (29 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	350 min	340 min	1.03	3
Area	2807 km^2	2657 km^2	1.06	6
Volume	11398 km^3	10766 km^3	1.06	6
Volume Above 6 km	3861 km^3	3661 km^3	1.05	5
Prec.Flux	16212 m^3/s	15458 m^3/s	1.05	5
Prec.Mass	222 340 kton	201 904 kton	1.10	10

An increase of 10 % in precipitation mass for a control value of 201 904 kton in 29 cases may mean:

Δ_3 = 29 x 0.10 x 201 904 kton ≈ 585 522 kton ≈ 474 858 ac-f (layer: 7.2 mm ≈ 0.28 in)

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 771 303 ac-f

(~ 851 ac-f per small storm; ~25 473 ac-f per large storm; ~ 16 374 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	**15**	**24**	**102 700**	**1.29**	**12.18 in**	**10.6 %**
Reagan	**16**	**20**	**97 600**	**1.55**	**15.01 in**	**10.3 %**
Irion	**07**	**17**	**116 600**	**2.07**	**20.54 in**	**10.1 %**
Tom Green	**07**	**17**	**109 600**	**2.69**	**18.48 in**	**14.6 %**
Crocket	**16**	**24**	**109 100**	**0.72**	**13.49 in**	**5.3 %**
Schleicher	**14**	**17**	**103 900**	**1.49**	**14.23 in**	**10.5 %**
Sutton	**13**	**19**	**108 700**	**1.42**	**18.31 in**	**7.8 %**
Outside TA	0	6	~ 23 000	**(~ 2 % of the total amount)**		
Total	**88**	**144**	**771 200 ac-f**			
Average (only for the bold values)				**1.60**	**16.03 in**	**9.98 %**

(**Initial seeding** means the counties where the operations began, whereas **extended seeding** means the counties favored by seeding after the initial operations took place).

Importance of hygroscopic seeding (really dual cases)

Hygroscopic seeding operations were still used as a complement of the glaciogenic seeding**.** For the small cases, it was possible to make a comparison between pure glaciogenic seeding (25 cases) and all the small cases (49 cases, table 2). Table 6 shows the results for the former (25 small pure glaciogenic seeding cases):

Table # 6 Seeded Sample versus Control Sample (25 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	60 min	40 min	1.50	50 (**43**)
Area	77.1 km^2	39.9 km^2	1.93	93 (**45**)
Volume	246.9 km^3	128.4 km^3	1.92	92 (**46**)
Top Height	8.8 km	8.4 km	1.05	5 (**3**)
Max dBz	50.6	49.1	1.03	3 (**1**)
Top Height of max dBz	3.9 km	3.9 km	1.00	0 (**-2**)
Volume Above 6 km	60.5 km^3	28.9 km^3	2.09	109 (**39**)
Prec.Flux	357.0 m^3/s	207.0 m^3/s	1.72	72 (**23**)
Prec.Mass	1647.3 kton	454.4 kton	3.63	263 (**110**)
CloudMass	133.8 kton	78.1 kton	1.71	71 (**10**)
η	12.3	5.8	2.12	112 (**89**)

A total of 127 AgI-flares were used in this sub-sample with a perfect timing (**100 %)** for an effective AgI-average dose about **40 ice-nuclei per liter**. The increases indicate a dynamic response. The vertical reflectivity gradient index for this sample was - 4.0 dBz/km, indicating a neutral value. The comparison of these results with those shown on table 2 points out to the existence of a synergy between glaciogenic and hygroscopic materials which favors the use of dual seeding when it is possible.

The increase from this sample: $\Delta = 25 \times 1.10 \times 454.4$ kton $\approx 12\,496$ kton $\approx 10\,134$ ac-f
(~ 405 ac-f per storm; layer: 6.48 mm ≈ 0.26 in)

Final Comments

1) Results are evaluated as **excellent**;

2) The micro-regionalization analysis showed increases per county; 2015 seedable conditions were more frequent over the southern part of the target area; the average increase in precipitation, referred to the seasonal value, is about **10 %.** Maximum relative increase in precipitation were located on Tom Green County;

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 was a strong synergy between the hygroscopic and the glaciogenic actions. More intensive uses of hygroscopic material is recommended when possible.