ANNUAL EVALUATION REPORT 2014 WTWMA (San Angelo)

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Cloud seeding operations 2014 began over the West Texas Weather Modification Association target area in April. This annual report serves as a summary of results. A total of **111 clouds** were seeded and identified by TITAN in **40 operational days**.
Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **April 3rd 2014**
Last operational day: **October 10th 2014**

Number of operational days: 40
(Six in April, five in May, three in June, five in July, ten in August, ten in September and one in October)

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

Twenty-seven with excellent performance
Five with very good performance
Four with good performance
Two with fair performance

One in experimental mode (July 11th)
One with corrupted data (June 11th)

Number of seeded clouds: 111 (58 small, 20 large, 33 type B)

Missed Opportunities: one with lifetime longer than 45 minutes (< 1 % of resources)

Storm # 287 on April 23rd over Sterling County (23:15 - 00:10 UTC)

Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 58 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (58 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	60 min	40 min	1.50	50 (**33**)
Area	59.0 km^2	37.8 km^2	1.56	56 (**40**)
Volume	199.1 km^3	107.9 km^3	1.85	85 (**52**)
Top Height	10.2 km	8.8 km	1.16	16 (**3**)
Max dBz	50.8	48.9	1.04	4 (**1**)
Top Height of max dBz	3.8 km	3.7 km	1.03	3 (**- 2**)
Volume Above 6 km	45.0 km^3	17.8 km^3	2.53	153 (**81**)
Prec.Flux	246.2 m^3/s	185.1 m^3/s	1.87	87 (**52**)
Prec.Mass	1545.8 kton	497.8 kton	3.11	211 (**130**)
CloudMass	128.1 kton	62.6 kton	2.05	105 (**58**)
η	12.1	8.0	1.51	51 (**45**)

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 367 AgI-flares and 37 hygroscopic flares were used in this sub-sample with an excellent timing (**80 %)** for an effective AgI average dose about **90 ice-nuclei per liter**. The seeding operation for small clouds lasted about **8 minutes** in average. An excellent increase of **130 %** in precipitation mass together with an increase of 58 % 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 (33 %), area (40 %) volume (52 %), volume above 6 km (81 %), and precipitation flux (52 %) are remarkable. There are slight increases in top height (3 %) and maximum reflectivity (1 %).

The seeded sub-sample seemed 45 % more efficient than the control sub-sample. Results are evaluated as **excellent**.

An increase of 130 % in precipitation mass for a control value of 497.8 kton in 58 cases means:

$\mathbf{\Delta_1 = 58 \times 1.30 \times 497.8}$ **kton ≈ 37 534 kton ≈ 30 440 ac-f (layer: 10.97 mm ≈ 0.47 in)**

Large Clouds

The sub-sample of 20 large seeded clouds received a synergetic analysis. In average, the seeding operations on these large clouds affected 65 % of their whole volume with a perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of 469 AgI-flares and 24 hygroscopic flares were used in this sub-sample for an effective AgI average dose about **80 ice-nuclei per liter**.

Also in average, large clouds were 20 minutes old when the operations took place; the operation lasted about 43 minutes, and the large seeded clouds lived 300 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (20 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	300 min	255 min	1.18	18
Area	1378 km^2	1122 km^2	1.23	23
Volume	5672 km^3	4411 km^3	1.29	29
Volume Above 6 km	2009 km^3	1425 km^3	1.41	41
Prec.Flux	8674 m^3/s	6745 m^3/s	1.29	29
Prec.Mass	153 517 kton	97 116 kton	1.58	58

An increase of 58 % in precipitation mass for a control value of 97 116 kton in 20 cases may mean:

$\mathbf{\Delta_2 = 20 \times 0.58 \times 97\ 116}$ **kton = 1 126 546 kton ≈ 913 628 ac-f (layer: 40.9 mm ≈ 1.61 in)**

Type B Clouds

The sub-sample of 33 type B seeded clouds received a synergetic analysis. In average, the seeding operations on the type B clouds affected 10 % of their whole volume with an excellent timing (88 % of the material went to the clouds in their first half-lifetime). A total of 525 AgI-flares and 46 hygroscopic flares were used in this sub-sample for an effective AgI average dose of about **110 ice-nuclei per liter**.

Also in average, type B clouds were 135 minutes old when the operations took place; the operation lasted about 35 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 (33 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	300 min	290 min	1.03	3
Area	1505 km^2	1462 km^2	1.03	3
Volume	6384 km^3	6165 km^3	1.04	4
Volume Above 6 km	2380 km^3	2273 km^3	1.05	5
Prec.Flux	12642 m^3/s	12210 m^3/s	1.04	4
Prec.Mass	96 253 kton	90 805 kton	1.06	6

An increase of 6 % in precipitation mass for a control value of 90 805 kton in 33 cases may mean:

Δ_3 = 33 x 0.06 x 90 805 kton ≈ 179 794 kton ≈ 145 813 ac-f (layer: 3.6 mm ≈ 0.14 in)

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 1 089 881 ac-f

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	**14**	**16**	**92 000**	**1.16**	**10.59 in**	**11.0 %**
Reagan	**13**	**22**	**175 900**	**2.80**	**15.52 in**	**18.0 %**
Irion	**16**	**25**	**154 500**	**2.74**	**13.18 in**	**20.9 %**
Tom Green	**18**	**28**	**108 100**	**2.65**	**15.46 in**	**17.1 %**
Crocket	**11**	**19**	**179 700**	**1.19**	**13.01 in**	**9.1 %**
Schleicher	**26**	**39**	**164 400**	**2.35**	**15.38 in**	**15.3 %**
Sutton	**11**	**17**	**95 000**	**1.24**	**9.20 in**	**13.5 %**
Outside TA	2	8	~ 118 800	**(~ 11 % of the total amount)**		
Total	**111**	**174**	**1 088 000**			
Average (only for the bold values)				**2.02**	**14.13 in**	**15.0 %**

(**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 (26 cases) and all the small cases (58 cases, table 2). Table 6 shows the results for the former (26 small pure glaciogenic seeding cases):

Table # 6 Seeded Sample versus Control Sample (26 couples, averages)

Variable	**Seeded Sample**	**Control Sample**	**Simple Ratio**	**Increases (%)**
Lifetime	50 min	40 min	1.25	25 (**14**)
Area	50.9 km^2	38.0 km^2	1.34	34 (**19**)
Volume	159.6 km^3	105.7 km^3	1.51	51 (**36**)
Top Height	7.8 km	7.4 km	1.05	5 (**2**)
Max dBz	50.0	48.7	1.03	3 (**1**)
Top Height of max dBz	3.8 km	3.7 km	1.03	3 (**0**)
Volume Above 6 km	27.8 km^3	17.1 km^3	1.63	63 (**54**)
Prec.Flux	275.8 m^3/s	187.2 m^3/s	1.47	47 (**28**)
Prec.Mass	1117.7 kton	515.7 kton	2.17	117 (**93**)
CloudMass	97.4 kton	61.1 kton	1.59	59 (**38**)
η	11.5	8.4	1.37	37 (**40**)

A total of 107 AgI-flares were used in this sub-sample with a good timing (**65 %)** for an effective AgI-average dose about **70 ice-nuclei per liter**. The increases indicate a dynamic response. The vertical reflectivity gradient index for this sample was - 4.1 dBz/km, indicating a slight maritime trail (neutral value is - 4.0 dBz/km). The comparison of these results with those shown on table 2 indicates 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: Δ = 26 x 0.93 x 515.7 kton ≈ 12 465 kton ≈ 10 109 ac-f

Final Comments

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

2) The micro-regionalization analysis showed increases per county; 2014 seedable conditions were more frequent over Schleicher County; the average increase in precipitation, referred to the seasonal value, is about **15 %.** Maximum relative increases in precipitation were located on Reagan and Irion 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 improved the dynamics of seeded clouds;

This year, hygroscopic seeding was continued as an important component of the operations, and the results indicate a noticeable improvement in the dynamics of the 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 adviced when possible.