ANNUAL EVALUATION REPORT 2013 WTWMA (San Angelo)

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Cloud seeding operations 2013 began over the West Texas Weather Modification Association target area in March. This annual report serves as a summary of results. A total of **106 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 9th 2013**
Last operational day: **October 18th 2013**

Number of operational days: 38
(Two in March, one in April, five in May, six in June, six in July, twelve in August, five in September and one in October)

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

Nineteen with excellent performance
Eleven with very good performance
Six with good performance

One in experimental mode (August 25th)
One with corrupted data (March 9th)

Number of seeded clouds: 106 (62 small, 19 large, 25 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 62 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (62 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	60 min	40 min	1.50	50 (**33**)
Area	72.5 km^2	46.3 km^2	1.57	57 (**31**)
Volume	273.3 km^3	174.7 km^3	1.56	56 (**29**)
Top Height	9.5 km	9.1 km	1.04	4 (**2**)
Max dBz	50.5	48.6	1.04	4 (**3**)
Top Height of max dBz	4.0 km	4.1 km	0.98	- 2 (**- 2**)
Volume Above 6 km	94.5 km^3	61.2 km^3	1.54	54 (**21**)
Prec.Flux	425.2 m^3/s	237.1 m^3/s	1.79	79 (**30**)
Prec.Mass	1662.6 kton	700.2 kton	2.37	137 (**116**)
CloudMass	170.7 kton	102.1 kton	1.67	67 (**33**)
η	9.7	6.9	1.41	41 (**60**)

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 381 AgI-flares and 29 hygroscopic flares were used in this sub-sample with an excellent timing (**87 %)** for an effective AgI average dose about **30 ice-nuclei per liter**. The seeding operation for small clouds lasted about **9 minutes** in average. An excellent increase of **116 %** in precipitation mass together with an increase of 33 % 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 (31 %) volume (29 %), volume above 6 km (21 %), and precipitation flux (30 %) are notable. There are slight increases in top height (2 %) and maximum reflectivity (3 %).

The seeded sub-sample seemed 60 % more efficient than the control sub-sample. Results are evaluated as **excellent**.

An increase of 116 % in precipitation mass for a control value of 700.2 kton in 62 cases means:

Δ_1 = 62 x 1.16 x 700.2 kton ≈ 50 358 kton ≈ 40 841 ac-f

Large Clouds

The sub-sample of 19 large seeded clouds received a synergetic analysis. In average, the seeding operations on these large clouds affected 73 % of their whole volume; with an almost perfect timing (99 % of the material went to the clouds in their first half-lifetime). A total of 334 AgI-flares and 21 hygroscopic flares were used in this sub-sample for an effective AgI average dose about **90 ice-nuclei per liter**.

Also in average, large clouds were 30 minutes old when the operations took place; the operation lasted about 36 minutes, and the large seeded clouds lived 195 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (19 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	195 min	165 min	1.18	18
Area	1010 km^2	837 km^2	1.21	21
Volume	5127 km^3	4290 km^3	1.20	20
Volume Above 6 km	2390 km^3	2089 km^3	1.14	14
Prec.Flux	9712 m^3/s	8087 m^3/s	1.20	20
Prec.Mass	80 484 kton	49 105 kton	1.64	64

An increase of 64 % in precipitation mass for a control value of 49 105 kton in 19 cases may mean:

Δ_2 = 19 x 0.64x 49 105 kton = 597 117 kton ≈ 484 262 ac-f

Type B Clouds

The sub-sample of 25 type B seeded clouds received a synergetic analysis. In average, the seeding operations on the type B clouds affected 27 % of their whole volume; with an excellent timing (91 % of the material went to the clouds in their first half-lifetime). A total of 532 AgI-flares and 24 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 125 minutes old when the operations took place; the operation lasted about 38 minutes, and the type B seeded clouds lived ~ 290 minutes.

Table 4 shows the results:

Table 4: Type B Seeded Sample versus Virtual Control Sample (25 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	290 min	280 min	1.04	4
Area	1761 km^2	1649 km^2	1.07	7
Volume	7448 km^3	6999 km^3	1.06	6
Volume Above 6 km	2938 km^3	2801 km^3	1.05	5
Prec.Flux	12667 m^3/s	11881 m^3/s	1.07	7
Prec.Mass	95 366 kton	81 620 kton	1.17	17

An increase of 17 % in precipitation mass for a control value of 81 620 kton in 25 cases may mean:

Δ_3 = 25 x 0.17 x 81 620 kton ≈ 346 885 kton ≈ 281 324 ac-f

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 806 427 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)
Glasscock	**8**	**14**	**63 900**	**1.33**	**12.36 in**	**10.8 %**
Sterling	**11**	**16**	**78 700**	**1.00**	**13.73 in**	**7.3 %**
Reagan	**12**	**18**	**138 200**	**2.20**	**14.49 in**	**15.2 %**
Irion	**15**	**25**	**120 300**	**2.14**	**14.64 in**	**14.6 %**
Tom Green	**12**	**15**	**70 100**	**1.72**	**16.34 in**	**10.5 %**
Crocket	**17**	**22**	**161 400**	**1.07**	**17.88 in**	**6.0 %**
Schleicher	**17**	**19**	**65 800**	**0.94**	**17.53 in**	**5.4 %**
Sutton	**12**	**15**	**105 900**	**1.38**	**18.86 in**	**7.3 %**
Total	**104**	**144**	**804 300**			
Outside TA	2	5	~ 14 400			
Average (only for the bold values)				**1.47**	**15.73 in**	**9.6 %**

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

Hygroscopic Cases (really dual cases)

Hygroscopic seeding operations were used as a complement of the glaciogenic seeding**.** They have become an important component of the whole campaign. A total of 43 dual cases were achieved (22 small cloud, 9 large cloud, and 12 type B clouds).

For the small cases it was possible to make a comparison between pure glaciogenic seeding (40 cases) and dual seeding (22 cases). Tables 6 and 7 show the results:

Table 6 below shows the results of the TITAN evaluation for the small 41 glaciogenic cases:

Table # 6 Seeded Sample versus Control Sample (40 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	50 min	40 min	1.25	25 (**11**)
Area	64.1 km^2	45.0 km^2	1.42	42 (**20**)
Volume	239.8 km^3	157.9 km^3	1.52	52 (**22**)
Top Height	9.4 km	9.0 km	1.04	4 (**3**)
Max dBz	50.2	48.4	1.04	4 (**2**)
Top Height of max dBz	3.9 km	3.9 km	1.00	0 (**0**)
Volume Above 6 km	79.2 km^3	45.6 km^3	1.74	74 (**20**)
Prec.Flux	349.6 m^3/s	228.4 m^3/s	1.53	53 (**28**)
Prec.Mass	1207.6 kton	995.4 kton	2.02	102 (**94**)
CloudMass	146.2 kton	92.5 kton	1.58	58 (**28**)
η	8.3	6.4	1.30	30 (**54**)

A total of 186 AgI-flares were used in this sub-sample with an excellent timing (**83 %)** 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 - 3.45 dBz/km, indicating a clear continentalization (neutral value is - 4.0 dBz/km).

Table 7 illustrates the results corresponding to the small dual seeded cases.

Table 7: **Seeded Sample versus Control Sample (22 couple, averages)**

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	75 min	45 min	1.67	67 (**50**)
Area	87.7 km^2	48.8 km^2	1.80	80 (**47**)
Volume	334.2 km^3	205.1 km^3	1.63	63 (**38**)
Top Height	9.7 km	9.3 km	1.04	4 (**2**)
Max dBz	51.0	49.2	1.04	4 (**4**)
Top Height of max dBz	4.1 km	4.4 km	0.93	-7 (**-6**)
Volume Above 6 km	122.4 km^3	89.7 km^3	1.36	36 (**20**)
Prec.Flux	562.8 m^3/s	252.9 m^3/s	2.23	123 (**30**)
Prec.Mass	2490.0 kton	890.7 kton	2.80	180 (**140**)
CloudMass	215.3 kton	119.7 kton	1.80	80 (**40**)
η	11.6	7.4	1.57	57 (**71**)

A total of 195 AgI and 29 hygroscopic flares were used in this sample with an excellent timing (93 %) for silver iodide average dose of about 10 ice-nuclei per liter (static level). The seeded sample shows like-dynamic responses (see the increases) suggesting that the hygroscopic material was able to provide enough ice particles in order to reach dynamic dose levels. Results are evaluated as excellent. The vertical reflectivity gradient index for this sample was -3.98 dBz/km, very close to the normal index of - 4.0 dBz/km for neutral clouds (neither continentalization nor maritimization). The hygroscopic material seemed to improve the cloud efficiency.

Final Comments

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

2) The micro-regionalization analysis showed increases per county; seedable conditions were more frequent over the central zone of the target area (Reagan, Irion, and Tom Green Counties); the average increase in precipitation, referred to the seasonal value, is about **10 %.** 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, seeding operations appeared to improve 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 idea that there exist a strong synergy between the hygroscopic and the glaciogenic actions. More intensive uses of hygroscopic material is advice.