ANNUAL EVALUATION REPORT 2012 **WTWMA (San Angelo)**

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Cloud seeding operations 2012 began over the West Texas Weather Modification Association target area in March. This annual report serves as a summary of results. A total of **131 clouds** were seeded and identified by TITAN in **44 operational days**.
Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **March 19th 2012**
Last operational day: **October 13th 2012**

Number of operational days: 44
(Three in March, one in April, four in May, four in June, seventeen in July, ten in August, three in September and two in October)

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

Twenty-nine with excellent performance
Eight with very good performance
Six with good performance
One with fair performance

Number of seeded clouds: 131 (73 small, 15 large, 43 type B)

Missed Opportunities: Two with lifetime longer than 45 minutes, < 2 %

Storm # 700 on July 11th over Tom Green-Irion Counties 17:04-19:20

Storm # 2228 on July 27th over Glasscock-Reagan-Schleicher Counties 20:56-00:00

Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 73 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (73 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	50 min	1.30	30 (**40**)
Area	69.8 km^2	51.4 km^2	1.36	36 (**43**)
Volume	273.6 km^3	193.5 km^3	1.41	41 (**49**)
Top Height	9.4 km	8.9 km	1.06	6 (**1**)
Max dBz	52.5	50.5	1.04	4 (**2**)
Top Height of max dBz	4.0 km	3.8 km	1.05	5 (**0**)
Volume Above 6 km	91.3 km^3	65.9 km^3	1.39	39 (**51**)
Prec.Flux	504.6 m^3/s	305.7 m^3/s	1.65	65 (**67**)
Prec.Mass	2334.1 kton	1095.0 kton	2.13	113 (**116**)
CloudMass	191.9 kton	123.2 kton	1.56	56 (**64**)
η	12.2	8.9	1.37	37 (**33**)

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 335 AgI-flares and 39 hygroscopic flares were used in this sub-sample with an excellent timing (**90 %)** for an effective AgI average dose about **35 ice-nuclei per liter**. The seeding operation for small clouds lasted about **6 minutes** in average. An excellent increase of **116 %** in precipitation mass together with an increase of 64 % 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 (40 %), area (43 %) volume (49 %), volume above 6 km (51 %), and precipitation flux (67 %) are notable. There are slight increases in top height (1 %) and maximum reflectivity (2 %).

The seeded sub-sample seemed 33 % more efficient than the control sub-sample. Results are evaluated as **excellent**.

An increase of 116 % in precipitation mass for a control value of 1095 kton in 73 cases means:

Δ_1 = 73 x 1.16 x 1095 kton = 92 724.6 kton ≈ 75 200 ac-f

Large Clouds

The sub-sample of 15 large seeded clouds received a synergetic analysis. In average, the seeding operations on these large clouds affected 69 % of their whole volume; with a perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of 228 AgI-flares and 27 hygroscopic flares were used in this sub-sample for an effective AgI average dose about **70 ice-nuclei per liter**.

Also in average, large clouds were 29 minutes old when the operations took place; the operation lasted about 34 minutes, and the large seeded clouds lived 160 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (15 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	160 min	135 min	1.19	19
Area	797 km^2	632 km^2	1.26	26
Volume	4167 km^3	3222 km^3	1.29	29
Volume Above 6 km	2022 km^3	1551 km^3	1.30	30
Prec.Flux	9551 m^3/s	6907 m^3/s	1.38	38
Prec.Mass	96 441 kton	61 736 kton	1.56	56

An increase of 56 % in precipitation mass for a control value of 61 736 kton in 15 cases may mean:

Δ_2 = 15 x 0.56 x 61 736 kton = 518 582.4 kton ≈ 420 570 ac-f

Type B Clouds

The sub-sample of 43 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 an excellent timing (94 % of the material went to the clouds in their first half-lifetime). A total of 796 AgI-flares and 73 hygroscopic flares were used in this sub-sample for an effective AgI average dose of about **105 ice-nuclei per liter**.

Also in average, type B clouds were 100 minutes old when the operations took place; the operation lasted about 45 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 (43 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	300 min	290 min	1.03	3
Area	2512 km^2	2391 km^2	1.05	5
Volume	10371 km^3	9826 km^3	1.06	6
Volume Above 6 km	3696 km^3	3497 km^3	1.06	6
Prec.Flux	16659 m^3/s	15590 m^3/s	1.07	7
Prec.Mass	224 521 kton	205 786 kton	1.09	9

An increase of 9 % in precipitation mass for a control value of 205 786 kton in 43 cases may mean:

Δ_3 = 43 x 0.09 x 205 786 kton ≈ 796 392 kton ≈ 645 874 ac-f

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 1 141 644 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	Extended	Acre-feet (increase)	Inches (increase)	Rain (season value)	% (increase)
	Seeding					
Glasscock	**9**	**16**	**146 000**	**3.03**	**15.53 in**	**19.5 %**
Sterling	**16**	**21**	**169 200**	**2.15**	**19.96 in**	**11.8 %**
Reagan	**9**	**19**	**166 800**	**2.66**	**13.97 in**	**19.0 %**
Irion	**23**	**31**	**122 000**	**2.17**	**13.66 in**	**15.9 %**
Tom Green	**26**	**31**	**121 300**	**2.98**	**18.77 in**	**15.9 %**
Crockett	**12**	**18**	**142 200**	**0.94**	**12.80 in**	**7.4 %**
Schleicher	**27**	**35**	**161 800**	**2.31**	**14.10 in**	**16.4 %**
Sutton	**9**	**15**	**81 600**	**1.06**	**11.00 in**	**9.6 %**
Total	**131**	**186**	1 110 900			
Outside TA			~ 30 000			
Average (only for the bold values)				**2.16**	**14.97 in**	**14.4 %**

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

Hygroscopic Cases (really dual cases)

Hygroscopic seeding operations were finally introduced as an operational tool during the 2012 campaign**.** Initially conceived as a complement of the main glaciogenic seeding operations, they became an important component of the whole campaign. A total of 69 cases were achieved (32 small cloud, 12 large cloud, and 25 type B clouds).

For the small cases it was possible to make a comparison between pure glaciogenic seeding (41 cases) and dual seeding (32 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 (41 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	50 min	1.30	30 (**40**)
Area	69.3 km^2	46.9 km^2	1.48	48 (**50**)
Volume	268.4 km^3	166.9 km^3	1.61	61 (**63**)
Top Height	9.1 km	8.7 km	1.05	5 (**1**)
Max dBz	52.9	50.6	1.05	5 (**2**)
Top Height of max dBz	3.9 km	3.8 km	1.03	3 (**0**)
Volume Above 6 km	82.6 km^3	50.0 km^3	1.65	65 (**73**)
Prec.Flux	522.8 m^3/s	279.1 m^3/s	1.87	87 (**85**)
Prec.Mass	2404.5 kton	1018.0 kton	2.36	136 (**124**)
CloudMass	193.1 kton	106.1 kton	1.82	82 (**79**)
η	12.5	9.6	1.30	30 (**26**)

A total of 168 AgI-flares were used in this sub-sample with an excellent timing (**90 %)** for an effective AgI-average dose about **40 ice-nuclei per liter** which appeared to be higher in some particular cells (~ 60 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 maritimization (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 (32 couple, averages)**

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	70 min	50 min	1.40	40 (**50**)
Area	70.4 km2	57.1 km2	1.23	23 (**34**)
Volume	280.3 km3	227.5 km3	1.23	23 (**31**)
Top Height	9.8 km	9.1 km	1.08	8 (**1**)
Max dBz	51.9	50.2	1.03	3 (**2**)
Top Height of max dBz	4.0 km	3.9 km	1.03	3 (**0**)
Volume Above 6 km	102.3 km3	86.2 km3	1.19	19 (**23**)
Prec.Flux	481.4 m3/s	339.9 m3/s	1.42	42 (**44**)
Prec.Mass	2243.8 kton	1193.7 kton	1.88	88 (**105**)
CloudMass	190.2 kton	145.2 kton	1.31	31 (**33**)
η	11.8	8.2	1.44	44 (**53**)

A total of 167 AgI and 39 hygroscopic flares were used in this sample with an excellent timing for a glaciogenic average dose of about 35 ice-nuclei per liter. 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 -3.6 dBz/km, noticeably different than the normal index of - 4.0 dBz/km for neutral clouds (neither continentalization nor maritimization). This index indicates that the hygroscopic operations were done on the right clouds which had indications of continentalization. The hygroscopic material seemed to improve 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 (Irion, Tom Green and Schleicher Counties); the average increase in precipitation, referred to the seasonal value, is about **14 %;**

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 efficiency of seeded clouds even when the environment is "continentalizing" them. The results obtained for the seeded small clouds reinforce the idea that there exist a strong synergy between the hygroscopic and the glaciogenic actions.