ANNUAL EVALUATION REPORT 2011 WTWMA (San Angelo)

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Cloud seeding operations 2011 began over the West Texas Weather Modification Association target area in April. This annual report serves as a summary of results. A total of **128 clouds** were seeded and identified by TITAN in **36 operational days**.
Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **April 20th 2011**
Last operational day: **October 11th 2011**

Number of operational days: 36
(Two in April, two in May, four in June, nine in July, eight in August, ten in September and one in October)

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

Thirteen with excellent performance
Fourteen with very good performance
Five with good performance
One with fair performance

Three experimental days (July 1st, August 28th, and September 17th)

Number of seeded clouds: 128 (87 small, 19 large, 22 type B)

Missed Opportunities: None (with lifetime longer than 45 minutes)

Storm # 2985: June 30 at 20:28:00 over Sterling County

Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 87 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (87 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	40 min	1.63	63 (**44**)
Area	60.6 km^2	43.3 km^2	1.40	40 (**41**)
Volume	217.0 km^3	151.9 km^3	1.43	43 (**40**)
Top Height	8.9 km	8.4 km	1.06	6 (**3**)
Max dBz	58.5	56.2	1.04	4 (**3**)
Top Height of max dBz	4.0 km	4.0 km	1.00	0 (**3**)
Volume Above 6 km	67.3 km^3	44.9 km^3	1.50	50 (**37**)
Prec.Flux	396.3 m^3/s	261.9 m^3/s	1.51	51 (**43**)
Prec.Mass	1816.9 kton	848.8 kton	2.14	114 (**97**)
CloudMass	142.6 kton	96.7 kton	1.47	47 (**39**)
η	12.7	8.8	1.44	44 (**41**)

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 444 flares were used in this sub-sample with an excellent timing (**85 %)** for an effective dose about **40 ice-nuclei per liter**. The seeding operation for small clouds lasted about **10 minutes** in average. An excellent increase of **97 %** in precipitation mass together with an increase of 39 % 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 (44 %), area (41 %) volume (40 %), volume above 6 km (37 %), and precipitation flux (43 %) are notable. There are slight increases in top height (3 %) and maximum reflectivity (3 %).

The seeded sub-sample seemed 41 % more efficient than the control sub-sample. Results are evaluated as **excellent**.

An increase of 97 % in precipitation mass for a control value of 848.8 kton in 87 cases means:

Δ_1 = 87 x 0.97 x 848.8 kton = 71 630 kton = 58 092 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 71 % of their whole volume; with an excellent timing (98 % of the material went to the clouds in their first half-lifetime). A total of 371 flares were used in this sub-sample for an effective dose about **70 ice-nuclei per liter**.

Also in average, large clouds were 31 minutes old when the operations took place; the operation lasted about 37 minutes, and the large seeded clouds lived 295 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	295 min	240 min	1.23	23
Area	1421 km^2	1128 km^2	1.26	26
Volume	5870 km^3	4679 km^3	1.25	25
Volume Above 6 km	2191 km^3	1770 km^3	1.24	24
Prec.Flux	9150 m^3/s	7196 m^3/s	1.27	27
Prec.Mass	115 582 kton	75 053 kton	1.54	54

An increase of 54 % in precipitation mass for a control value of 75 053 kton in 19 cases may mean:

Δ_2 = 19 x 0.54 x 75 053 kton = 770 044 kton = 624 506 ac-f

Type B Clouds

The sub-sample of 22 type B seeded clouds received a synergetic analysis.
In average, the seeding operations on the type B clouds affected 15 % of their whole volume; with an excellent timing (93 % of the material went to the clouds in their first half-lifetime). A total of 496 flares were used in this sub-sample for an effective dose ~ **70 ice-nuclei per liter**.

Also in average, type B clouds were 110 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 (22 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	300 min	290 min	1.03	3
Area	2331 km^2	2229 km^2	1.05	5
Volume	11821 km^3	11315 km^3	1.04	4
Volume Above 6 km	5692 km^3	5461 km^3	1.04	4
Prec.Flux	61124 m^3/s	58367 m^3/s	1.05	5
Prec.Mass	75 944 kton	70 319 kton	1.08	8

An increase of 8 % in precipitation mass for a control value of 70 319 kton in 22 cases may mean:

Δ_3 = 22 x 0.08 x 70 319 kton = 123 761 kton = 100 371 ac-f

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 782 969 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)
Glascock	**9**	**11**	**53 400**	**1.11**	**4.88 in**	**23 %**
Sterling	**12**	**14**	**66 100**	**0.84**	**4.18 in**	**19 %**
Reagan	**8**	**15**	**61 400**	**0.98**	**3.91 in**	**25 %**
Irion	**17**	**22**	**79 700**	**1.42**	**6.87 in**	**21 %**
Tom Green	**9**	**14**	**62 600**	**1.54***	**6.83 in**	**23 %**
Crocket	**21**	**28**	**114 800**	**0.77**	**3.37 in**	**23 %**
Schleicher	**29**	**34**	**96 000**	**1.37**	**5.48 in**	**25 %**
Sutton	**23**	**31**	**69 400**	**0.90**	**4.08 in***	**22 %**
Total	**128**	**169**	**603 400**			
Outside TA			~ 180 000			
Average (only for the bold values)				**1.11**	**4.95 in**	**23 %**

(*) One half of the Tom Green Area considered

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

Hygroscopic Cases

Some hygroscopic seeding operations were done in order to explore its potentialities**.** These operations took place as a complement of the main glaciogenic seeding operations. A total of 4 cases were achieved (1 small cloud, 2 large cloud, and 1 type B clouds). Results are described below.

Table 6 illustrates the results corresponding to the small seeded case.

Table 6: **Hygroscopic Seeded Sample versus Control Sample (1 couple, averages)**

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	45 min	1.44	44 (**30**)
Area	56.1 km2	35.2 km2	1.59	59 (**60**)
Volume	210.3 km3	168.7 km3	1.25	25 (**38**)
Top Height	9.1 km	9.1 km	1.00	0 (**0**)
Max dBz	57.4	45.8	1.25	25 (**2**)
Top Height of max dBz	4.3 km	4.0 km	1.08	8 (**2**)
Volume Above 6 km	66.6 km3	71.9 km3	0.93	-7 (**30**)
Prec.Flux	558.7 m3/s	149.4 m3/s	3.74	274 (**79**)
Prec.Mass	2135.0 kton	390.9 kton	5.46	446 (**279**)
CloudMass	166.8 kton	101.9 kton	1.64	64 (**41**)
η	12.8	3.8	3.37	237 (**172**)

A total of 5 BIP and 1 hygroscopic flare were used in this sample with a mediocre timing for a glaciogenic dose of about 15 ice-nuclei per liter. Despite this static dose, the seeded sample shows like-dynamic responses (see the increases) probably suggesting that the hygroscopic material was able to provide enough ice particles in order to reach dynamic dose levels. Although results from such a small sample should be considered only preliminary, they have come to corroborate similar results from the last two years (seasons 2009 and 2010).

The type B seeded cloud (dual seeding) deserved a synergetic analysis scan by scan. Table 7 shows the results for some selected variables before, during and 30 minutes after the hygroscopic treatment:

Table 7: Average of one type B case (dual seeding: glaciogenic plus hygroscopic)

	Before	**during** (Hygroscopic Treatment)	**30-minutes after**
# cells	2.0	1.0	2.0
PrecMass per scan	542 kton	869 kton	867 kton
Top of MaxdBz	4.5 km	6.0 km	4.9 km
Centroid height	4.8 km	4.8 km	4.9 km

The average affected volume for this case was 20 %, whereas the timing was 100 %, with a silver iodide dose of about 125 ice-nuclei per liter. The glaciogenic dose was clearly a dynamic one, but the observed reaction after the hygroscopic seeding was pale and it is hard to find a well-defined signal.

Corresponding Increases:

	Seeded	**Control**	**Simple Ratio**	**Increase (%)**
Area	**443 km^2**	**410 km^2**	**1.03**	**3**
PrecMass	**57 665 kton**	**49 175 kton**	**1.17**	**17**

Δ = 1 x 0.17 x 49 175 kton = 8 360 kton = 6 780 ac-f

For the large seeded clouds, table 8 shows the corresponding results:

Table 8: Two large seeded cases (dual seeding: glaciogenic plus hygroscopic)

	Before	**during** (Hygroscopic Treatment)	**30-minutes after**
# cells	3.5	4.5	5.5
PrecMass per scan	1013 kton	1672 kton	1976 kton
Top of MaxdBz	4.9 km	4.5 km	4.4 km
Centroid height	5.2 km	5.0 km	4.7 km

Corresponding Increases:

	Seeded	**Control**	**Simple Ratio**	**Increase (%)**
Area	**870 km^2**	**697 km^2**	**1.25**	**25**
PrecMass	**61 525 kton**	**36 614 kton**	**1.68**	**68**

Δ = 2 x 0.68 x 36 614 kton = 49 795 kton = 40 384 ac-f

In this case, the observed increase in the average number of cells after seeding did correspond with an increase in Precipitation Mass per scan but with decreases in top height of maximum reflectivity and Centroid height. Those changes were associated to a perfect timing (100 %) and a relatively low silver iodide average dose (30 ice-nuclei per liter) and may indicate that the hygroscopic material went into the storms when the target units were still growing and supplied enough large droplets which became ice particles. Probably more ice particles were produced by the hygroscopic material. Again, the sample (two cases) is still too small to have any statistical significance, although supports the idea that the hygroscopic material might have affected the ice phase of the target units (like the cases for the last two years).

Final Comments

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

2) The micro-regionalization analysis showed increases per county; seedable conditions were more frequent over the southern zone of the target area (Crockett, Schleicher and Sutton Counties); the average increase in precipitation, referred to the seasonal value, is about **23 %;**

3) Radar estimations of precipitation should be considered as measurements of trend. Nevertheless, seeding operations appeared to improve the dynamics of seeded clouds;

4) During its first half, Season 2011 was affected by La Niña conditions which explained why only 8 operational days took place between April and June. ENSO neutral conditions dominated during the summer with 27 operational days. As La Niña conditions reappeared in October, only one more operational day occurred at the end of the season.

5) Some hygroscopic seeding operations were done and although the sample is still too small for any strong statement, the results for the last three seasons are promissory and appear to suggest that the hygroscopic seeding material may impact the ice phase of seedable clouds.