ANNUAL EVALUATION REPORT 2010 STWMA (Pleasanton)

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Cloud seeding operations 2010 began over South Texas Weather Modification Association target area in May. This annual report serves as a summary of results. A total of **113 clouds** were seeded and identified by TITAN in **34 operational days**. Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **May 17th 2010**
Last operational day: **September 25th 2010**

Number of operational days: 34
(Three in May, nine in June, eight in July, five in August, and nine in September)

According to the daily reports operational days were qualified as:

Twenty with excellent performance
Seven with very good performance
Five with good performance
Two with fair performance

Number of seeded clouds: 113
(67 small seeded clouds, 22 large seeded clouds, 24 type B seeded clouds)

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 67 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (67 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	45 min	1.44	44 (**30**)
Area	65.2 km^2	41.8 km^2	1.56	56 (**32**)
Volume	180.4 km^3	116.6 km^3	1.55	55 (**35**)
Top Height	7.4 km	7.0 km	1.06	6 (**3**)
Max dBz	51.5	50.3	1.02	2 (**0**)
Top Height of max dBz	3.4 km	3.4 km	1.03	0 (**0**)
Volume Above 6 km	23.7 km^3	15.8 km^3	1.50	50 (**53**)
Prec.Flux	459.5 m^3 /s	286.3 m^3 /s	1.60	60 (**30**)
Prec.Mass	2068.3 kton	842.8 kton	2.45	145 (**115**)
CloudMass	158.1 kton	99.1 kton	1.60	60 (**33**)
η	13.1	8.5	1.54	54 (**61**)

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 **248 flares** were used in this sub-sample with an excellent timing (**84 %)** for an effective dose about **55 ice-nuclei per liter**. The seeding operation for small clouds lasted about **4.7 minutes** in average. An excellent increase of 115 % 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 (30 %), area (32 %) volume (35 %), volume above 6 km (53 %), and precipitation flux (30 %) are notable. Slight increase in top height (3 %) and no increase in maximum reflectivity (0 %) are

reported. The seeded sub-sample seemed 61 % more efficient than the control sub-sample. Results are evaluated as **excellent**.

An increase of 115 % in precipitation mass for a control value of 842.8 kton in 67 cases means:

Δ^1 = 67 x 1.15 x 842.8 kton = 64 938 kton = 52 665 ac-f

Large Clouds

The sub-sample of 22 large seeded clouds received a synergetic analysis. In average, the seeding operations on these large clouds affected 75 % of their whole volume; with an excellent timing (96 % of the material went to the clouds in their first half-lifetime). A total of 279 flares were used in this sub-sample for an effective 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 29 minutes, and the large seeded clouds lived 180 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (40 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	180 min	155 min	1.16	16
Area	872 km ^{2}	713 km ^{2}	1.22	22
Volume	2750 km ^{3}	2215 km ^{3}	1.24	24
Volume Above 6 km	444 km ^{3}	329 km ^{3}	1.35	35
Prec.Flux	5387 m ^{3} /s	4455 m ^{3} /s	1.21	21
Prec.Mass	38 798 kton	23 234 kton	1.67	67

An increase of 67 % in precipitation mass for a control value of 23 234 kton in 22 cases may mean:

Δ_2 = 22 x 0.67 x 23 234 kton = 342 469 kton = 277 742 ac-f

Type B Clouds

The sub-sample of 24 type B seeded clouds also received a synergetic analysis. In average, the seeding operations on these type B clouds affected 24 % of their whole volume with a good timing (63 % of the material went to the clouds in their first half-lifetime). A total of 208 flares were used in this sub-sample for an effective dose about **150 ice-nuclei per liter.**

Also in average, type B clouds were 110 minutes old when the operations took place; the operation lasted about 21.7 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 (24 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	300 min	290 min	1.03	3
Area	854 km^2	802 km^2	1.06	6
Volume	3578 km^3	3346 km^3	1.07	7
Volume Above 6 km	1231 km^3	1124 km^3	1.10	10
Prec.Flux	7483 m^3 /s	7051 m^3 /s	1.06	6
Prec.Mass	59 334 kton	51 400 kton	1.15	15

An increase of 15 % in precipitation mass for a control value of 51 400 kton in 24 cases may mean:

Δ_3 = 24 x 0.15 x 51 400 kton = 185 040 kton = 150 067 ac-f

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 480 474 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 Seeding	Initial Seeding	Extended (increase)	Acre-feet (increase)	Inches (increase)	Rain Gage (season value)	% (increase)
Bandera	**6**	**7**	**36 000**	**0.90**	**18.48 in**	**4.9**
Medina	**13**	**21**	**71 400**	**0.90**	**16.53 in**	**5.4**
Frío	**7**	**15**	**38 000**	**0.63**	**14.09 in**	**4.5**
Bexar	**3**	**5**	**10 200**	**0.15**	**21.84 in**	**0.7**
Atascosa	**25**	**31**	**70 200**	**1.06**	**18.15 in**	**5.8**
McMullen	**10**	**14**	**48 000**	**0.81**	**19.70 in**	**4.1**
Wilson	**7**	**13**	**41 200**	**0.97**	**21.36 in**	**4.5**
Karnes	**7**	**9**	**39 500**	**0.99**	**19.79 in**	**5.0**
Live Oak	**15**	**17**	**34 700**	**0.63**	**20.66 in**	**3.0**
Bee	**14**	**15**	**42 000**	**0.90**	**27.83 in**	**3.2**
Kerr		2	1 700			
Real		2	3 900			
Uvalde	1	2	1 700			
La Salle		2	4 700			
Zavala		2	7 300			
Dimmitt		2	8 000			
Dewitt		2	1 700			

Goliad	5	5	7	100		
Total	**113**	**164**	**462**	**600**		
Average (only for the bold values)					**0.79**	**19.84 in** **4.1**

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

Considerations on Hygroscopic Seeding

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 7 cases were achieved (3 small storms, 3 large storms, and 1 type B storm).

Table 6 below shows the results of the TITAN evaluation for the small 3 cases:

Table # 6 Seeded Sample versus Control Sample (3 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	85 min	45 min	1.89	89 (**70**)
Area	77.2 km ^{2}	37.3 km ^{2}	2.07	107 (**100**)
Volume	165.8 km ^{3}	89.0 km ^{3}	1.86	86 (**107**)
Top Height	7.3 km	6.7 km	1.09	9 (**39**)
Max dBz	52.3	51.0	1.03	3 (**5**)
Top Height of max dBz	3.2 km	3.2 km	1.00	0 (**0**)
Volume Above 6 km	16.0 km ^{3}	6.0 km ^{3}	2.67	167 (**300**)
Prec.Flux	447.9 m ^{3} /s	250.7 m ^{3} /s	1.91	91 (**101**)
Prec.Mass	2382.0 kton	674.5 kton	3.53	253 (**200**)
CloudMass	137.6 kton	111.4 kton	1.24	84 (**118**)
η	17.6	9.2	1.91	91 (**78**)

Results appear to be explosive in some variables (see area, volume, top height, volume above 6 km, precipitation flux and precipitation mass). However, the sub-sample was seeded also with 9 BIP AgI-flares and a perfect timing for an effective average silver iodide dose of 75 ice-nuclei per liter and therefore credits cannot go alone to the hygroscopic seeding. Additionally, this sub-sample is too small (only 3 cases) and the results might be due to high variability. One needs more cases to get some confidence.

Average results for the 3 large cases are described below using the following variables: n (# of cells), precipitation mass per scan, top height of maximum reflectivity, and height of the Centroid.

Table # 7 (3 large cases averaged)

Average Case	Before Hyg.	During Hyg.	30 min after Hyg.
n	2	2	2
PrecMass/scan	6 342 kton	9 578	9 224
Top maxdBz	3.8 km	3.0	3.1
Centroid h	4.2 km	4.1	4.3

AgI dose: 40 ice-nuclei per liter; timing 100 %

No average increase in the number of cells and in precipitation mass per scan after the hygroscopic seeding seem to indicate that the hygroscopic material did not affect those large storms. However, there are slight increases in top of max reflectivity and Centroid height during the 30 minutes after hygroscopic seeding suggesting that some impacts in the upper part of the clouds might have taken place. The sample is too small for any conclusive argument but pinpoints some possible positive results.

Similar analysis was done for the one type B case:

Table # 8 (1 type B case)

Variable	Before Hyg.	During Hyg.	30 min after Hyg.
n	6	12	9
PrecMass/scan	10 972 kton	30 421	35 027
Top maxdBz	5.2 km	3.0	4.6
Centroid h	6.6 km	5.8	4.7

AgI dose: 25 ice-nuclei per liter; timing 100 %

In this case, the increases in precipitation mass per scan and top of maximum reflectivity might indicate some impacts of the hygroscopic seeding in the upper part of the clouds. Once again, only one case does not allow for confidence, although it is suggestive.

Final Comments

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

2) The micro-regionalization analysis showed increases per county; different zones received downwind benefits; the average increase in precipitation, referred to rain gage seasonal value, is about **4 %**;

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

4) In 2010, relative increases due to cloud seeding competed with rainfall values associated with active tropical activity and therefore they look pale when compared with seasonal values. However, the total increase in the region, estimated in about 0.5 million acre-feet, should be considered a great help to fresh water natural resources.

5) This year hygroscopic seeding was continued at a exploratory level and the results are again intriguing and promissory but inconclusive. More actions on this direction are advisable, especially on small clouds which usually get proper control clouds and therefore facilitate the contrastive analysis.