ANNUAL EVALUATION REPORT 2013 STWMA (Pleasanton)

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Cloud seeding operations 2013 began over South Texas Weather Modification Association target area in March. This annual report serves as a summary of results. A total of **161 clouds** were seeded and identified by TITAN in **46 operational days**. Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **March 31st 2013**
Last operational day: **October 12th 2013**

Number of operational days: 46
(One in March, one in April, three in May, eight in June, thirteen in July, eight in August, eleven in September and one in October)

According to the daily reports operational days were qualified as:

Twenty-seven with excellent performance
Eight with very good performance
Four with good performance
Five with fair performance
Two with corrupted data (May 26th and June 20th)

Number of seeded clouds: 161
(91 small seeded clouds, 15 large seeded clouds, 55 type B seeded clouds)

Missed Opportunities: two (with lifetime longer than 45 minutes)

It is ~ 1 % of the resources (2/163 = 0.012)

Storm # 592 over Frio County on September 11th (18:12 - 19:28 UTC)

Storm # 573 over Live Oak on September 15th (16:40-18:40 UTC)

Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 91 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (91 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	60 min	40 min	1.50	50 (**33**)
Area	65.6 km^2	42.1 km^2	1.56	56 (**25**)
Volume	180.2 km^3	110.7 km^3	1.63	63 (**27**)
Top Height	7.4 km	7.0 km	1.06	6 (**3**)
Max dBz	51.4	50.0	1.03	3 (**2**)
Top Height of max dBz	3.5 km	3.5 km	1.00	0 (**1**)
Volume Above 6 km	23.8 km^3	11.3 km^3	2.11	111 (**52**)
Prec.Flux	481.5 m^3/s	257.3 m^3/s	1.87	87 (**36**)
Prec.Mass	2114.3 kton	671.5 kton	3.15	215 (**140**)
CloudMass	158.5 kton	87.2 kton	1.82	82 (**31**)
η	13.3	7.7	1.73	73 (**82**)

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 **370 AgI-BIP and 15 Hygroscopic flares** were used in this sub-sample with an excellent timing **(86 %)** for an average effective silver iodide dose about **60 ice-nuclei per liter**. The seeding operation for small clouds lasted about **5 minutes** in average. An excellent increase of 140 % in precipitation mass together with an increase of 31 % 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 (25 %) volume (27 %), volume above 6 km (52 %), and precipitation flux (36 %) are notable. Slight increases in top height (3 %) and maximum reflectivity (2 %) are reported. The seeded sub-sample seemed 82 % more efficient than the control sub-sample. Results are evaluated as **excellent**.

An increase of 140 % in precipitation mass for a control value of 671.5 kton in 91 cases means:

$$\mathbf{\Delta_1 = 91 \times 1.40 \times 671.5\ kton \approx 85\ 549\ kton \approx 69\ 380\ ac\text{-}f}$$

Large Clouds

The sub-sample of 15 large seeded clouds received a synergetic analysis. In average, the seeding operations on these large clouds affected 65 % of their whole volume; with an excellent timing (98 % of the material went to the clouds in their first half-lifetime). A total of 245 AgI-BIP and 15 Hygroscopic flares were used in this sub-sample for an average effective silver iodide dose about **90 ice-nuclei per liter**.

Also in average, large clouds were 36 minutes old when the operations took place; the operation lasted about 38 minutes, and the large seeded clouds lived 215 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	215 min	185 min	1.16	16
Area	650 km^2	566 km^2	1.15	15
Volume	2646 km^3	2280 km^3	1.16	16
Volume Above 6 km	924 km^3	719 km^3	1.29	29
Prec.Flux	8326 m^3/s	6893 m^3/s	1.21	21
Prec.Mass	49 230 kton	30 564 kton	1.61	61

An increase of 61 % in precipitation mass for a control value of 30 564 kton in 15 cases may mean:

$$\mathbf{\Delta_2 = 15 \times 0.61 \times 30\ 564\ kton \approx 279\ 661\ kton \approx 226\ 805\ ac\text{-}f}$$

Type B Clouds

The sub-sample of 55 type B seeded clouds also received a synergetic analysis. In average, the seeding operations on these type B clouds affected 18 % of their whole volume with an excellent timing (71 % of the material went to the clouds in their first half-lifetime). A total of 552 AgI-BIP and 39 Hygroscopic flares were used in this sub-sample for an average effective silver iodide dose about **120 ice-nuclei per liter.**

Also in average, type B clouds were 110 minutes old when the operations took place; the operation lasted about 20 minutes, and the type B seeded clouds lived 285 minutes.

Table 4 shows the results:

Table 4: Type B Seeded Sample versus Virtual Control Sample (55 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	285 min	275 min	1.04	4
Area	537 km^2	518 km^2	1.04	4
Volume	1793 km^3	1723 km^3	1.04	4
Volume Above 6 km	426 km^3	399 km^3	1.07	7
Prec.Flux	4680 m^3/s	4452 m^3/s	1.05	5
Prec.Mass	38 715 kton	34 560 kton	1.12	12

An increase of 12 % in precipitation mass for a control value of 34 560 kton in 55 cases may mean:

Δ_3 = 55 x 0.12 x 34 560 kton ≈ 228 096 kton ≈ 184 986 ac-f

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 481 171 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)
Uvalde	**11**	**14**	**25 300**	**0.30**	**17.21 in**	**2.0**
Bandera	**4**	**6**	**14 400**	**0.36**	**16.07 in**	**2.2**
Medina	**11**	**21**	**60 200**	**0.77**	**19.36 in**	**4.0**
Bexar	**6**	**16**	**29 300**	**0.44**	**24.07 in**	**2.0**
Frío	**9**	**17**	**27 400**	**0.46**	**12.61 in**	**3.6**
Atascosa	**31**	**42**	**56 900**	**0.86**	**19.35 in**	**4.4**
McMullen	**15**	**22**	**66 500**	**1.12**	**22.19 in**	**5.0**
Wilson	**13**	**20**	**43 200**	**1.02**	**23.71 in**	**4.3**
Karnes	**19**	**26**	**36 600**	**0.92**	**17.52 in**	**5.3**
Live Oak	**17**	**29**	**53 300**	**0.97**	**21.56 in**	**4.5**
Bee	**18**	**22**	**45 200**	**0.96**	**21.39 in**	**4.5**
Outside	7	15	28 900			
Total	**161**	**250**	**487 200**			
Average				**0.74**	**19.55 in**	**3.8**

(**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 Dual Seeding (glaciogenic plus hygroscopic)

Hygroscopic seeding operations were done in 2013. A total of 44 cases received dual treatment (15 small storms, 6 large storms, and 23 type B storms).

For the small cases it was possible to make a comparison between pure glaciogenic seeding (76 cases) and dual seeding (15 cases). Tables 6 and 7 show the results:

Table 6 below shows the results of the TITAN evaluation for the small 76 glaciogenic cases:

Table # 6 Seeded Sample versus Control Sample (76 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	60 min	40 min	1.50	50 (**33**)
Area	64.2 km^2	41.5 km^2	1.55	55 (**21**)
Volume	169.1 km^3	107.8 km^3	1.57	57 (**19**)
Top Height	7.2 km	6.9 km	1.04	4 (**2**)
Max dBz	51.3	49.9	1.03	3 (**2**)
Top Height of max dBz	3.4 km	3.5 km	0.97	- 3 (**- 2**)
Volume Above 6 km	18.5 km^3	10.2 km^3	1.81	81 (**24**)
Prec.Flux	461.1 m^3/s	250.8 m^3/s	1.84	84 (**28**)
Prec.Mass	1962.4 kton	672.8 kton	2.92	192 (**135**)
CloudMass	147.9 kton	84.8 kton	1.74	74 (**21**)
η	13.3	7.9	1.68	68 (**96**)

Results seem to be similar of those obtained by glaciogenic seeding before. However, a comparison with table 2 (page 2 in this report) indicates that the increase in precipitation mass for the small seeded cases was slightly greater than the corresponding increase for pure glaciogenic small seeded cases (140 % versus 135 %: difference = 5 %). There is almost no difference in timing (0.86 versus 0.85) but there is a noticeable difference is in the doses (60 icn/l versus 80 icn/l); for the whole sample of small clouds the AgI- dose was estimated in 60 ice-nuclei per liter, whereas for the pure glaciogenic cases the AgI-dose was estimated in 80 ice-nuclei per liter, ~ 1.33 times higher. It is possibly an indication that hygroscopic seeding is producing the additional ice that balances the difference.

Table 7 now shows the results of the TITAN evaluation for the small 15 remaining dual cases:

Table # 7 Seeded Sample versus Control Sample (15 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	35 min	1.86	86 (**33**)
Area	72.4 km^2	44.9 km^2	1.61	61 (**45**)
Volume	236.3 km^3	125.3 km^3	1.89	89 (**68**)
Top Height	8.1 km	7.2 km	1.13	13 (**5**)
Max dBz	52.2	50.4	1.04	4 (**2**)
Top Height of max dBz	3.7 km	3.6 km	1.03	3 (**2**)
Volume Above 6 km	51.0 km^3	16.9 km^3	3.02	202 (**155**)
Prec.Flux	584.8 m^3/s	290.0 m^3/s	2.02	102 (**75**)
Prec.Mass	2883.8 kton	664.8 kton	4.34	334 (**165**)
CloudMass	212.6 kton	99.3 kton	2.14	114 (**81**)
η	13.6	6.7	2.03	103 (**48**)

Results in this table seem to suggest that dual seeding improves even more the rain-efficiency of seeded clouds: the comparison with table 6 (previous page) indicates that the increase in precipitation mass for small dual seeded cases was noticeable greater that the one for the pure glaciogenic small seeded cases: 165 % versus 135 %, a difference of **30 %**! In practical terms, the average amount of AgI flares used in glaciogenic cases was about 4.2 per cloud, whereas the corresponding number for the dual cases was 3.3 per cloud (plus 1 hygroscopic flare per cloud), suggesting that due to greater increases, one hygroscopic flare seemed to improve even more the dynamics of the seeded cases. Notice also the large increase in the variable "Volume above 6 km" which might be indicating a great impact on the ice-phase of the seeded cases. These affirmations are still heuristic because larger samples will be needed to cope with the extreme variability in the data.

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 2013, the total increase in the region, estimated in about 0.487 million acre-feet, should be considered as a great help to fresh water natural resources.

5) This year hygroscopic seeding was continued as an important component of the operations, and the results indicate a noticeable improvement in the dynamics of 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. A more intensive use of hygroscopic flares is recommended.