ANNUAL EVALUATION REPORT 2010 **State of Texas**

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Cloud seeding operations 2010 began over Texas Weather Modification target area in March. This annual report is a compilation of the evaluation reports already made and published for five local projects. SOAR program did not ask for an evaluation. Therefore, this annual report serves as a summary of the results obtained over Panhandle, Trans-Pecos, WTWMA, STWMA, and SWTREA target areas (EAA target area is included in the last two). A total of **399 clouds** were seeded and identified by TITAN in **166 target area operational days**. Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **March 8th, 2010 (WTWMA)**
Last operational day: **October 12th, 2010 (SWTREA)**

Net Number of operational days: 166
(Most active period May to September: 157 ~ 95 % of the operational days,
Less active months: March: 2 ~ 1 % of the operational days
April: 6 ~3.4 % of the operational days
October: 1 ~ 0.6 % of the operational days)

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

Seventy-five with excellent performance
Thirty-five with very good performance
Thirty-seven with good performance
Six with fair performance

Additionally, thirteen days with non proper data

Number of seeded clouds: 399
(193 small seeded clouds, 79 large seeded clouds, 127 type B seeded clouds)

Missed Opportunities: 2 (~ 0.5 % of the seedable conditions)

Small Clouds

Table 2 shows the results from the classic TITAN evaluation for the 193 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (193 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	40 min	1.63	63 (**44**)
Area	66.0 km^2	44.1 km^2	1.50	50 (**31**)
Volume	221.9 km^3	141.1 km^3	1.57	57 (**33**)
Top Height	8.1 km	7.6 km	1.07	7 (**4**)
Max dBz	52.1	50.3	1.04	4 (**1**)
Top Height of max dBz	3.7 km	3.7 km	1.00	0 (**0**)
Volume Above 6 km	54.7 km^3	33.3 km^3	1.64	64 (**33**)
Prec.Flux	473.1 m^3/s	288.6 m^3/s	1.64	64 (**27**)
Prec.Mass	2142.9 kton	839.1 kton	2.55	155 (**110**)
CloudMass	175.0 kton	108.1 kton	1.62	62 (**37**)
η	12.2	7.8	1.56	56 (**53**)

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 **954 flares** were used in this sub-sample with an excellent timing (**87 %),** for an effective dose about **60 ice-nuclei per liter,** which might have reached slightly higher levels in some individual cells. An excellent increase of 110 % in precipitation mass together with an increase of 37 % 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 (31 %), volume (33 %), volume above 6 km (33 %), and precipitation flux (27 %) are notable. There are slight increases in maximum reflectivity (1 %), and in top height (4 %). The seeded sub-sample seemed 53 % more efficient than the control sub-sample. Results are evaluated as **excellent** for this sub-sample.

An increase of 110 % in precipitation mass for a control value of 839.1 kton in 193 cases means:

Δ_1 = 193 x 1.10 x 839.1 kton = 178 141 kton = 144 472 ac-f

Large Clouds

The sub-sample of 79 large seeded clouds received a synergetic analysis. In average the seeding operations on these large clouds affected 66 % of their whole volume, with an excellent timing (98 % of the material went to the clouds in their first half-lifetime). A total of **1349 flares** were used in this sub-sample for an effective dose near **90 ice-nuclei per liter**.

Also in average, large clouds were 28 minutes old when the operations took place; the operation lasted about 35 minutes, and the large seeded clouds lived 240 minutes (4 hours).

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (79 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	240 min	200 min	1.20	20
Area	1384 km^2	1133 km^2	1.22	22
Volume	5731 km^3	4675 km^3	1.23	23
Volume Above 6 km	2029 km^3	1725 km^3	1.18	18
Prec.Flux	11348 m^3/s	9361 m^3/s	1.21	21
Prec.Mass	121 115 kton	81 968 kton	1.48	48

An increase of 48 % in precipitation mass for a control value of 81 968 kton in 79 cases may mean:

Δ_2 = 79 x 0.48 x 81 968 kton = 3 108 227 kton = 2 520 772 ac-f

Type B Clouds

The sub-sample of 127 type B seeded clouds also received a synergetic analysis.
In average the seeding operations on these type B clouds affected 20 % of their whole volume with an excellent timing (72 % of the material went to the clouds in their first half-lifetime). A total of **2394 flares** were used in this sub-sample for an effective dose near **100 ice-nuclei per liter.** .

Also in average, type B clouds were 140 minutes old when the operations took place; the operation lasted about 40 minutes, and the type B seeded clouds lived 295 minutes (4 hours and 55 minutes)

Table 4 shows the results:

Table 4: Type B Seeded Sample versus Virtual Control Sample (127 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	295 min	285 min	1.04	4
Area	2995 km^2	2834 km^2	1.06	6
Volume	12949 km^3	12253 km^3	1.06	6
Volume Above 6 km	4698 km^3	4485 km^3	1.05	5
Prec.Flux	21210 m^3/s	20121 m^3/s	1.05	5
Prec.Mass	205 715 kton	184 939 kton	1.11	11

An increase of 11 % in precipitation mass for a control value of 184 939 kton in 127 cases may mean:

Δ_3 = 127 x 0.11 x 184 939 kton = 2 583 598 kton = 2 095 298 ac-f

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 4 760 542 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:

Table 5: Results per county

County Seeding	Initial Seeding	Extended (increase)	Acre-feet (increase)	Inches (increase)	Rain gage (season value)	% (increase)
PGCD						
Armstrong	**10**	**14**	**240 600**	**4.82**	**19.97 in**	**24**
Carson	**8**	**15**	**150 400**	**3.05**	**21.12 in**	**14**
Donley	**6**	**17**	**193 600**	**3.93**	**24.40 in**	**16**
Gray	**7**	**14**	**156 300**	**3.25**	**19.89 in**	**16**
Potter	**7**	**9**	**104 500**	**2.16**	**15.25 in**	**14**
Roberts	**5**	**7**	**82 800**	**1.67**	**15.38 in**	**11**
Wheeler	**2**	**9**	**90 700**	**1.85**	**21.67 in**	**9**
Hemphill		3	5 800			
Moore		2	4 700			
Collingsworth		3	96 000			
Hutchinson		1	3 900			
Sub-total	**45**	**94**	**1 129 300**			
Partial Averages (only for the bold values)				**2.96**	**19.67 in**	**15 %**
WTWMA						
Glascock	**10**	**14**	**108 200**	**2.25**	**12.80 in**	**18 %**

Sterling	**13**	**22**	**232 900**	**2.82**	**17.55 in**	**16 %**
Reagan	**15**	**24**	**206 100**	**3.29**	**12.23 in**	**27 %**
Irion	**19**	**29**	**196 000**	**3.49**	**10.23 in**	**34 %**
Tom Green	**18**	**28**	**174 400**	**4.29**	**14.43 in**	**29 %**
Crocket	**12**	**19**	**247 300**	**1.67**	**11.66 in**	**14 %**
Schleicher	**26**	**29**	**129 000**	**1.84**	**13.06 in**	**14 %**
Sutton	**14**	**20**	**171 800**	**2.23**	**11.69 in***	**19 %**
Sub-total	**127**	**185**	**1 371 500**			
Outside TA			~ 244 500			
Partial Averages (only for the bold values)				**2.74**	**12.96 in**	**21 %**

TRANS-PECOS

Reeves	18	18	83 800	0.59	6.79	**9 %**
Culberson	1	1	10 500	0.06	5.35	**1 %**
Loving		3	15 500	0.43	5.38	**8 %**
Ward	2	7	28 000	0.51	6.43	**8 %**
Pecos	16	19	187 500	0.74	7.53	**10 %**
Wrinkler		1	2300			
Ector		1	2200			
Sub-total	**37**	**50**	**329 800**			
Partial Averages (only for the bold values)				**0.47**	**6.30 in**	**8 %**

STWMA

Bandera	**7**	**8**	**38 300**	**0.96**	**18.48 in**	**5 %**
Medina	**15**	**25**	**97 300**	**1.23**	**16.53 in**	**7 %**
Frío	**10**	**20**	**67 400**	**1.12**	**14.09 in**	**8 %**
Bexar	**3**	**5**	**10 200**	**0.15**	**21.84 in**	**1 %**
Atascosa	**25**	**31**	**70 200**	**1.06**	**18.15 in**	**6 %**
McMullen	**11**	**15**	**48 600**	**0.82**	**19.70 in**	**4 %**
Wilson	**7**	**13**	**41 200**	**0.97**	**21.36 in**	**5 %**
Karnes	**7**	**9**	**39 500**	**0.99**	**19.79 in**	**5 %**
Live Oak	**15**	**17**	**34 700**	**0.63**	**20.66 in**	**3 %**
Bee	**14**	**15**	**42 000**	**0.90**	**27.83 in**	**3 %**
Kerr		2	1 700			
Real		2	3 900			
Dewitt		2	1 700			
Goliad	5	5	7 100			
Sub-total	**119**	**169**	**503 800**			
Average (only for the bold values)				**0.88**	**19.84 in**	**5 %**

SWTREA

Uvalde	**22**	**26**	**129 900**	**1.56**	**17.11 in**	**9 %**
Zavala	**7**	**15**	**113 400**	**1.64**	**13.08 in**	**13 %**
Dimmit	**10**	**17**	**80 500**	**1.12**	**24.82 in**	**5 %**

La Salle	**13**	**21**	**62 600**	**0.79**	**16.68 in**	**5 %**
Webb	**17**	**19**	**169 800**	**0.93**	**20.85 in**	**5 %**
Duval	2	2	4 100			
Sub-total	**71**	**100**	**560 300**			
Partial Averages				**1.21**	**18.51 in**	**7 %**
Total	**399**	**598**	**3 894 700 ac-f**			
Averages				**1.65 in**	**15.46 in**	**11.2 %**

Hail mitigation operations over SWTREA

Two case studies are presented here to illustrate the evaluation of hail suppression operations. In summary, two operational days were dedicated to this type of operations, April 23rd (case 1: one type B storm) and August 24th (case 2: one small cloud). Two radar variables, D1 and D2 are used for the evaluation. Variable D1 is defined as the quotient between the mass of the storm in kton and the corresponding volume in cubic kilometers as offered by the generated TITAN files. Variable D2 is defined in an analogous form using the same variables above 6 km altitude. The following table # 6 shows the behaviors of these variables for the two cases for three different periods in the storms lifetimes (before seeding, during seeding, and after seeding):

Table # 6: Analysis of anti-hail seeding operations (two case studies)

	Before seeding	during seeding	after seeding
Case 1: variable D1	**0.99**	**1.11**	**1.20**
variable D2	**0.96**	**1.06**	**1.08**

(April 23rd, Storm ID: # 65 over Zavala Co., 39 flares used, dose: **55** ice-nuclei per liter)

Case 2: variable D1	**1.07**	**0.73**	**0.64**
variable D2	**0.71**	**0.43**	**0.36**

(Aug 24th, Storm ID: # 105, over Uvalde Co.,17 flares used, dose: **225** ice-nuclei per liter)

Average: variable D1	**1.03**	**0.92**	**0.92**
variable D2	**0.84**	**0.75**	**0.72**

(56 flares used (in average 28 per storm), average dose: ~ 140 in/ l)

Data in table # 6 suggest that the seeding operations did not diminish the values of variables D1 and D2 for case # 1, probably because the dose was not high enough for hail mitigation. For the second case (a small cloud), the dose appeared to affect the natural evolution of the seeded cloud when both variables did diminish after the operation, although one can also think that the short life time of such a small cloud might be considered as the main cause. These two cases do not seem to be conclusive. However, the average of both cases seemed to show a small signal, especially in variable D2 which decreased after seeding.

Final Comments

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

2) The micro-regionalization analysis showed increases per county; the average increase in precipitation, referred to an average seasonal value, is about **11.2 %**;

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 in South Texas competed with rainfall values associated with active tropical activity and therefore they may look pale when compared with seasonal values. However, the total increase in the region, estimated in more than 1 million acre-feet (STWMA and SWTREA combined), should be considered a great help to fresh water natural resources.

5) Anti-hail seeding operations over the SWTREA seemed to partially mitigate the hail formation in the corresponding seeded storms.