ANNUAL EVALUATION REPORT 2008 **State of Texas**

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Cloud seeding operations 2008 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. Data from the Trans-Pecos program did not allow the TITAN evaluation due to their different format (an issue to be discussed with WDT). SOAR program did not ask for an evaluation. Therefore, this annual report serves as a summary of the results obtained over Panhandle, WTWMA, STWMA, and SWTREA target areas (EAA target area is included in the last two). A total of **233 clouds** were seeded and identified by TITAN in **124 target area operational days**. Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **March 17th, 2008 (WTWMA)**
Last operational day: **October 13th, 2008 (SWTREA)**

Net Number of operational days: 124
(Most active period May to September: 114 ~ 92 % of the operational days,
Less active months: March: 2 ~ 2 % of the operational days)
October: 1 ~ 1 % of the operational days)

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

Thirty-eight with excellent performance
Thirty-six with very good performance
Twenty-three with good performance
Five with fair performance

Additionally, seventeen days with non proper data

Number of seeded clouds: 233
(119 small seeded clouds, 59 large seeded clouds, 55 type B seeded clouds)

Missed Opportunities: 6 (~ 3 % of the seedable conditions)

Small Clouds

Table 2 shows the results from the classic TITAN evaluation for the 119 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (119 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	40 min	1.63	63 (**48**)
Area	88.0 km^2	57.8 km^2	1.52	52 (**44**)
Volume	253.2 km^3	157.0 km^3	1.61	61 (**51**)
Top Height	7.9 km	7.6 km	1.05	5 (**2**)
Max dBz	50.7	49.3	1.03	3 (**1**)
Top Height of max dBz	4.3 km	4.3 km	1.00	0 (**0**)
Volume Above 6 km	25.1 km^3	12.7 km^3	1.98	98 (**64**)
Prec.Flux	695.6 m^3/s	415.8 m^3/s	1.67	67 (**53**)
Prec.Mass	3150.6 kton	1124.2 kton	2.80	180 (**121**)
CloudMass	223.5 kton	131.7 kton	1.70	70 (**51**)
η	14.6	9.0	1.62	62 (**45**)

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 **618 flares** were used in this sub-sample with an excellent timing **(88 %),** for an effective dose about **80 ice-nuclei per liter,** which might have reached slightly higher levels in some individual cells. An excellent increase of 121 % in precipitation mass together with an increase of 51 % 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 (48 %), area (44 %), volume (51 %), volume above 6 km (64 %), and precipitation flux (53 %) are notable.

There are slight increases in maximum reflectivity (1 %), and in top height (2 %). The seeded sub-sample seemed 45 % more efficient than the control sub-sample. Results are evaluated as **excellent** for this sub-sample.

An increase of 121 % in precipitation mass for a control value of 1124.2 kton in 119 cases means:

Δ_1 **= 119 x 1.21 x 1124.2 kton = 161 874 kton = 131 279 ac-f**

Large Clouds

The sub-sample of 59 large seeded clouds received a synergetic analysis. In average the seeding operations on these large clouds affected 57 % of their whole volume, with an excellent timing (94 % of the material went to the clouds in their first half-lifetime). A total of **1196 flares** were used in this sub-sample for an effective dose near **100 ice-nuclei per liter**.

Also in average, large clouds were 28 minutes old when the operations took place; the operation lasted about 38 minutes, and the large seeded clouds lived 210 minutes (3 hours and 30 minutes).

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (59 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	210 min	180 min	1.17	17
Area	1075 km^2	913 km^2	1.18	18
Volume	4357 km^3	3906 km^3	1.12	12
Volume Above 6 km	1394 km^3	1198 km^3	1.16	16
Prec.Flux	13954 m^3/s	11672 m^3/s	1.20	20
Prec.Mass	130 716 kton	94 339 kton	1.39	39

An increase of 39 % in precipitation mass for a control value of 94 339 kton in 59 cases may mean:

Δ_2 = 59 x 0.39 x 94 339 kton = 2 170 740 kton = 1 760 470 ac-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 24 % of their whole volume with a very good timing (67 % of the material went to the clouds in their first half-lifetime). A total of **902 flares** were used in this sub-sample for an effective dose near **145 ice-nuclei per liter.** .

Also in average, type B clouds were 115 minutes old when the operations took place; the operation lasted about 34 minutes, and the type B seeded clouds lived 270 minutes (4 hours and 30 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	270 min	255 min	1.06	6
Area	1211 km^2	1136 km^2	1.07	7
Volume	4202 km^3	3911 km^3	1.07	7
Volume Above 6 km	981 km^3	918 km^3	1.07	7
Prec.Flux	11881 m^3/s	11047 m^3/s	1.08	8
Prec.Mass	79 549 kton	69 327 kton	1.15	15

An increase of 15 % in precipitation mass for a control value of 69 327 kton in 55 cases may mean:

Δ_3 = 55 x 0.15 x 69 327 kton = 571 948 kton = 463 850 ac-f

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 2 355 599 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)
Armstrong	**4**	**5**	**45 000**	**0.92**	**14.93 in**	**6.2**
Carson	**10**	**14**	**42 400**	**0.86**	**15.75 in**	**5.5**
Donley	**4**	**7**	**33 000**	**0.67**	**15.95 in**	**4.2**
Gray	**6**	**9**	**75 500**	**1.57**	**16.77 in**	**9.1**
Potter	**3**	**4**	**37 600**	**0.78**	**12.80 in**	**6.1**
Roberts	**1**	**5**	**32 500**	**0.66**	**18.56 in**	**3.6**
Wheeler	**1**	**3**	**24 600**	**0.50**	**21.57 in**	**2.3**
Hemphill		3	26 800			
Hutchinson		5	12 600			
Randall		1	18 300			
Collingsworth		1	2 600			
Glascock	**9**	**10**	**47 500**	**0.99**	**9.55 in**	**10.4**
Sterling	**9**	**15**	**153 400**	**3.12**	**13.75 in**	**22.7**

Reagan	**9**	**13**	**247 000**	**3.94**	**11.11 in***	**35.5**
Irion	**16**	**21**	**166 200**	**2.96**	**11.69 in**	**25.3**
Tom Green	**3**	**15**	**126 400**	**3.11****	**12.24 in**	**25.4**
Crocket	**14**	**19**	**287 800**	**1.92**	**12.93 in**	**15.0**
Schleicher	**8**	**11**	**189 500**	**2.71**	**12.06 in**	**22.5**
Sutton	**9**	**14**	**52 400**	**0.68**	**13.29 in**	**5.1**
Uvalde	**4**	**5**	**47 400**	**0.57**	**9.09 in**	**6.3**
Zavala	**5**	**15**	**54 900**	**0.67**	**8.78 in**	**7.6**
Dimmit	**6**	**11**	**35 400**	**0.39**	**10.93 in**	**3.6**
La Salle	**15**	**19**	**79 700**	**0.83**	**12.83 in**	**6.5**
Webb	**11**	**15**	**38 300**	**0.21**	**21.50 in**	**1.0**
Maverick	1	1	26 600			
Kinney	1	1	21 400			
Bandera	**1**	**1**	**1 200**	**0.03**	**9.90 in**	**0.3**
Medina	**3**	**7**	**12 300**	**0.17**	**12.15 in**	**1.4**
Frío	**6**	**9**	**21 900**	**0.36**	**12.26 in**	**3.0**
Bexar	**2**	**3**	**10 000**	**0.15**	**9.16 in**	**1.6**
Atascosa	**15**	**19**	**38 300**	**0.58**	**18.26 in**	**3.2**
McMullen	**9**	**13**	**56 200**	**0.95**	**11.86 in**	**7.9**
Wilson	**10**	**11**	**15 300**	**0.36**	**9.65 in**	**3.7**
Karnes	**12**	**14**	**50 500**	**1.26**	**12.47 in**	**10.1**
Live Oak	**12**	**16**	**50 600**	**0.92**	**12.52 in**	**7.3**
Bee	**13**	**18**	**58 100**	**1.24**	**14.21 in**	**8.7**

Gonzalez	1	1	2 900			
Total	**233**	**357**	**2 285 600 ac-f**			
Averages				**1.13 in**	**13.28 in**	**9.3 %**

Hail mitigation operations over SWTREA

Three case studies are presented here to illustrate the evaluation of hail mitigation operations. In summary, six operational days were dedicated to this type of operations for the SWTREA program, but two of those days did not get proper data. Previous observations of hail storms have suggested that two derivate variables defined below seem to be very useful for hail signatures (particularly when their values approach unity). 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. Both variables have density dimensions, but it should be pinpointed that they are radar variables which only take in consideration what the radar sees. The following table 6 shows the behaviors of these variables for three storms cases for three different periods in the storms lifetimes (before seeding, during seeding, and after seeding):

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

	Before seeding	during seeding	after seeding
Case 1: variable D1	**0.92**	**0.87**	**0.72**
variable D2	**0.81**	**0.83**	**0.61**

(April 17, Storm ID: # 001, 45 flares used, dose: 50 ice-nuclei per liter)

	Before seeding	during seeding	after seeding
Case 2: variable D1	**1.27**	**1.35**	**1.08**
variable D2	**1.21**	**1.24**	**0.96**

(April 23, Storm ID: # 216, 20 flares used, dose: 10 ice-nuclei per liter)

	Before seeding	during seeding	after seeding
Case 3: variable D1	**1.10**	**1.20**	**1.00**
variable D2	**1.00**	**1.00**	**0.80**

(April 25, Storm ID: # 58, 53 flares used, dose: 230 ice-nuclei per liter)

Average: variable D1	**1.10**	**1.14**	**0.93**
variable D2	**1.01**	**1.02**	**0.79**

(39.3 flares used, average dose: 96.7 ice-nuclei per liter)

Data in table 6 suggest that the seeding operations appeared to diminish the values of variables D1 and D2, especially for case study # 1 when the operation started early. For cases # 2 and # 3 the seeding operations began when the hail activities were near their maxima and therefore the seeding had to compete with mature hail processes. Additionally, case # 2 received a static dose. However, the seeding operations seemed to have in the three cases under analysis some favorable impacts in mitigating the hail. Recommendations for improvement should include the need for early operations and proper doses, at least as similar as those used for rain enhancement purposes (~ 100 ice-nuclei per liter).

Final Comments

1) Results are evaluated as **excellent**. The main problem detected was the loss of radar data (16 target area operational days did not get proper files);

2) The micro-regionalization analysis showed increases per county; the average increase in precipitation, referred to an average seasonal value, is slightly above **9 %**;

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

4) Anti-hail seeding operations over the SWTREA seemed to partially mitigate the hail formation in the corresponding seeded storms. Improvements in this type of operations should be pursued, especially in timing and doses.