ANNUAL EVALUATION REPORT 2009 State of Texas

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Cloud seeding operations 2009 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 **466 clouds** were seeded and identified by TITAN in **171 target area operational days**. Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **March 11th, 2009 (SWTREA)**
Last operational day: **October 8th, 2009 (WTWMA)**

Net Number of operational days: 163
(Most active period May to September: 150 ~ 94 % of the operational days,
Less active months: March: 3 ~ 2 % of the operational days)
October: 1 less than 1 % of the operational days)

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

Ninety-one with excellent performance
Forty with very good performance
Twenty-seven with good performance
Five with fair performance

Three in experimental regime

Additionally, five days with non proper data

Number of seeded clouds: 466
(218 small seeded clouds, 126 large seeded clouds, 117 type B seeded clouds, 5 npf)

Missed Opportunities: 6 (~ 1.3 % of the seedable conditions)

Small Clouds

Table 2 shows the results from the classic TITAN evaluation for the 218 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (218 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	45 min	1.44	44 (**27**)
Area	73.9 km^2	49.7 km^2	1.49	49 (**35**)
Volume	251.6 km^3	158.0 km^3	1.58	58 (**34**)
Top Height	8.4 km	7.9 km	1.07	7 (**3**)
Max dBz	53.5	51.3	1.04	4 (**1**)
Top Height of max dBz	3.8 km	3.8 km	1.00	0 (**-2**)
Volume Above 6 km	66.9 km^3	40.3 km^3	1.62	62 (**39**)
Prec.Flux	530.2 m^3/s	311.0 m^3/s	1.73	73 (**42**)
Prec.Mass	2285.0 kton	1015.4 kton	2.30	130 (**95**)
CloudMass	191.4 kton	112.5 kton	1.71	71 (**43**)
η	12.0	8.9	1.36	36 (**40**)

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 **914 flares** were used in this sub-sample with an excellent timing **(87 %),** for an effective dose about **55 ice-nuclei per liter,** which might have reached slightly higher levels in some individual cells. An excellent increase of 95 % in precipitation mass together with an increase of 43 % 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 (27 %), area (35 %), volume (34 %), volume above 6 km (39 %), and precipitation flux (42 %) are notable. There are slight increases in maximum reflectivity (1 %), and in top height (3 %). The seeded sub-sample seemed 40 % more efficient than the control sub-sample. Results are evaluated as **excellent** for this sub-sample.

An increase of 95 % in precipitation mass for a control value of 1015.4 kton in 218 cases means:

Δ_1 = 218 x 0.95 x 1015.4 kton = 210 289 kton = 170 545 ac-f

Large Clouds

The sub-sample of 126 large seeded clouds received a synergetic analysis. In average the seeding operations on these large clouds affected 54 % of their whole volume, with an excellent timing (90 % of the material went to the clouds in their first half-lifetime). A total of **1879 flares** were used in this sub-sample for an effective dose near **75 ice-nuclei per liter**.

Also in average, large clouds were 29 minutes old when the operations took place; the operation lasted about 32 minutes, and the large seeded clouds lived 215 minutes (3 hours and 35 minutes).

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (126 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	215 min	190 min	1.13	13
Area	1087 km^2	951 km^2	1.14	14
Volume	4599 km^3	3923 km^3	1.17	17
Volume Above 6 km	1809 km^3	1537 km^3	1.18	18
Prec.Flux	9501 m^3/s	7662 m^3/s	1.19	19
Prec.Mass	80 669 kton	58 308 kton	1.38	38

An increase of 38 % in precipitation mass for a control value of 58 308 kton in 126 cases may mean:

Δ_2 = 126 x 0.38 x 58 308 kton = 2 791 787 kton = 2 264 139 ac-f

Type B Clouds

The sub-sample of 117 type B seeded clouds also received a synergetic analysis.
In average the seeding operations on these type B clouds affected 14 % of their whole volume with an excellent good timing (77 % of the material went to the clouds in their first half-lifetime). A total of **2223 flares** were used in this sub-sample for an effective dose near **60 ice-nuclei per liter.** .

Also in average, type B clouds were 124 minutes old when the operations took place; the operation lasted about 39 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 (117 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	295 min	285 min	1.04	4
Area	3396 km^2	3278 km^2	1.04	4
Volume	13708 km^3	13166 km^3	1.04	4
Volume Above 6 km	4808 km^3	4621 km^3	1.04	4
Prec.Flux	24408 m^3/s	23396 m^3/s	1.04	4
Prec.Mass	215 440 kton	200 451 kton	1.07	7

An increase of 7 % in precipitation mass for a control value of 200 451 kton in 117 cases may mean:

Δ_3 = 117 x 0.07 x 200 451 kton = 1 641 694 kton = 1 331 414 ac-f

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 3 766 098 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**	**9**	**95 700**	**1.96**	**17.17 in**	**11.4**
Carson	**5**	**7**	**47 200**	**0.96**	**22.71 in**	**4.2**
Donley	**8**	**18**	**125 100**	**2.54**	**16.28 in**	**15.6**
Gray	**3**	**9**	**87 400**	**1.82**	**18.93 in**	**9.6**
Potter	**4**	**5**	**96 100**	**1.99**	**13.81 in**	**14.4**
Roberts	**6**	**8**	**34 700**	**0.70**	**16.62 in**	**4.2**
Wheeler	**1**	**8**	**77 500**	**1.58**	**18.55 in**	**8.5**
Hemphill		2	25 300			
Randall		3	69 800			
Collingsworth		6	59 100			
Sub- total	**31**	**75**	**717 900**			
Reeves	15	21	121 100	0.85	5.17	16.4
Culberson	9	9	40 500	0.22	6.01	3.7
Loving	1	5	14 700	0.41	7.70*	5.4
Ward	6	10	48 500	0.88	3.88	22.6
Pecos		7	67 700	0.27	8.30	3.3
Sub- total	**31**	**51**	**292 500**			

Glascock	**19**	**27**	**280 300**	**5.84**	**16.06 in**	**36 %**
Sterling	**20**	**34**	**232 900**	**4.74**	**25.47 in**	**19 %**
Reagan	**33**	**43**	**220 200**	**3.51**	**16.10 in***	**22 %**
Irion	**30**	**42**	**202 300**	**3.60**	**16.82 in**	**21 %**
Tom Green	**15**	**35**	**215 700**	**5.31****	**20.90 in**	**25 %**
Crocket	**24**	**34**	**146 200**	**0.98**	**16.13 in**	**6 %**
Schleicher	**29**	**45**	**201 100**	**2.88**	**20.06 in**	**14 %**
Sutton	**20**	**32**	**146 400**	**1.90**	**13.96 in**	**14 %**
Sub- total	**190**	**292**	**1 645 100**			
Uvalde	**21**	**24**	**98 300**	**1.18**	**9.94 in**	**11.9**
Zavala	**16**	**24**	**47 000**	**0.68**	**7.16 in**	**9.5**
Dimmit	**15**	**17**	**61 500**	**0.86**	**8.47 in**	**10.2**
La Salle	**12**	**14**	**45 500**	**0.57**	**8.63 in**	**6.6**
Webb	**13**	**17**	**97 100**	**0.53**	**7.65 in**	**6.9**
Frio	1	7	44 200			
Maverick	2	9	9 400			
Medina	1	4	16 100			
Bandera	1	2	17 000			
Sub- total	**82**	**118**	**436 100**			
Bandera	**10**	**14**	**23 700**	**0.59**	**10.40 in**	**5.8**
Medina	**20**	**25**	**63 200**	**0.87**	**9.59 in**	**9.1**
Frío	**5**	**9**	**29 400**	**0.48**	**7.50 in**	**6.4**

Bexar	**2**	**10**	**51 000**	**0.77**	**9.02 in**	**8.5**
Atascosa	**17**	**27**	**69 600**	**1.05**	**7.87 in**	**13.3**
McMullen	**10**	**11**	**80 200**	**1.36**	**8.45 in**	**16.1**
Wilson	**12**	**18**	**55 500**	**1.31**	**8.71 in**	**15.0**
Karnes	**16**	**21**	**56 500**	**1.41**	**12.54 in**	**11.2**
Live Oak	**19**	**22**	**59 500**	**1.08**	**9.20 in**	**11.7**
Bee	**15**	**17**	**47 200**	**1.01**	**7.50 in**	**13.5**
Uvalde	2	7	9 000			
La Salle	1	5	36 100			
Zavala		2	3 800			
Nueces	1	1	900			
Goliad	1	1	2 900			
Sub- total	**131**	**190**	**516 500**			
Total	**466**	**726**	**3 608 100 ac-f**			
Averages				**1.42 in**	**11.92 in**	**11.5 %**

Hail mitigation operations over SWTREA

Four case studies are presented here to illustrate the evaluation of hail suppression operations. In summary, four operational days were dedicated to this type of operations but one of those days (April 17th) 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**	**1.05**	**1.07**	**0.94**
	variable D2	**1.01**	**1.00**	**0.83**

(March 26th, Storm ID: # 004, 28 flares used, dose: 65 ice-nuclei per liter)

		Before seeding	during seeding	after seeding
Case 2:	**variable D1**	**0.86**	**1.21**	**1.08**
	variable D2	**0.73**	**1.18**	**0.93**

(May 27th, Storm ID: # 1215, 43 flares used, dose: 300 ice-nuclei per liter)

		Before seeding	during seeding	after seeding
Case 3:	**variable D1**	**1.24**	**1.31**	**0.93**
	variable D2	**1.17**	**1.27**	**1.00**

(May 27th, Storm ID: # 1571, 50 flares used, dose: 300 ice-nuclei per liter)

		Before seeding	during seeding	after seeding
Case 4:	**variable D1**	**1.10**	**1.22**	**1.23**
	variable D2	**0.98**	**1.10**	**1.13**

(May 31st, Storm ID: # 14, 56 flares used, dose: 90 ice-nuclei per liter)

		Before seeding	during seeding	after seeding
Average:	**variable D1**	**1.06**	**1.17**	**1.05**
	variable D2	**0.97**	**1.14**	**0.97**

(177 flares used (44.25 per storm), average dose: ~ 190 in/ l)

Data in table # 6 suggest that the seeding operations appeared to diminish the values of variables D1 and D2 for all the cases but one (case # 4) which seemed to continue to grow after seeding; however, the corresponding TITAN file stopped abruptly and did not record the whole storm evolution, and therefore it is impossible to enounce a fair conclusion. However, the seeding operations seemed to have in the other three cases under analysis some favorable impacts in mitigating the hail. Doses in general were very dynamic with an average about **190 ice-nuclei per liter** (almost twice the value in 2008).

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 **11.5 %**;

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.