ANNUAL EVALUATION REPORT 2013 **State of Texas**

Dr. Arquímedes Ruiz Columbié
Active Influence & Scientific Management

Cloud seeding operations 2013 began over Texas Weather Modification target area in March. This annual report is a compilation of the evaluation reports already made and published for four local projects: Panhandle, Trans-Pecos, WTWMA, and STWMA target areas (EAA target area is included in the last one). A total of **325 clouds** were seeded and identified by TITAN in **121 target area operational days**. Table 1 summarizes the general figures:

Table 1: Generalities

First operational day: **March 9th, 2013 (WTWMA)**
Last operational day: **October 18th, 2013 (WTWMA)** **Season: 241 days**

Net Number of operational days: 121
Most active period: May to September: 113 ~ 93 % of the operational days,
Less active months: March: 3 ~ 2.5 % of the operational days
April: 3 ~ 2.5 % of the operational days
October: 2 ~ 2.0 % of the operational days

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

Sixty-two with excellent performance
Thirty with very good performance
Sixteen with good performance
Five with fair performance

Additionally, seven days with non proper data

Number of seeded clouds: 325
(172 small seeded clouds, 53 large seeded clouds, 100 type B seeded clouds)

Missed Opportunities: 3 (~ 0.9 % of the seedable conditions)

Small Clouds

Table 2 shows the results from the classic TITAN evaluation for the 172 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (172 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	60 min	41 min	1.46	46 (**31**)
Area	71.2 km^2	46.1 km^2	1.54	54 (**27**)
Volume	241.5 km^3	149.2 km^3	1.62	62 (**27**)
Top Height	8.6 km	8.1 km	1.06	6 (**2**)
Max dBz	51.5	49.6	1.04	4 (**2**)
Top Height of max dBz	3.8 km	3.8 km	1.00	0 (**-0.1**)
Volume Above 6 km	68.8 km^3	39.4 km^3	1.75	75 (**39**)
Prec.Flux	487.6 m^3/s	264.4 m^3/s	1.84	84 (**36**)
Prec.Mass	2051.3 kton	730.8 kton	2.81	181 (**130**)
CloudMass	179.3 kton	100.6 kton	1.78	78 (**32**)
η	11.4	7.3	1.56	56 (**73**)

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 **830 AgI and 44 hygroscopic flares** were used in this sub-sample with an excellent timing (**88 %),** for an effective AgI dose about **45 ice-nuclei per liter,** which might have reached slightly higher levels in some individual cells. An excellent increase of 130 % in precipitation mass together with an increase of 32 % 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 (31 %), area (27 %), volume (27 %), volume above 6 km (39 %), and precipitation flux (36 %) are notable. There are slight increases in maximum reflectivity (2 %), and in top height (2 %). The seeded sub-sample seemed 73 % more efficient than the control sub-sample. Results are evaluated as **excellent** for this sub-sample.

An increase of 130 % in precipitation mass for a control value of 730.8 kton in 172 cases means:

Δ_1 **= 172 x 1.30 x 730.8 kton ≈ 163 407 kton ≈ 132 523 ac-f**

Large Clouds

The sub-sample of 53 large seeded clouds received a synergetic analysis. In average the seeding operations on these large clouds affected 68 % of their whole volume, with an excellent timing (99 % of the material went to the clouds in their first half-lifetime). A total of **670 AgI and 48 hygroscopic flares** were used in this sub-sample for an effective silver iodide average dose near **75 ice-nuclei per liter**.

Also in average, large clouds were 32 minutes old when the operations took place; the operation lasted about 43 minutes, and the large seeded clouds lived 235 minutes (3 hours and 55 minutes).

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (53 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	235 min	205 min	1.15	15
Area	1492 km^2	1252 km^2	1.19	19
Volume	7032 km^3	5817 km^3	1.21	21
Volume Above 6 km	3083 km^3	2507 km^3	1.23	23
Prec.Flux	13878 m^3/s	10719 m^3/s	1.29	29
Prec.Mass	86 610 kton	59 009 kton	1.47	47

An increase of 47 % in precipitation mass for a control value of 59 009 kton in 53 cases may mean:

Δ_2 **= 53 x 0.47 x 59 009 kton ≈ 1 469 914 kton = 1 192 100 ac-f**

Type B Clouds

The sub-sample of 100 type B seeded clouds also received a synergetic analysis.
In average the seeding operations on these type B clouds affected 19 % of their whole volume with an excellent timing (79 % of the material went to the clouds in their first half-lifetime). A total of **1399 AgI and 64 hygroscopic flares** were used in this sub-sample for an effective silver iodide average dose about **100 ice-nuclei per liter.** .

Also in average, type B clouds were 117 minutes old when the operations took place; the operation lasted about 28 minutes, and the type B seeded clouds lived 290 minutes (4 hours and 50 minutes)

Table 4 shows the results:

Table 4: Type B Seeded Sample versus Virtual Control Sample (100 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	290 min	280 min	1.04	4
Area	1234 km^2	1114 km^2	1.08	8
Volume	5381 km^3	5149 km^3	1.05	5
Volume Above 6 km	1725 km^3	1655 km^3	1.04	4
Prec.Flux	9549 m^3/s	9064 m^3/s	1.05	5
Prec.Mass	62 999 kton	56 384 kton	1.12	12

An increase of 12 % in precipitation mass for a control value of 56 384 kton in 100 cases may mean:

Δ_3 = 100 x 0.12 x 56 384 kton ≈ 676 608 kton ≈ 548 729 ac-f

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 1 873 352 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	Initial seeding	Extended seeding	Acre-feet (increase)	Inches (increase)	Rain gage (season value)	% (increase)
PGCD						
Armstrong	**6**	**9**	**61 800**	**1.25**	**16.31 in**	**7.7**
Carson	**5**	**11**	**57 500**	**1.16**	**16.49 in**	**7.0**
Donley	**2**	**10**	**53 100**	**1.07**	**16.67 in**	**6.4**
Gray	**5**	**11**	**62 600**	**1.30**	**20.28 in**	**6.4**
Potter	**7**	**8**	**41 100**	**0.85**	**9.86 in**	**8.6**
Roberts	**2**	**8**	**31 400**	**0.63**	**17.22 in**	**3.7**
Wheeler	**1**	**4**	**17 900**	**0.37**	**20.49 in**	**1.8**
Hemphill		3	4 400			
Hutchinson		1	9 700			
Collingsworth		5	13 400			
Ochiltree		2	8 600			
Briscoe		1	10 500			
Moore		1	8 000			
Sub-total	**28**	**74**	**380 000**			
Partial Average (only for the bold values)				**0.95 in**	**16.76 in**	**6.0 %**

WTWMA

Glasscock	**8**	**14**	**63 900**	**1.33**	**12.36 in**	**10.8 %**
Sterling	**11**	**16**	**78 700**	**1.00**	**13.73 in**	**7.3 %**
Reagan	**12**	**18**	**138 200**	**2.20**	**14.49 in**	**15.2 %**
Irion	**15**	**25**	**120 300**	**2.14**	**14.64 in**	**14.6 %**
Tom Green	**12**	**15**	**70 100**	**1.72**	**16.34 in**	**10.5 %**
Crocket	**17**	**22**	**161 400**	**1.07**	**17.88 in**	**6.0 %**
Schleicher	**17**	**19**	**65 800**	**0.94**	**17.53 in**	**5.4 %**
Sutton	**12**	**15**	**105 900**	**1.38**	**18.86 in**	**7.3 %**
Sub-total	**104**	**144**	**804 300**			
Outside TA	2	5	~ 14 400			
Partial Average (only for the bold values)				**1.47 in**	**15.73 in**	**9.6 %**

TRANS-PECOS

Culberson	**5**	**6**	**15500**	**0.08**	**6.76**	**1.2**
Reeves	**15**	**17**	**59100**	**0.42**	**4.56**	**9.2**
Pecos	**6**	**8**	**26600**	**0.11**	**4.70**	**2.3**
Ward	**3**	**3**	**12500**	**0.28**	**2.61**	**10.7**
Loving	**1**	**1**	**10200**	**0.28**	**2.99**	**9.4**
Sub-total	**30**	**35**	**123 900**			
Partial Averages				**0.23 in**	**4.32 in**	**6.6 %**

STWMA

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			
Sub-total	**161**	**250**	**487 200**			
Partial Averages				**0.74**	**19.55 in**	**3.8 %**

Totals	**325**	**508**	**1 809 800 ac-f (inside plus outside)**			
Averages				**0.85 in**	**14.09 in**	**6.5 %**

Dual Seeding Analysis

In 2013, a subtotal of 37 small seeded clouds received **dual seeding** (glaciogenic plus hygroscopic), 22 of them over the WTWMA target area and 17 over the STWMA target area. Table 6 shows the combined TITAN analysis for that pool sample.

Table 6: Seeded Sample versus Control Sample (dual seeding, 37 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	71 min	41 min	1.73	73 (**43**)
Area	81.5 km^2	47.3 km^2	1.72	72 (**46**)
Volume	294.5 km^3	172.7 km^3	1.71	71 (**50**)
Top Height	9.1 km	8.4 km	1.08	8 (**3**)
Max dBz	51.5	49.7	1.04	4 (**3**)
Top Height of max dBz	3.9 km	4.1 km	0.95	-5 (**-4**)
Volume Above 6 km	93.5 km^3	60.2 km^3	1.55	55 (**75**)
Prec.Flux	571.7 m^3/s	267.9 m^3/s	2.13	113 (**48**)
Prec.Mass	2649.6 kton	799.1 kton	3.32	232 (**150**)
CloudMass	214.2 kton	111.4 kton	1.92	92 (**57**)
η	12.4	7.2	1.72	72 (**59**)

A subtotal of 244 AgI flares and 44 hygroscopic flares were used in this subsample with an excellent timing (92 %) for an effective AgI dose of 15 ice-nuclei per liter (static mode). However, the increases illustrate the presence of a dynamic response for this subsample which might suggest that the hygroscopic material enhanced the ice-phase of the seeded clouds. Notice that the increases reported on this table are larger than those on table 2. The 150 % increase in precipitation mass is noticeable.

On the other hand, table 7 shows the corresponding TITAN analysis for the pure glaciogenic seeding. A subtotal of 117 small clouds received only glaciogenic material (AgI), 40 over the WTWMA target area and 76 over the STWMA.

Table 7: Seeded Sample versus Control Sample (AgI seeding, 117 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	56 min	40 min	1.40	40 (**25**)
Area	64.0 km^2	43.0 km^2	1.49	49 (**21**)
Volume	193.9 km^3	125.4 km^3	1.55	55 (**20**)
Top Height	8.0 km	7.6 km	1.05	5 (**2**)
Max dBz	50.9	49.4	1.03	3 (**2**)
Top Height of max dBz	3.6 km	3.6 km	1.00	0 (**-1**)
Volume Above 6 km	39.8 km^3	22.6 km^3	1.76	76 (**23**)
Prec.Flux	422.0 m^3/s	243.0 m^3/s	1.74	74 (**28**)
Prec.Mass	1697.9 kton	645.7 kton	2.63	163 (**121**)
CloudMass	147.3 kton	87.5 kton	1.68	68 (**24**)
η	11.5	7.4	1.55	55 (**77**)

A subtotal of 321 AgI flares were used in this subsample with an excellent timing (in average 84 % of the material went into those clouds in the first half-lifetime) for an average dose of about 65 ice-nuclei per liter (dynamic mode). The increases correspond to that dynamic level, but the comparison between these increases in table 7 (glaciogenic seeding) and those on table 6 (dual seeding) are clear in favor of the latter, indicating the synergy that dual seeding seems to produce. In average, clouds that received dual seeding had stronger responses that those clouds that only received silver iodide, despite the fact that for the former the silver iodide dose reached static levels (15 ice-nuclei per liter).

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 **6.5 %**;

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

4) During the 2013 cloud seeding campaign in Texas two projects used hygroscopic seeding as an important component of the operations (WTWMA and STWMA). The results corroborated the idea that a synergy between hygroscopic and glaciogenic seeding can improve even more the dynamic of seeded clouds.