ANNUAL EVALUATION REPORT 2015 **State of Texas**

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Cloud seeding operations 2015 began over the Texas Weather Modification Target Area in March (first operational day for the WTWMA target area) . This annual report is a compilation of the evaluation reports already made and published for three local projects: Panhandle, WTWMA, and STWMA target areas (EAA target area is included in the last one). A total of **237 clouds** were seeded and identified by TITAN in **96 target area operational days**. Table 1 summarizes the general figures:

Table 1: Generalities

First evaluated operational day: **March 31st, 2015 (WTWMA)**
Last operational day: **October 8th, 2015 (STWMA)** **Season: 192 days**

Net Number of operational days: 96

Most active period: April to September: 94		~ 98 % of the operational days,
Less active months:	March: 1	~ 1 % of the operational days
	October: 1	~ 1 % of the operational days

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

Fifty-nine with excellent performance
Fifteen with very good performance
Seven with good performance
Three with fair performance

Additionally, nine days with non proper data, and three were defined as experimental

Number of seeded clouds: 237
(127 small seeded clouds, 33 large seeded clouds, 77 type B seeded clouds)

Missed Opportunities: none (with lifespan longer than 45 minutes)

Small Clouds

Table 2 shows the average results from the classic TITAN evaluations for the 127 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (127 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65.4 min	45.2 min	1.45	45 (**34**)
Area	70.9 km^2	42.1 km^2	1.68	68 (**42**)
Volume	217.2 km^3	122.2 km^3	1.78	78 (**47**)
Top Height	8.1 km	7.6 km	1.06	6 (**2**)
Max dBz	51.9	50.7	1.02	2 (**0**)
Top Height of max dBz	3.7 km	3.7 km	1.00	0 (**0**)
Volume Above 6 km	48.1 km^3	22.5 km^3	2.13	113 (**52**)
Prec.Flux	531.5 m^3/s	278.6 m^3/s	1.91	91 (**52**)
Prec.Mass	2313.4 kton	856.7 kton	2.70	170 (**137**)
CloudMass	166.0 kton	92.0 kton	1.80	80 (**45**)
η	13.9	9.3	1.50	50 (**64**)

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 **851 AgI and 41 hygroscopic flares** were used in this sub-sample with an excellent timing (**96 %),** for an effective AgI dose about **55 ice-nuclei per liter,** which might have reached slightly higher levels in some individual cells. An excellent increase of 137 % in precipitation mass together with an increase of 45 % 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 (34 %), area (42 %), volume (47 %), volume above 6 km (52 %), and precipitation flux (52 %) are notable. There were no increases in maximum reflectivity (0 %), and in top height (0 %). The seeded sub-sample seemed 64 % more efficient than the control sub-sample. Results are evaluated as **excellent** for this sub-sample.

An increase of 137 % in precipitation mass for a control value of 856.7 kton in 127 cases means:

Δ_1 = 127 x 1.37 x 856.7 kton ≈ 149 057 kton ≈ 120 885 ac-f **(mean layer: 0.65 in)**

Large Clouds

The sub-sample of 33 large seeded clouds received a synergetic analysis. In average the seeding operations on these large clouds affected 75 % of their whole volume, with an excellent timing (98 % of the material went to the clouds in their first half-lifetime). A total of **538 AgI and 67 hygroscopic flares** were used in this sub-sample for an effective silver iodide average dose near **100 ice-nuclei per liter**.

Also in average, large clouds were 26 minutes old when the operations took place; the operation lasted about 40 minutes, and the large seeded clouds lived 237 minutes
(3 hours and 57 minutes).

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (33 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	237 min	195 min	1.22	22
Area	1231 km^2	981 km^2	1.25	25
Volume	4584 km^3	3488 km^3	1.31	31
Volume Above 6 km	1271 km^3	962 km^3	1.32	32
Prec.Flux	11 413 m^3/s	7 184 m^3/s	1.59	59
Prec.Mass	80 376 kton	49 905 kton	1.61	61

An increase of 61 % in precipitation mass for a control value of 49 905 kton in 33 cases may mean:

Δ_2 = 33 x 0.61 x 49 905 kton ≈ 1 004 588 kton ≈ 814 721 ac-f **(mean layer: 0.97 in)**

Type B Clouds

The sub-sample of 77 type B seeded clouds also received a synergetic analysis.
In average the seeding operations on these type B clouds affected 13 % of their whole volume with an excellent timing (84 % of the material went to the clouds in their first half-lifetime). A total of **1264 AgI and 140 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 126 minutes old when the operations took place; the operation lasted about 31 minutes, and the type B seeded clouds lived 277 minutes (4 hours and 37 minutes)

Table 4 shows the results:

Table 4: Type B Seeded Sample versus Virtual Control Sample (77 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	277 min	269 min	1.03	3
Area	3188 km^2	3025 km^2	1.05	5
Volume	12542 km^3	11755 km^3	1.07	7
Volume Above 6 km	4134 km^3	3867 km^3	1.07	7
Prec.Flux	19 236 m^3/s	17 771 m^3/s	1.08	8
Prec.Mass	208 067 kton	193 885 kton	1.07	7

An increase of 7 % in precipitation mass for a control value of 193 885 kton in 77 cases may mean:

Δ_3 = 77 x 0.07 x 193 885 kton ≈ 1 045 040 kton ≈ 847 528 ac-f **(mean layer: 0.17 in)**

The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 1 783 134 ac-f ≈ 1.78 millions 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)
Panhandle Ground Water Conservation District Program						
Armstrong	**2**	**7**	**90 500**	**1.83**	**29.39 in**	**6.2**
Carson	**2**	**8**	**69 100**	**1.40**	**32.50 in**	**4.3**
Donley	**2**	**9**	**72 700**	**1.46**	**35.83 in**	**4.1**
Gray	**5**	**8**	**70 900**	**1.47**	**35.98 in**	**4.1**
Potter	**8**	**11**	**99 800**	**2.06**	**31.18 in**	**6.6**
Roberts	**3**	**5**	**41 200**	**0.83**	**27.62 in**	**3.0**
Wheeler	**2**	**6**	**63 500**	**1.32**	**36.94 in**	**3.6**
Hutchinson		1	3 200			
Collingsworth		3	19 800			
Randall		3	21 200			
Moore		2	13 500			
Sub-total	**24**	**63**	**565 400** **(~10 % outside the target area)**			
Average (only for the bold values)				**1.48 in**	**32.78 in**	**4.6 %**

West Texas Weather Modification Association Program

County	Initial	Extended Seeding	Acre-feet (increase)	Inches (increase)	Rain (season value)	% (increase)
Sterling	**15**	**24**	**102 700**	**1.29**	**12.18 in**	**10.6 %**
Reagan	**16**	**20**	**97 600**	**1.55**	**15.01 in**	**10.3 %**
Irion	**07**	**17**	**116 600**	**2.07**	**20.54 in**	**10.1 %**
Tom Green	**07**	**17**	**109 600**	**2.69**	**18.48 in**	**14.6 %**
Crocket	**16**	**24**	**109 100**	**0.72**	**13.49 in**	**5.3 %**
Schleicher	**14**	**17**	**103 900**	**1.49**	**14.23 in**	**10.5 %**
Sutton	**13**	**19**	**108 700**	**1.42**	**18.31 in**	**7.8 %**
Outside TA	0	6	~ 23 000	**(~ 2 % of the total amount)**		

Sub-total	**88**	**144**	**771 200 ac-f**			
Average (only for the bold values)				**1.60**	**16.03 in**	**9.98 %**

South Texas Weather Modification Association Program

County	Initial Seeding	Extended Seeding	Acre-feet (increase)	Inches (increase)	Rain Gage (season value)	% (increase)
Uvalde	**6**	**9**	**42 800**	**0.50**	**21.52 in**	**2.3**
Bandera	**4**	**5**	**9 500**	**0.26**	**23.19 in**	**1.1**
Medina	**14**	**17**	**81 200**	**1.06**	**14.17 in**	**7.5**
Bexar	**4**	**15**	**13 900**	**0.21**	**17.23 in**	**1.2**
Frío	**9**	**15**	**15 600**	**0.27**	**23.51 in**	**1.1**
Atascosa	**15**	**22**	**74 300**	**1.12**	**31.42 in**	**3.6**
McMullen	**8**	**13**	**26 200**	**0.44**	**20.32 in**	**2.2**
Wilson	**12**	**16**	**24 300**	**0.57**	**27.98 in**	**2.0**
Karnes	**17**	**19**	**51 200**	**1.29**	**28.94 in**	**4.5**
Live Oak	**7**	**11**	**19 000**	**0.35**	**23.39 in***	**1.2**
Bee	**21**	**25**	**34 800**	**0.74**	**26.45 in**	**2.8**
Outside	8	12	6 300			
Sub-total	**125**	**170**	**399 100**			
Average				**0.62**	**23.47 in**	**2.7**

(**Initial seeding** means the counties were the operations began, whereas **extended seeding** means the counties favored by seeding after the initial operations took place).

(*) Interpolated value of seasonal precipitation for Live Oak County

(**Initial seeding** means the counties were the operations began, whereas **extended seeding** means the counties favored by seeding after the initial operations took place).

Table 6: Synoptic Summary

Program	Initial	Extended	Acre-feet	Increase	Season Rain	%
PGCD	**24**	**63**	**565 400**	**1.48 in**	**32.78 in**	**4.6**
WTWMA	**88**	**144**	**771 200**	**1.60 in**	**16.03 in**	**9.98**
STWMA	**125**	**170**	**399 100**	**0.62 in**	**23.47 in**	**2.7**
Totals	**237**	**377**	**1 735 700 ac-f**			
Averages				**1.23 in**	**24.09 in**	**5.8 %**

Outside the target areas (downwind effect): 57 900 ac-f (~ 3 % of the total increase)

Total amount of flares used: 2653 (AgI) plus 248 (Hygroscopic)

Final Comments

1) Results are evaluated as **excellent** (no miss-opportunities, 92 % average timing, 75 in/l average glaciogenic dose).

2) The micro-regionalization analysis showed increases per county; the average increase in precipitation, referred to an average seasonal value, is about **6.0 %**;

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

4) During the 2015 cloud seeding campaign in Texas, hygroscopic seeding became an important component of the operations. When possible, **it is recommended to perform dual seeding operations in order to obtain the desire synergy** between the glaciogenic and hygroscopic effects (see details on the corresponding aforementioned regional evaluation reports).