

Dr. Arquímedes Ruiz-Columbié

Active Influence & Scientific Management

Cloud seeding operations 2016 began over South Texas Weather Modification Association target area in April. This annual report serves as a summary of results. A total of **120 clouds** were seeded and identified by TITAN in **44 operational days**. Table 1 in page 1 summarizes the general figures:

Table 1: Generalities

First operational day: **April 25th, 2016**

Last operational day: **November 11th, 2016**

Number of operational days: 44

(One in April, four in May, seven in June, thirteen in July, nine in August, five in September, three in October, and two in November)

According to the daily reports operational days were qualified as:

Twenty-seven with excellent performance

Twelve with very good performance

Five with good performance

Number of seeded clouds: 120

(81 small seeded clouds, 27 large seeded clouds, 12 type B seeded clouds)

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

Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 81 small seeded clouds which obtained proper control clouds.

Table 2: Seeded Sample versus Control Sample (81 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	40 min	1.63	63 (44)
Area	65.6 km ²	42.8 km ²	1.53	53 (36)
Volume	191.9 km ³	122.9 km ³	1.56	56 (36)
Top Height	7.6 km	7.3 km	1.05	5 (3)
Max dBz	52.4	51.2	1.02	2 (1)
Top Height of max dBz	3.5 km	3.5 km	1.00	0 (0)
Volume Above 6 km	33.4 km ³	20.7 km ³	1.62	62 (30)
Prec.Flux	541.2 m ³ /s	319.0 m ³ /s	1.70	70 (40)
Prec.Mass	2370.3 kton	951.3 kton	2.49	149 (127)
CloudMass	179.5 kton	109.0 kton	1.65	65 (39)
η	13.2	8.7	1.52	52 (63)

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 **667 AgI-BIP and 62 Hygroscopic flares** were used in this sub-sample with an excellent timing (**93 %**) for an average effective silver iodide dose about **90 ice-nuclei per liter**. The seeding operation for small clouds lasted about **8 minutes** in average. An excellent increase of 127 % in precipitation mass together with an increase of 63 % 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 %), in area (36 %), in volume (36 %), in volume above 6 km (30 %), and in precipitation flux (40 %) are notable. There were slight increases in

top height (3 %) and in maximum reflectivity (1 %). The seeded sub-sample was 63 % more efficient than the control sub-sample. Results are evaluated as **excellent** for this subsample.

An increase of 127 % in precipitation mass for a control value of 951.3 kton in 81 cases means:

$$\Delta^1 = 81 \times 1.27 \times 951.3 \text{ kton} \approx 97\,860 \text{ kton} \approx 79\,365 \text{ ac-f} \quad (\text{layer: } 18.4 \text{ mm} \approx 0.72 \text{ in})$$

Large Clouds

The sub-sample of 27 large seeded clouds received a synergetic analysis. In average, the seeding operations on these large clouds affected 80 % of their whole volume with an excellent timing (99 % of the material went to the clouds in their first half-lifetime). A total of 927 AgI-BIP and 97 Hygroscopic flares were used in this sub-sample for an average effective silver iodide dose about **120 ice-nuclei per liter**.

Also in average, large clouds were 24 minutes old when the operations took place; the operation lasted about 30 minutes, and the large seeded clouds lived 230 minutes.

Table 3 shows the corresponding results:

Table 3: Large Seeded Sample versus Virtual Control Sample (27 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	230 min	195 min	1.18	18
Area	1108 km ²	925 km ²	1.20	20
Volume	3804 km ³	3174 km ³	1.20	20
Volume Above 6 km	1054 km ³	871 km ³	1.21	21
Prec.Flux	14781 m ³ /s	12315 m ³ /s	1.20	20
Prec.Mass	55 527 kton	36 055 kton	1.54	54

An increase of 54 % in precipitation mass for a control value of 36 055 kton in 27 cases may mean:

$$\Delta^2 = 27 \times 0.54 \times 36\,055 \text{ kton} \approx 525\,682 \text{ kton} \approx 426\,328 \text{ ac-f} \quad (\text{layer: } 17.6 \text{ m} \approx 0.69 \text{ in})$$

Type B Clouds

The sub-sample of 12 type B seeded clouds also received a synergetic analysis. In average, the seeding operations on these type B clouds affected 23 % of their whole volume with a satisfactory timing (81 % of the material went to the clouds in their first half-lifetime). A total of 291 AgI-BIP and 34 Hygroscopic flares were used in this sub-sample for an average effective silver iodide dose about **115 ice-nuclei per liter**.

Also in average, type B clouds were 110 minutes old when the operations took place; the operation lasted about 20 minutes, and the type B seeded clouds lived 280 minutes.

Table 4 shows the results:

Table 4: Type B Seeded Sample versus Virtual Control Sample (12 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	280 min	270 min	1.04	4
Area	1095 km ²	1030 km ²	1.06	6
Volume	7405 km ³	6948 km ³	1.07	7
Volume Above 6 km	1059 km ³	1004 km ³	1.05	5
Prec.Flux	10054 m ³ /s	9410 m ³ /s	1.07	7
Prec.Mass	56 751 kton	49 672 kton	1.14	14

An increase of 14 % in precipitation mass for a control value of 49 672 kton in 12 cases may mean:

$$\Delta^3 = 12 \times 0.14 \times 49\,672 \text{ kton} \approx 83\,449 \text{ kton} \approx 67\,677 \text{ ac-f (layer: 6.35 mm} \approx 0.25 \text{ in)}$$

$$\text{The total increase: } \Delta = \Delta_1 + \Delta_2 + \Delta_3 = 573\,370 \text{ ac-f}$$

(~ 980 ac-f per small, 15 790 per large, 5640 per type B)

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:

County Seeding	Initial Seeding	Extended (increase)	Acre-feet (increase)	Inches (increase)	Rain Gage (season value)	% (increase)
Uvalde	6	10	80 500	0.94	22.47 in	4.2
Bandera	3	5	38 200	1.05	23.00 in ^(*)	4.6
Medina	8	13	43 800	0.57	22.59 in	2.5
Bexar	5	11	26 400	0.40	34.99 in	1.1
Frío	8	11	40 700	0.70	22.93 in	3.1
Atascosa	27	40	93 500	1.41	29.88 in ^(*)	4.7
McMullen	9	17	73 100	1.23	24.76 in	5.0
Wilson	10	18	36 600	0.86	31.46 in	2.7
Karnes	21	27	48 400	1.22	28.11 in	4.3
Bee	14	17	56 800	1.21	30.09 in ^(*)	4.0
Outside	9	15	18 400			
Total	120	184	556 400			
Average				0.96	27.03 in	3.6

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

(*) Interpolated value of seasonal precipitation

Glaciogenic cases (small clouds)

For the small cases, it was possible to make a comparison between pure glaciogenic seeding (22 cases, the majority of cases) and all the small cases (81 cases, table 2). Table 6 shows the results for the former:

Table # 6 Seeded Sample versus Control Sample (22 couples, averages)

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	60 min	40 min	1.50	50 (36)
Area	67.6 km ²	40.2 km ²	1.68	68 (33)
Volume	203.1 km ³	128.0 km ³	1.59	59 (35)
Top Height	7.5 km	7.4 km	1.03	3 (2)
Max dBz	52.5	51.4	1.02	2 (1)
Top Height of max dBz	3.5 km	3.5 km	1.00	0 (1)
Volume Above 6 km	28.2 km ³	21.0 km ³	1.34	34 (27)
Prec.Flux	579.4 m ³ /s	316.7 m ³ /s	1.83	83 (53)
Prec.Mass	2245.3 kton	982.6 kton	2.29	129 (109)
CloudMass	166.3 kton	110.4 kton	1.82	82 (39)
η	13.5	8.9	1.51	51 (50)

A total of 156 AgI-flares were used in this sub-sample with an excellent timing (**95 %**) for an effective AgI-average dose about **95 ice-nuclei per liter**, although some over-seeded cases were detected. The increases indicate a dynamic response. The vertical reflectivity gradient index for this sample was - 4.1 dBz/km, indicating slightly maritime value (the neutral value is -4.0 dBz/km). The comparison of these results with

those shown on table 2 points out to the existence of a synergy between glaciogenic and hygroscopic materials which favors the use of dual seeding when it is possible.

The increase from this sample: $\Delta = 22 \times 1.09 \times 982.6 \text{ kton} \approx 23\,563 \text{ kton} \approx 19\,109 \text{ ac-f}$
 (~ 869 ac-f per storm; layer: 15.8 mm \approx 0.62 in)

Final Comments

- 1) Results are evaluated as **excellent**;
- 2) The micro-regionalization analysis showed increases per county; different zones received downwind benefits; the average increase in precipitation, referred to rain gage seasonal value, is about **4 %**;
- 3) Radar estimations of precipitation should be considered as measurements of trend. Nevertheless, seeding operations improved the dynamics of seeded clouds.
- 4) In 2016, the total increase in the region, estimated in about 0.55 million acre-feet, should be considered as a great help to fresh water natural resources.
- 5) Hygroscopic seeding was properly used in the operations, as the following small table indicates:

Type of storm	AgI-flares used	Hygroscopic flares used
Small	667 (~ 8.2 per storm)	62 (~ 0.8 per storm)
Large	927 (~ 34.3 per storm)	97 (~ 3.6 per storm)
Type B	291 (~ 24.3 per storm)	34 (~ 2.8 per storm)

Those data show that Large storms received a more dual treatment than the other two types. However, the comparison between tables 2 and 6 indicates that a the use of hygroscopic seeding implies a clear improvement of the cloud dynamics.

Note: Some over-seeding situations were detected, especially on small storms during the last third of the season, when the volumes above 6 km were smaller than the corresponding spring values. The over-seeding did not hurt the clouds,

but an estimate of about 60 AgI flares might have been saved. It is suggested to check the volume above 6 km of each target cloud in order to avoid over-seeding.