**ANNUAL EVALUATION REPORT 2010 WTWMA (San Angelo)**

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Cloud seeding operations 2010 began over the West Texas Weather Modification Association target area in March. This annual report serves as a summary of results. A total of **127 clouds** were seeded and identified by TITAN in **43 operational days**. Table 1 in page 1 summarizes the general figures:

**Table 1: Generalities**

First operational day: **March 8th 2010**
Last operational day: **September 12th 2010**

**Number of operational days: 43**
(Two in March, none in April, four in May, ten in June, twelve in July, ten in August, and five in September)

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

**Twenty-one with excellent performance**
**Eleven with very good performance**
**Five with good performance**
**Three with fair performance**

Three operational days with corrupted data (June 1st and 2nd, and July 6th)

**Number of seeded clouds: 127 (78 small, 26 large, 23 type B)**

**Missed Opportunities: 1 (~ 0.8 %)**

Storm # 2985: June 30 at 20:28:00 over Sterling County

## Small Clouds

Evaluations were done using TITAN and NEXRAD data.

Table 2 shows the results from the classic TITAN evaluation for the 78 small seeded clouds which obtained proper control clouds.

**Table 2: Seeded Sample versus Control Sample (78 couples, averages)**

| Variable | Seeded Sample | Control Sample | Simple Ratio | Increases (%) |
|---|---|---|---|---|
| **Lifetime** | 65 min | 40 min | 1.63 | 63 (**47**) |
| **Area** | 63.2 $km^2$ | 41.8 $km^2$ | 1.51 | 51 (**36**) |
| **Volume** | 235.9 $km^3$ | 147.7 $km^3$ | 1.60 | 60 (**38**) |
| **Top Height** | 8.7 km | 8.0 km | 1.09 | 9 (**5**) |
| **Max dBz** | 52.2 | 50.3 | 1.04 | 4 (**2**) |
| **Top Height of max dBz** | 3.8 km | 3.7 km | 1.03 | 3 (**0**) |
| **Volume Above 6 km** | 67.7 $km^3$ | 41.5 $km^3$ | 1.63 | 63 (**31**) |
| **Prec.Flux** | 474.6 $m^3/s$ | 290.5 $m^3/s$ | 1.63 | 63 (**30**) |
| **Prec.Mass** | 2162.8 kton | 852.4 kton | 2.54 | 154 (**111**) |
| **CloudMass** | 172.8 kton | 106.7 kton | 1.62 | 62 (**52**) |
| $\boldsymbol{\eta}$ | 12.5 | 8.0 | 1.56 | 56 (**39**) |

Bold values in parentheses are modeled values, whereas $\boldsymbol{\eta}$ is defined as the quotient of Precipitation Mass divided by Cloud Mass, and is interpreted as efficiency. A total of 505 flares were used in this sub-sample with an excellent timing (**91 %)** for an effective dose about **70 ice-nuclei per liter**. The seeding operation for small clouds lasted about **10 minutes** in average. An excellent increase of **111 %** in precipitation mass together with an increase of 52 % 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 (47 %), area (36 %) volume (38 %), volume above 6 km (31 %), and precipitation flux (30 %) are notable. There are slight increases in top height (5 %) and maximum reflectivity (2 %).

The seeded sub-sample seemed 52 % more efficient than the control sub-sample. Results are evaluated as **excellent**.

An increase of 111 % in precipitation mass for a control value of 852.4 kton in 78 cases means:

**$\Delta_1$ = 78 x 1.11 x 852.4 kton = 73 801 kton = 59 852 ac-f**

## Large Clouds

The sub-sample of 26 large seeded clouds received a synergetic analysis. In average, the seeding operations on these large clouds affected 61 % of their whole volume; with a perfect timing (100 % of the material went to the clouds in their first half-lifetime). A total of 524 flares were used in this sub-sample for an effective dose about **85 ice-nuclei per liter**.

Also in average, large clouds were 25 minutes old when the operations took place; the operation lasted about 43 minutes, and the large seeded clouds lived 270 minutes.

Table 3 shows the corresponding results:

**Table 3: Large Seeded Sample versus Virtual Control Sample (26 couples, averages)**

| Variable | Seeded Sample | Control Sample | Simple Ratio | Increases (%) |
|---|---|---|---|---|
| **Lifetime** | 270 min | 220 min | 1.23 | 23 |
| **Area** | 1309 $km^2$ | 1098 $km^2$ | 1.19 | 19 |
| **Volume** | 5402 $km^3$ | 4495 $km^3$ | 1.20 | 20 |
| **Volume Above 6 km** | 1850 $km^3$ | 1583 $km^3$ | 1.17 | 17 |
| **Prec.Flux** | 10452 $m^3/s$ | 8981 $m^3/s$ | 1.16 | 16 |
| **Prec.Mass** | 143 232 kton | 97 269 kton | 1.47 | 47 |

An increase of 47 % in precipitation mass for a control value of 97 269 kton in 26 cases may mean:

**$\Delta_2$ = 26 x 0.47 x 97 269 kton = 1 188 627 kton = 963 977 ac-f**

## Type B Clouds

The sub-sample of 23 type B seeded clouds received a synergetic analysis.
In average, the seeding operations on the type B clouds affected 16 % of their whole volume; with a very good timing (71 % of the material went to the clouds in their first half-lifetime). A total of 728 flares were used in this sub-sample for an effective dose ~ **105 ice-nuclei per liter**.

Also in average, type B clouds were 125 minutes old when the operations took place; the operation lasted about 54 minutes, and the type B seeded clouds lived ~ 300 minutes.

Table 4 shows the results:

**Table 4: Type B Seeded Sample versus Virtual Control Sample (23 couples, averages)**

| Variable | Seeded Sample | Control Sample | Simple Ratio | Increases (%) |
|---|---|---|---|---|
| **Lifetime** | 300 min | 290 min | 1.03 | 3 |
| **Area** | 4376 $km^2$ | 4191 $km^2$ | 1.04 | 4 |
| **Volume** | 19225 $km^3$ | 18378 $km^3$ | 1.05 | 5 |
| **Volume Above 6 km** | 6904 $km^3$ | 6642 $km^3$ | 1.04 | 4 |
| **Prec.Flux** | 30066 $m^3/s$ | 28956 $m^3/s$ | 1.04 | 4 |
| **Prec.Mass** | 385 150 kton | 352 732 kton | 1.09 | 9 |

An increase of 9 % in precipitation mass for a control value of 352 732 kton in 23 cases may mean:

**$\Delta_3$ = 23 x 0.09 x 352 732 kton = 730 155 kton = 592 156 ac-f**

**The total increase: $\Delta = \Delta_1 + \Delta_2 + \Delta_3$ = 1 615 985 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:

| County | Initial Seeding | Extended Seeding | Acre-feet (increase) | Inches (increase) | Rain (season value) | % (increase) |
|---|---|---|---|---|---|---|
| **Glascock** | **10** | **14** | **108 200** | **2.25** | **12.80 in** | **18 %** |
| **Sterling** | **13** | **22** | **232 900** | **2.82** | **17.55 in** | **16 %** |
| **Reagan** | **15** | **24** | **206 100** | **3.29** | **12.23 in*** | **27 %** |
| **Irion** | **19** | **29** | **196 000** | **3.49** | **10.23 in** | **34 %** |
| **Tom Green** | **18** | **28** | **174 400** | **4.29**** | **14.43 in** | **29 %** |
| **Crocket** | **12** | **19** | **247 300** | **1.67** | **11.66 in** | **14 %** |
| **Schleicher** | **26** | **29** | **129 000** | **1.84** | **13.06 in** | **14 %** |
| **Sutton** | **14** | **20** | **171 800** | **2.23** | **11.69 in*** | **19 %** |
| **Total** | **127** | **185** | **1 371 500** | | | |
| Outside TA | | | ~ 244 500 | | | |
| **Average** (only for the bold values) | | | | **2.74** | **12.96 in** | **21 %** |

(*) Missed data recreated by spatial interpolation
(**) One half of the Tom Green Area considered

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

## Hygroscopic Cases

Some hygroscopic seeding operations were done in order to explore its potentialities**.** These operations took place as a complement of the main glaciogenic seeding operations. A total of 4 cases were achieved (1 small cloud, 1 large cloud, and 2 type B clouds). Results are described below.

Table 6 illustrates the results corresponding to the small seeded case.

**Table 6**: **Hygroscopic Seeded Sample versus Control Sample (1 couple, averages)**

| Variable | Seeded Sample | Control Sample | Simple Ratio | Increases (%) |
|---|---|---|---|---|
| Lifetime | 85 min | 45 min | 1.89 | 89 (**70**) |
| Area | 137.7 km2 | 81.6 km2 | 1.69 | 69 (**82**) |
| Volume | 567.6 km3 | 357.6 km3 | 1.59 | 59 (**63**) |
| Top Height | 10.9 km | 9.8 km | 1.11 | 11 (**6**) |
| Max dBz | 58.2 | 53.9 | 1.08 | 8 (**4**) |
| Top Height of max dBz | 4.2 km | 3.9 km | 1.08 | 8 (**0**) |
| Volume Above 6 km | 193.5 km3 | 119.2 km3 | 1.62 | 62 (**27**) |
| Prec.Flux | 1487.4 m3/s | 960.6 m3/s | 1.55 | 55 (**56**) |
| Prec.Mass | 7849.6 kton | 1839.2 kton | 4.27 | 327 (**198**) |
| CloudMass | 484.6 kton | 334.3 kton | 1.45 | 45 (**46**) |
| $\eta$ | 16.2 | 5.5 | 2.95 | 195 (**105**) |

A total of 5 BIP and 1 hygroscopic flare were used in this sample with a perfect timing for a glaciogenic dose of about 10 ice-nuclei per liter. Despite this static dose, the seeded sample shows like-dynamic responses (see the increases) probably suggesting that the hygroscopic material was able to provide enough ice particles in order to reach dynamic dose levels. Although results from such a small sample should be considered only preliminary, they have come to corroborate similar results from last year (season 2009).

The two type B seeded clouds (dual seeding) deserved a synergetic analysis scan by scan. Table 7 shows the results for some selected variables before, during and 30 minutes after the hygroscopic treatment:

**Table 7: Average of two Type B cases (dual seeding: glaciogenic plus hygroscopic)**

| | **Before** | **during** (Hygroscopic Treatment) | **30-minutes after** |
|---|---|---|---|
| # cells | 3.4 | 2.5 | 2.5 |
| PrecMass per scan | 356 kton | 1258 kton | 1062 kton |
| Top of MaxdBz | 4.5 km | 5.5 km | 4.2 km |
| Centroid height | 4.6 km | 4.9 km | 4.9 km |

The average affected volume for these two cases was 15 %, whereas the average timing was 50 %, with an average effective dose of about 200 ice-nuclei per liter. Although the dose was clearly a dynamic one, the observed reaction after seeding was pale and it is hard to find a well-defined signal.

For the large seeded cloud, table 8 shows the corresponding results:

**Table 8: One large seeded case (dual seeding: glaciogenic plus hygroscopic)**

| | **Before** | **during** (Hygroscopic Treatment) | **30-minutes after** |
|---|---|---|---|
| # cells | 3.3 | 3 | 3.1 |
| PrecMass per scan | 252 kton | 686 kton | 673 kton |
| Top of MaxdBz | 3.7 km | 3.0 km | 4.9 km |
| Centroid height | 4.5 km | 4.3 km | 4.5 km |

In this case, the observed increase in the average number of cells after seeding together with an increase in top height of maximum reflectivity and Centroid height were associated to a perfect timing (100 %) and may indicate that the hygroscopic material went into the storms when the target units were still growing. It might suggest that probably more ice particles were produced by the hygroscopic material. However, the silver iodide dose in this case was relatively high (190 ice-nuclei per liter) and it should have been a major impact. Again, the sample (one case) is still too small to have any statistical significance, although supports the idea that the hygroscopic material might have affected the ice phase of the target units (like the cases last year).

## Final Comments

1) Results are evaluated as **excellent**;

2) The micro-regionalization analysis showed increases per county; seedable conditions were more frequent over the central zone of the target area (Reagan, Irion, Schleicher and Tom Green Counties); the average increase in precipitation, referred to the seasonal value, is about **21 %;**

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

4) Season 2010 was a very atypical one which began under the influence of El Niño conditions. However, in July a rapid transition to neutral conditions over the Equatorial Pacific Ocean seemed to indicate that La Niña conditions were going to take place by late summer. This forecast was very accurate and the late 2010 season was under the current La Niña conditions which provide less moisture from the Pacific and therefore less fuel for the convective activity over the target area. It may explain the early closing of WTWMA cloud seeding operations.

5) Some hygroscopic seeding operations were done and although the sample is still too small for any strong statement, the results are promissory and appear to suggest that the hygroscopic seeding material may impact the ice phase of seedable clouds.