**Arquimedes Ruiz**
Active Influence & Scientific Management

## Introduction

Cloud seeding operations 2002 began over Texas target areas in March. These operations were aided by daily and monthly evaluation reports using the **T**ITAN **e**valuation **s**oftware **p**ackage (**Tesp**) that helped to improve their management. The partial evaluations offered estimations about the modifications that the seeding operations caused in the clouds by comparison with control clouds, and statements about seeding timing, dosages, missed opportunities, etc. This annual report serves as a summary of these results. During the aforementioned period a total of **897 clouds** were seeded and identified by TITAN in **237 target-area operational days (tao days)**. Fifty-six seeded clouds did not obtain proper files, whereas **two hundred forty-two clouds were reserved for the synergetic analysis** (135 large, and 107 type B clouds). The second section of this report presents the details.

## Generalities

As we mentioned, a total of **897 clouds were seeded** and identified by TITAN in **237 operational days** during the period **March-October 2002**. Fifty-six clouds did not receive proper files to be considered in the evaluations. Therefore, a final sample of **841 seeded clouds** is available for the analyses using the **T**ITAN **e**valuation **s**oftware **p**ackage (**Mittermaier and Dixon**, 2000). This package consists of four different stages that help to obtain a statistical evaluation of seeding impacts by comparison among seeded and control clouds. The statistical evaluation permits the use of the arithmetic mean and the first, second, and third quartiles as measures of central tendency. **The arithmetic mean** has been selected for our reports because of its easy interpretation, and despite it is greatly influenced by extreme scores (**Bates and Ruiz**, 2001, 2002). The raw values of different variables are presented together with modeled values (the H-model, **Ruiz et al**, 2002) to eliminate initial biases of the seeded sample (sometimes of the control sample). However, **242 seeded clouds** (135 large and 107 type B cases) were taken away from the classical TITAN evaluation and reserved for synergetic analyses. **Section one** presents the comparison for the seeded sub-sample of small clouds and clusters versus its corresponding sub-sample of control clouds, and besides additional considerations and comparisons that can help us to obtain further insights. **Section two** contains all the contents about the synergetic analysis.

## **SECTION ONE**: The classical TITAN evaluation

A sub-total of **599 seeded clouds** obtained proper control clouds in the process of their evaluation. Table 1.1 shows the results of the comparison "seeded versus control":

**Table 1.1 Small Seeded Clouds versus Small Control Clouds (599 couples, averages)**

| Variable | Seeded Sample | Control Sample | Simple Ratio | Increases (%) |
|---|---|---|---|---|
| **Lifetime** | 85 min | 55 min **(61)** | 1.55 (**1.39**) | 55 (**39**) |
| **Area** | 58.2 km$^2$ | 46.7 km$^2$ | 1.25 (**1.18**) | 25 (**18**) |
| **Volume** | 193.2 km$^3$ | 140.1 km$^3$ | 1.38 (**1.22**) | 38 (**25**) |
| **Top Height** | 8.0 km | 7.5 km | 1.07 (**1.04**) | 7 (**4**) |
| **Max dBz** | 47.3 | 45.6 | 1.04 (**1.02**) | 4 (**2**) |
| **Top Height of max dBz** | 4.2 km | 4.3 km | 0.98 (**1.00**) | -2 (**0**) |
| **Volume Above 6 km** | 55.4 km$^3$ | 34.8 km$^3$ | 1.59 (**1.33**) | 59 (**33**) |
| **Prec.Flux** | 289.0 m$^3$/s | 190.7 m$^3$/s | 1.52 (**1.36**) | 52 (**36**) |
| **Prec.Mass** | 1439.3 kton | 667.4 kton | 2.16 (**1.89**) | 116 (**89**) |
| **CloudMass** | 119.8 kton | 79.5 kton | 1.51 (**1.35**) | 51 (**35**) |
| **$\eta$** | 12.0 | 8.4 (**8.5**) | 1.43 (**1.41**) | 43 (**41**) |

Bold values in parentheses are modeled values, whereas **$\eta$** is defined as the quotient between Precipitation Mass and Cloud Mass and is interpreted as efficiency. A total of 3225 flares and 3480 generator-minutes were used in this sub-sample with a very good timing (**69 %),** for an effective dose around **30 ice-nuclei per liter which should have reached dynamical levels** in many seeded clouds by judging the results (8 % of the seeding agent came from generators). A very good increase of 89 % in precipitation mass together with an increase of 35 % 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 (39 %), in volume (25 %), in volume above 6 km (33 %), and in precipitation flux (36 %) are appreciable, whereas the increase in area (18 %) is around the radar uncertainty. There is a slight increase in maximum reflectivity (2 %), and a little greater increase in top height (4 %). The seeded sub-sample seemed 41 % more efficient than the control sub-sample.

Our cluster analysis was extended to different other sub-samples. For instance, table 1.2 shows the results for 267 cases where the couple is composed of "a single seeded case versus a single control case" (267 couples):

**Table 1.2 Single Seeded Clouds versus Single Control Clouds (267 couples, averages)**

| Variable | Seeded Sample | Control Sample | Simple Ratio | Increases (%) |
|---|---|---|---|---|
| Lifetime | 40 min | 30 min **(33)** | 1.33 (**1.21**) | 33 (**21**) |
| Area | 29.0 $km^2$ | 25.5 $km^2$ | 1.14 (**1.08**) | 14 (**8**) |
| Volume | 82.8 $km^3$ | 69.3 $km^3$ | 1.19 (**1.12**) | 19 (**12**) |
| Top Height | 7.3 km | 7.0 km | 1.04 (**1.01**) | 4 (**1**) |
| Max dBz | 45.9 | 44.8 | 1.02 (**1.01**) | 2 (**1**) |
| Top Height of max dBz | 4.0 km | 4.2 km | 0.95 (**0.98**) | -5 (**-2**) |
| Volume Above 6 km | 18.9 $km^3$ | 14.3 $km^3$ | 1.32 (**1.07**) | 32 (**7**) |
| Prec.Flux | 146.2 $m^3/s$ | 105.0 $m^3/s$ | 1.39 (**1.20**) | 39 (**20**) |
| Prec.Mass | 368.8 kton | 203.2 kton | 1.81 (**1.57**) | 81 (**57**) |
| CloudMass | 52.1 kton | 38.5 kton | 1.35 (**1.17**) | 35 (**17**) |
| $\eta$ | 7.1 | 5.3 (**5.3**) | 1.34 (**1.34**) | 34 (**34**) |

A total of 958 flares and 1477 generator-minutes were used in this sub-sample with a very good timing **(68 %**), for an effective dose around **60 ice-nuclei per liter** (10 % of the seeding agent came from generators). Here the increases are pale in area, in volume, in volume above 6 km, and in precipitation flux, while in precipitation mass (57 %) is appreciable, indicating that the expected dynamical response did not occur but microphysical changes promoted the increase in precipitation mainly through an appreciable increase in lifetime. For this seeded sub-sample and its control sub-sample, an analysis of **top debris** (sometimes anvil losses) indicates that at the end of their lifetime the top debris of the seeded clouds had a height of 9.2 km, while for the control cloud this value is 9.1 km, for a difference of **0.1 km = 328 feet**. The average top debris of the single seeded clouds was higher than the top debris of the corresponding control clouds, a signal that points out the losses of moisture at the top level.

A similar analysis of top debris for the single clouds seeded only with generators (this situation occurred only in Abilene and Cotulla target areas) shows that these losses were yet worse for these cases (29 couples). The average top debris for these 29 cases was 8.5 km, whereas for the control cases is 7.8 km, but the difference is **0.7 km** = **2295 feet**, seven times greater than the value obtained for the sub-sample of 267 cases (328 feet).

Table 1.3 shows the results for the sub-sample of multi-cell small clouds and clusters matched with multi-cell control clouds (205 couples).

**Table 1.3 Multi-cell Seeded Clouds versus Multi-cell Control Clouds**
**(205 multi-cell couples, averages)**

| Variable | Seeded Sample | Control Sample | Simple Ratio | Increases (%) |
|---|---|---|---|---|
| **Lifetime** | 120 min | 80 min (**88**) | 1.50 (**1.36**) | 50 (**36**) |
| **Area** | 93.0 $km^2$ | 77.7 $km^2$ | 1.20 (**1.19**) | 20 (**19**) |
| **Volume** | 323.7 $km^3$ | 244.3 $km^3$ | 1.33 (**1.27**) | 33 (**27**) |
| **Top Height** | 8.9 km | 8.2 km | 1.09 (**1.09**) | 9 (**9**) |
| **Max dBz** | 48.9 | 46.7 | 1.05 (**1.03**) | 5 (**3**) |
| **Top Height of max dBz** | 4.3 km | 4.5 km | 0.96 (**0.98**) | -4 (**-2**) |
| **Volume Above 6 km** | 95.9 $km^3$ | 65.0 $km^3$ | 1.48 (**1.41**) | 48 (**41**) |
| **Prec.Flux** | 462.2 $m^3/s$ | 314.9 $m^3/s$ | 1.47 (**1.41**) | 47 (**41**) |
| **Prec.Mass** | 2818.6 kton | 1385.7 kton | 2.03 (**2.13**) | 103 (**113**) |
| **CloudMass** | 201.4 kton | 140.5 kton | 1.43 (**1.39**) | 43 (**39**) |
| $\eta$ | 14.0 | 9.9 (**9.1**) | 1.41 (**1.54**) | 41 (**54**) |

A total of 1865 flares and 1040 generator-minutes were used in this seeded sub-sample, with a very good timing (**70 %**), for an effective dose around **40 ice-nuclei per liter, which should have reached dynamical levels in many particular clouds** (5 % of the seeding material came from the generators). Appreciable increases in the main variables but area indicate the occurrence of dynamical responses, with an excellent increase in precipitation mass (113 %). The seeded sub-sample seemed 54 % more efficient than its corresponding control.

Table 1.3.1 shows the results of the evaluation of the clouds (singles and multi-cells) that were seeded only with generators (cases from Abilene and Cotulla target areas only).

**Table 1.3.1 Seeded Sample versus Control Sample (38 couples, averages)**
**(Single and Multi-cell clouds seeded only with generators versus their control clouds)**

| Variable | Seeded Sample | Control Sample | Simple Ratio | Increases (%) |
|---|---|---|---|---|
| **Lifetime** | 70 min | 40 min (**44**) | 1.75 (**1.59**) | 75 (**59**) |
| **Area** | 47.6 km$^2$ | 43.2 km$^2$ | 1.10 (**1.01**) | 10 (**1**) |
| **Volume** | 122.3 km$^3$ | 113.1 km$^3$ | 1.08 (**1.00**) | 8 (**0**) |
| **Top Height** | 6.9 km | 6.6 km | 1.05 (**0.99**) | 5 (**-1**) |
| **Max dBz** | 45.2 | 44.1 | 1.02 (**0.98**) | 2 (**-2**) |
| **Top Height of max dBz** | 3.7 km | 3.8 km | 0.97 (**1.03**) | -3 (**3**) |
| **Volume Above 6 km** | 17.8 km$^3$ | 19.7 km$^3$ | 0.90 (**0.81**) | -10 (**-19**) |
| **Prec.Flux** | 190.7 m$^3$/s | 154.3 m$^3$/s | 1.24 (**1.08**) | 24 (**8**) |
| **Prec.Mass** | 819.4 kton | 547.0 kton | 1.50 (**1.36**) | 50 (**36**) |
| **CloudMass** | 65.1 kton | 57.0 kton | 1.14 (**1.02**) | 14 (**2**) |
| **$\eta$** | 12.6 | 9.6 (**9.4**) | 1.31 (**1.34**) | 31 (**34**) |

A total of 1065 generator-minutes were used in this sub-sample with a good timing (58 %), for an effective dose around **35 ice-nuclei per liter**. Now, only the increases in lifetime (59 %), and precipitation mass (36 %) are appreciable, whereas the increases in area and precipitation flux are very pale, inside the radar uncertainties. There is not increase in volume, and a decrease in volume above 6 km, which may indicate that the extension of the seeded clouds at the upper levels occurred with values of reflectivity below the tracking threshold, mainly as top debris (**blown top effect**). The dose is considered intermediate, not bad, but it seems like the very small ice particles made a counter-effect.

Coming back to the sub-sample of 267 multi-cell couples, a further analysis of multiplicity using the information about the amount of cells in each scan for every case shows very interesting features.  Table 1.4 summarizes these issues:

Table 1.4 **Analysis of multiplicity using the amount of cells (n)**
**(Multi-cell Seeded Clouds versus their Multi-cell Control Clouds)**

| | **<n>** | **abs. maximum** | **<maximum>** | **<max. occurrence>** | **<transition>** |
|---|---|---|---|---|---|
| **Seeded Sample** | **1.9** | **16** | **3.8** | **34 min** | **18 min** |
| **Control Sample** | **1.7** | **15** | **3.1** | **24 min** | **12 min** |

Here, **<n>** is the average of existing cells in the multi-cells, **abs. maximum** is the absolute maximum in the amount of cells, **<maximum>** is the average of maximum number of cells, **<max.occurrence>** is the average time of the maximum occurrence, and **<transition>** is the average time of transition from the single stage to the multi-cell stage.

According to these results, the seeded clouds showed a greater multiplicity in average than the control clouds, with a greater absolute maximum, and a greater averaged maximum.  The maximum occurrence seemed to occur 10 minutes later in the seeded cases (perhaps because the maximums were usually greater), whereas the transition to a multi-cell stage had a difference of 6 minute.  It seems like if the first updraft of a future multi-cell system is seeded it will last longer than expected naturally, producing a little delay in the transition to the multi-cell stage. These results are to some extension slightly different from those obtained during the season 2001, but the use of a lower reflectivity threshold (32 dBz in 2002 versus 39 dBz in 2001) may have affected the final issues.

One consideration about the relationship between synoptic conditions and the efficiency of cloud seeding operations was made for the small clouds and clusters in every local project.  For the whole state, a sub-total of “172 northerner clouds”, and “427 southerner clouds” were seeded and identified.  A northerner case is defined as a cloud formed in a predominant extra-tropical condition, whereas a southerner case is the opposite case. Northerner cases represented the 29 % of the small clouds and cluster, and were predominant over the Texas Panhandle during the season, while the southerner cases were predominant in the rest of the target areas. There were slightly better responses to the seeding operations from the northerner cases in the Texas Panhandle projects and in Plains and San Angelo target areas, although very close to the radar uncertainties, and no meaningful differences in the rest. An interested situation was detected in Pleasanton target area, where the very small differences between extra-tropical and more tropical cases may be indicating that clouds formed under strong maritime influence, but inland, receive a quick continental imprint, which rapidly "continentalizes" them, giving us better opportunities for the weather modification actions. This conclusion is preliminary. Another interested conclusion is the fact that tropical conditions had a great influence during the season for all the target areas but the Panhandle projects.

Returning to table 1, it may be used to obtain an estimation of the amount of water associated with the increase reported in precipitation mass. Such increase of **89 %** in precipitation mass over a control value of 667.4 **kton** represents a value of 0.89 times 667.4 = **594 kton** of increase for an average cloud, which should be multiplied by the amount of seeded clouds to obtain a figure for the sub-sample:

For 599 small seeded clouds: 599 times 594 kton = **355 806 kton = 288 559 ac-f**

Now, if we consider in this figure the seeded clouds that belonged to the large and type B systems as isolated additional units (TITAN cannot isolate these clouds), they add 400 more clouds to the sample. In this case, a total of 999 small seeded clouds would produce (maintaining the same precipitation control value):

**999 times 594 kton = 593 406 kton = 481 252 ac-f**

The latter consideration forgets the synergy associated with the large systems. In the next section we attempt to consider this feature.

## **SECTION TWO**: **The synergetic analysis**

We already know the recognized limitations that TITAN has to track properly seeded cloud systems. At least in Texas, these limitations have transcended to real problems in the determination of proper control clouds for large clouds. Additional, the TITAN authors have always advised that the use of the TrackMatch facility to obtain control candidates should be limited to "type A" seeded clouds (clouds seeded before they are too old, we selected in Texas 1 hour-period). These facts leave out of the analysis the large clouds (precipitation mass greater than 10 000 kilotons) and the "type B" clouds (seeded when they were one hour old or older). The synergetic analysis is a tool designed to evaluate these cases, which studies scan by scan the properties of the clouds, making statistical calculations for the periods before, during, and after seeding, and for the whole lifetime, and at the end uses these results to build a virtual control cloud (a model that estimates how the seeded cloud would have evolved as a unseeded cloud). The bases of this analysis are in a known fact: **clouds working in a system are more efficient**, and produce more precipitation than isolated clouds; and also in the idea that for large and more complex system we need to know the whole history of the system to figure out how its natural evolution would have been. For small clouds and cluster the control cases obtained with TITAN are appropriate enough, but for large and type B systems they are not.

Furthermore, it is very important to know whether or not the seeding operation took place in a cloud already in a steady state situation. If this is the case, the period before the seeding operation may be used as "a control cloud" which had a lifetime shorter than the seeded case, determined using the results for multi-cell clouds in table 1. Type B clouds usually fall in this category. It is important always to determine what percent of the cloud was really affected by the seeding operation. If the cloud was seeded before reaching a steady state, the percent of the cloud affected is considered as a system seeded in its early stages, normalized, taking away the period before seeding, to build a control case. The values obtained are later subtracted to the seeded cloud to construct its final virtual control case. In both cases we construct a virtual control cloud by a method that may be named "of the normalized increases".

The synergetic analysis deserved its name because of its focus primarily in the amount of cells involved in the process (Greek synergos, working together). For large clouds with precipitation mass greater than 10 000 kton (135 cases), an average summary of the evolution for some variables indicated the following:

| **Large Clouds** | **Before seeding** | **During seeding** | **After seeding** | **Whole lifetime** |
|---|---|---|---|---|
| **<n>** | 3.4 | 5.2 | 4.9 | 4.7 |
| **dn/dt** | 1.3 | 2.0 | -1.2 | 0.0 |
| **PrecMass/scan** | 586 | 1177 | 1903 | 1292 |
| **PrecMass/cell. scan** | 186 | 226 | 388 | 275 |

(<n> is the average of cells; dn/dt is the rate of increase in the amount of cells every 20 minutes)

These values indicate an increase of 53 % in the amount of cells during the seeding operation in large clouds (5.2/3.4 = 1.53), accompanied by an increase in precipitation mass per scan of 101 % (1177/586 = 2.01). For the whole lifetime respective increases were 38 % and 120 %. However, these increases must be normalized before being used in the construction of the virtual control cases. It is very important to point out that the rate of production of cells did increase during the operations, and later became negative in association with the processes of merging and dissipation.

For type B clouds (107 cases), the corresponding results were:

| **Type B Clouds** | **Before seeding** | **During seeding** | **After seeding** | **Whole lifetime** |
|---|---|---|---|---|
| **<n>** | 4.7 | 6.3 | 5.0 | 5.2 |
| **dn/dt** | 0.8 | 0.2 | -1.1 | 0.0 |
| **PrecMass/scan** | 594 | 992 | 1258 | 892 |
| **PrecMass/cell. scan** | 126 | 157 | 252 | 172 |

(<n> is the average of cells; dn/dt is the rate of increase in the amount of cells every 20 minutes)

These values show an increase of 34 % (6.3/4.7 = 1.34) in the amount of cells during the seeding operations of type B clouds, together with an increase of 67 % in precipitation mass per scan (992/594 = 1.67). For the whole lifetime the respective increases were 11% and 50 %. In average type B clouds lasted 255 minutes, while large clouds lasted 210 minutes, and this difference in 45 minutes seems decisive.

As we have said, during the season 2002 two hundred forty-two seeded clouds deserved synergetic analyses, one hundred and five type A large cases, and one hundred and seven type B cases. However, five large clouds and six type B clouds were discarded for different reasons: four were seeded too late during their senescence period (after full maturity, without SSS signs), two were too maritime and seeded relatively late, and five received really marginal doses. These eleven cases did not show responses to the seeding operations.

Table 2.1 shows the results for the large clouds, whereas table 2.2 corresponds to the type B clouds.

**Table 2.1. Seeded Sample versus Virtual Control Sample (130 couples, averages)**
**(Large Seeded Clouds versus their Virtual Large Control Clouds)**

| Variable | Seeded Sample | Virtual Control | Simple Ratio | Increases (%) |
|---|---|---|---|---|
| Lifetime | 210 min | 185 min | 1.14 | 14 |
| Area | 856 $km^2$ | 812 $km^2$ | 1.05 | 5 |
| Volume | 4285 $km^3$ | 3975 $km^3$ | 1.08 | 8 |
| Top Height | 13.2 km | 12.6 km | 1.05 | 5 |
| Max dBz | 53.4 | 52.4 | 1.02 | 2 |
| Top Height of max dBz | 5.4 km | 5.4 km | 1.00 | 0 |
| Volume Above 6 km | 2165 $km^3$ | 1966 $km^3$ | 1.10 | 10 |
| Prec.Flux | 5435 $m^3/s$ | 4940 $m^3/s$ | 1.10 | 10 |
| Prec.Mass | 82324 kton | 70282 kton | 1.17 | 17 |
| CloudMass | 3166 kton | 2871 kton | 1.10 | 10 |
| $\eta$ | 26.0 | 24.5 | 1.06 | 6 |

A total of 3496 flares and 1165 generator-minutes were used in this sub-sample for an average dose around 30 ice-nuclei per liter, which may have reached higher levels in some individual turrets (4% of the seeding agent came from generators). A virtual increase of 17 % in precipitation mass represents an appreciable amount of water around a value of

**Q = 130 times 0.17 times 70282 kton = 1 553 232 kton ~ 1 259 671 ac-f**

For the 101 type B cases:

**Table 2.2. Seeded Sample versus Virtual Control Sample (101 couples, averages)**
**(Type B Seeded Clouds versus their Virtual Control Clouds)**

| Variable | Seeded Sample | Virtual Control | Simple Ratio | Increases (%) |
|---|---|---|---|---|
| **Lifetime** | 255 min | 245 min | 1.04 | 4 |
| **Area** | 702 $km^2$ | 657 $km^2$ | 1.07 | 7 |
| **Volume** | 3399.3 $km^3$ | 3138 $km^3$ | 1.08 | 8 |
| **Top Height** | 11.8 km | 11.2 km | 1.05 | 5 |
| **Max dBz** | 50.3 | 49.9 | 1.01 | 1 |
| **Top Height of max dBz** | 4.9 km | 5.0 km | 0.98 | -2 |
| **Volume Above 6 km** | 1761 $km^3$ | 1603 $km^3$ | 1.10 | 10 |
| **Prec.Flux** | 3616 $m^3/s$ | 3328 $m^3/s$ | 1.09 | 9 |
| **Prec.Mass** | 59639 kton | 52399 kton | 1.14 | 14 |
| **CloudMass** | 2330 kton | 2101 kton | 1.11 | 11 |
| $\eta$ | 25.6 | 24.9 | 1.03 | 3 |

A total of 1409 flares and 1165 generator-minutes were used in this sub-sample for an average dose around 20 ice-nuclei per liter, which may have reached higher levels in some particular turrets. A virtual increase of 14 % in precipitation mass represents an appreciable amount of water around a value of

**Q = 107 times 0.14 times 52399 kton = 784 937 kton ~ 636 584 ac-f**

Increases (in percent) are very similar in table 6 and in table 7. Type B clouds in average lasted more than large type A clouds, but offered less precipitation. Most of the virtual increases in the last two tables are inside the radar uncertainties and therefore are undetectable with our actual tools. Nevertheless, the synergetic analysis and its derivate results allow us to approach the evaluation of the seeding operations on seeded clouds that did not get proper controls and to obtain estimations about the values of the possible increases in the radar variables. In fact, we have now a better idea about how proper control clouds must be for large seeded clouds. The problem might be partially solved with an improved TITAN version that might evaluate individual convective seeded clouds without considering a family tracking number. However, for large single clouds, which are rare events, the problem would persist.

Probably the interpretation of results from the different tables presented in this report might be more clarified with the presentation of the different precipitation masses as water layers. We can define these layers with the variable "layer depth", D,

**D = Precipitation Mass (kton) / Area ($km^2$), which has unit of millimeters**.

(One inch is equal to 25.4 millimeters)

From table 1.1 (small clouds and clusters):

| | Seeded Sample | Control Sample | Increase | % to Seeded Sample |
|---|---|---|---|---|
| **D** | **0.97 inch** | **0.56 inch** | **0.40 inch** | **41 %** |

It is important to notice that the increase in this case is not the arithmetic difference between the seeded and the control values because different values of area are in the calculations. The values of D simulate depth values of layers below an average cloud for each sample and the equivalent layer for the increase calculated from the radar data. Here the percent of increase referred to the seeded sample is 41 %, and might be a close figure to the values that may be obtained by a proper rain gage network.

From table 2.1 (large clouds):

| | Seeded Sample | Control Sample | Increase | % to Seeded Sample |
|---|---|---|---|---|
| **D** | **3.79 inches** | **3.40 inches** | **0.55 inch** | **14 %** |

A 14 % of increase is reported in the depth of a virtual layer below the average large seeded cloud.

From table 2.2 (type B clouds):

| | Seeded Sample | Control Sample | Increase | % to Seeded Sample |
|---|---|---|---|---|
| **D** | **3.34 inches** | **3.13 inches** | **0.41 inch** | **12 %** |

A 7 % of increase is reported in the depth of a virtual layer below the average type B seeded cloud.

The average figure for **all the seeded clouds**:

| | Seeded Sample | Control Sample | Increase | % to Seeded Sample |
|---|---|---|---|---|
| **D** | **1.70 inches** | **1.32 inches** | **0.42 inch** | **25 %** |

A 25 % of increase is reported in the depth of a virtual layer below the average seeded cloud of the season 2002.

## SECTION THREE: Assessments and Conclusions

A further evaluation of performance based on a scale of 5 was done under daily bases. An **excellent operational day** is defined as one with an excellent timing (75 % or higher), an excellent dosage (dynamic levels), an excellent increase in precipitation mass (90 % or more), and no missed opportunities. Excellent days receive a mark of 5. A very **good operational day** is defined as one with a very good timing (between 65 and 74%), a **very** good dose (intermediate to dynamic levels), a very good increase in precipitation mass (between 60 and 89 %), and 15 % or less missed opportunities. Very good days receive a mark of 4. A **good operational day** is defined as one with a good timing (between 55 and 64 %), a good dose (intermediate), a good increase in precipitation mass (between 30 and 59 %), and between 16 and 30 % missed opportunities. Good days receive a mark of 3. Days with a mixture of excellent, very good, and good marks for the different indexes are evaluated according with the predominant nuance, determined by using the median, and more qualitative criteria. Days with lower performance than those described in this paragraph but with some increases in variables as area, volume, volume above 6 km, precipitation flux, and precipitation mass are classified as **fair**, which sometimes means failure, and receive a mark of 2. Days with decreases in precipitation mass and other variables are classified as **poor** and receive a mark of 1. Using this scale to classify the 237 target area operational days reported, the following distribution was obtained:

**Thirty excellent tao days, seventy-nine very good tao days, eighty-six good tao days, and thirty-two fair tao days, for a median of three (ten tao days were out of data)**

A total of **93 missed opportunities** (990 seedable clouds were present over the whole state target area during the operations) were distributed as:

7 over NPWMA target area (Dumas): 10 %
9 over PGCD target area (White Deer): 10 %
14 over HPWD target area (Littlefield): 17 %
11 over SOAR target area (Plains): 18 %
2 over CRMWD (Big Spring): 10 %
4 over WCTWMA (Abilene): 3 %
17 over WTWMA (San Angelo): 6 %
9 over TBWMA (Del Rio): 8 %

6 over (STWMA): 12 %
14 over (SWTREA): 20 %

**Table 3.1: An Analysis of Performance**

**Missed Opportunities (M.O), Efficiency using Seedable Conditions, Timing, Dosages used, and Increase**

| Project | M.O | Efficiency(%) | Timing(%) | Dosage (in/ l) | Layer increase (%) |
|---|---|---|---|---|---|
| CRMWD (Big Spring) | 2 (10 %) | 90 | 70 | 25 | 23 |
| HPUWCD (Littlefield) | 14 (17 %) | 86 | 63 | 40(1) | 17 |
| NPWMA (Dumas) | 7 (10 %) | 90 | 84 | 20 | 26 |
| PGWD (White Deer) | 9 (10 %) | 90 | 73 | 20 | 24 |
| SOAR (Plains) | 11 (18 %) | 82 | 69 | 20 | 27 |
| STWMA (Pleasanton) | 6 (12 %) | 88 | 74 | 55 | 31 |
| SWTREA (Cotulla) | 14 (20 %) | 80 | 55 | 35(2) | 13 |
| TBWMA (Del Río) | 9 (8 %) | 92 | 70 | 120(3) | 28 |
| WCTWMA (Abilene) | 4 (3 %) | 97 | 65 | 40(4) | 21 |
| WTWMA (San Angelo) | 17 (6 %) | 94 | 69 | 40 | 29 |
| **TEXAS** | **93 (9%)** | **91** | **69** | **40** | **25** |

(1) Problems of over-seeding during top seeding operations (too many flares per turrets)
(2) Pale increases in seeded clouds mainly due to generators that promoted "blown top" effects
(3) Slight over-seeding during base seeding operations which did not hurt the clouds
(4) Pale increases in seeded clouds mainly due to generators that promoted "blown top" effects

**A final comment**: Despite the good results obtained during the season 2002 three main concerns must be pointed out. **One** is the use of generators, which has demonstrated to have a small, and sometimes negative, impact over the seeded clouds, with indexes that pinpoint toward losses of moisture as top debris due to the high concentration of ice particles too small, and also pale increases in the main variables used in the evaluation. It is time to abandon the use of these generators, at least in convective clouds. **Second**, meteorologists and pilots should improve the communication during the operational flight. The over-seeding problems can be avoided with a more intelligent use of TITAN side windows and a better link pilot-meteorologist. The over-seeding factor is more probable in top seeding operations, which aim small turrets, undetectable by radar. **Third**, very often during the season we suffered data delivering problems, which interrupted the flow of daily reports. A better delivery should take place for the season to come.

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