TEXAS WEATHER MODIFICATION OPERATIONS IN 2008

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Abstract. The State of Texas completed another year of successful weather modification operations in 2008. During this season, a total of seven projects were operational in Texas conducting rain enhancement and, in one project, hail suppression operations. Operationally, some projects experienced a below average year flight-wise due to the emergence of a drought that began in the fall of 2007. As well, some clouds exhibited tropical characteristics that resulted in less than desirable seeding by glaciogenic materials. Most parts of the state were dry, with the exception of a few spots in northern and far southern Texas. This paper will serve as an update for the Texas projects in 2008, offering a comprehensive summary of each of the operational projects in the state. Additionally, this paper will provide an analysis of the Texas projects conducted by Active Influence and Scientific Management.

1. INTRODUCTION

Weather modification activities continued in 2008 over six target areas spread across parts of Texas. These operational areas cover 29.9 million acres of a total 172 million acres in the state of Texas. For the most part, flight activity was below average. The reason for the below average flight activity was due to the abundance of tropical moisture resulting in cloud structures that were not best suited for glaciogenic seeding.

For the 2008 season, seven projects were operational: Panhandle Groundwater Conservation District's (PGCD) precipitation enhancement project in White Deer, Seeding Operations and Atmospheric Research (SOAR) in Plains, Trans-Pecos Weather Modification Association (TPWMA) in Pecos, West Texas Weather Modification Association (WTWMA) in San Angelo, Southwest Texas Rain Enhancement Association (SWTREA) in both Carrizo Springs and Pleasanton, South Texas Weather Modification Association (STWMA) in Pleasanton, and the Edwards Aquifer Authority's (EAA) precipitation enhancement project. The EAA project is operated by the STWMA and the SWTREA. A map showing the location of all the projects is presented in Figure 1.

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2. TEXAS WEATHER IN 2008

2008 and 2007 were very different years in terms of the overall weather pattern. In 2007, the state experienced a very wet pattern that persisted through most of the summer months. 2008 contrasted with 2007, as most of the state fell into drought conditions. However, there was an exception to this drier pattern in 2008, as portions of the Texas coast throughout the summer and into fall were affected by tropical cyclones. Almost all areas of the state emerged back into drought conditions except for a few locations. Areas that escaped drought for the most part during 2008 were the lower Rio Grande Valley, parts of the Panhandle, some locations in the Pecos River Valley, and spots in east Texas. Most parts of the state received 75% or less of the average annual rainfall. In some of the most drought stricken areas, only 25-50% of the average annual rainfall occurred. Drought conditions can be traced back to the fall of 2007.

Two hurricanes and one tropical storm affected the state of Texas during the summer months. Hurricane Dolly made landfall near Brownsville in late July as a Category 2 storm, providing very heavy rainfall to portions of the Rio Grande Valley. Early in August, Tropical Storm Edouard made landfall in southeastern Texas as a strong tropical storm. Finally, Hurricane Ike made landfall at Galveston in mid-September as a strong Category 2 storm. Figure 2 illustrates the radar-derived yearly rainfall for Texas.

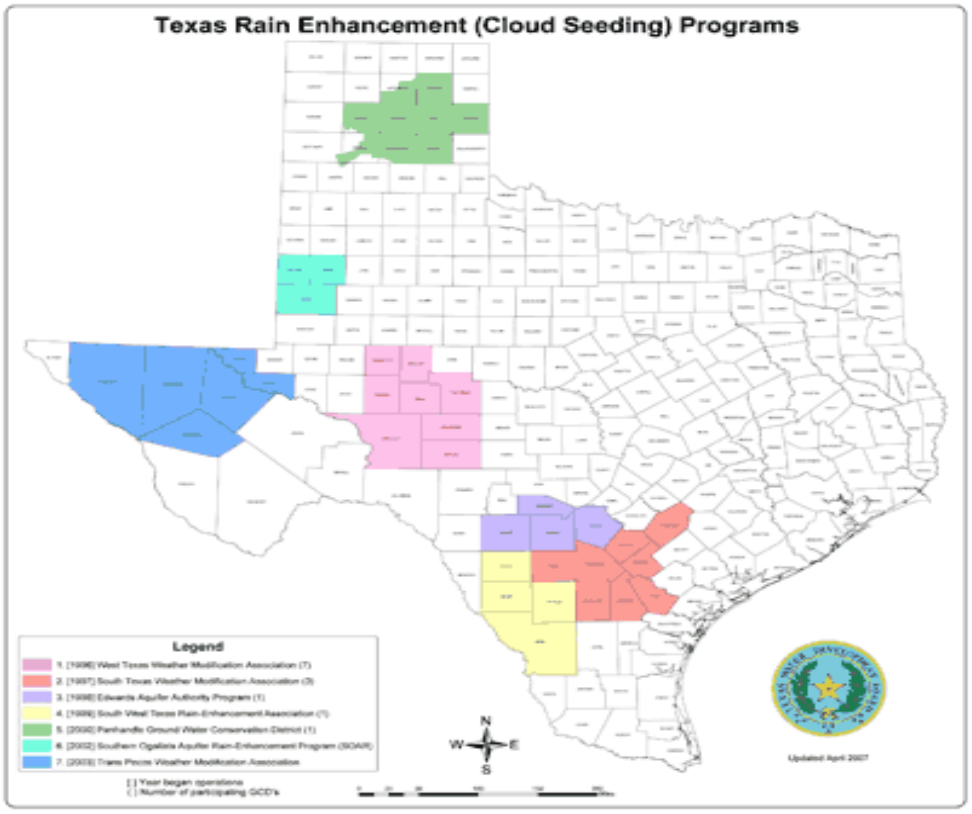

Figure 1. *Locations of Weather Modification Programs in Texas in 2008*

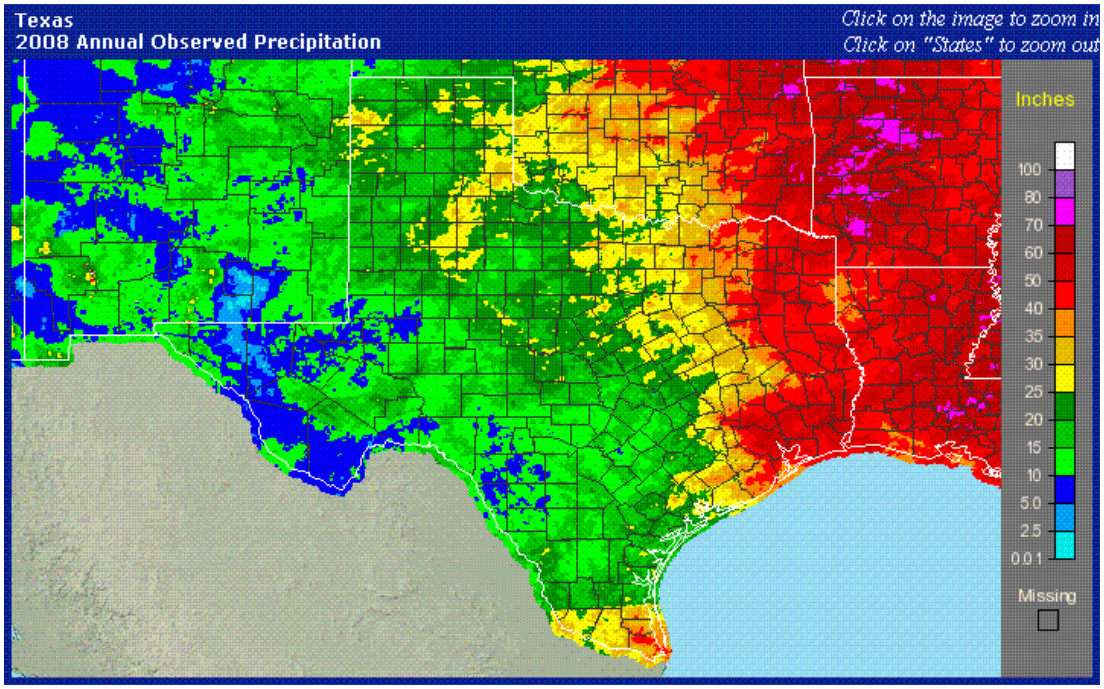

Figure 2. *Radar-derived yearly precipitation for Texas in 2008. Image courtesy of NWS Precipitation Analysis website, http://www.srh.noaa.gov/rfcshare/precip_analysis_new.php .*

3. PROJECT SUMMARIES

3.1 Panhandle Groundwater Conservation District (PGCD)

The conclusion of the Panhandle Groundwater Conservation District's 2008 Precipitation Enhancement Program marked the ninth year of cloud seeding in the Texas Panhandle. This season began with the first mission on April 23rd and concluded on September 5th with the last mission. Typically, the season runs from April 15th until September 30th; however, if suitable opportunities are present before the 15th the season will commence.

The 2008 seeding season contained 23 days with seeding events, which consisted of 26 seeding missions and six reconnaissance missions. This season had the least amount of seeding days since 2000 which had only 22 days of seeding. This year we seeded 15 less days and 33 fewer clouds than in 2007, which can be attributed to very few seeding opportunities through the summer. Each month contributed its own factor for fewer seeding conditions.

During April, the Texas Panhandle experienced many cold fronts, warm fronts, trough passages and dry lines; however, the missing ingredient for convection was moisture. May was characterized by stratus clouds with little to no convection, and concluded with a few dry line events that the National Weather Service (NWS) issued severe thunderstorm warnings on. In the beginning of June much of the precipitation favored the eastern Texas Panhandle; however, at the end of June the pattern changed. During most days precipitation formed off the mountains with a trough and upper-level shortwave being the focus for initiation. This activity moved southeast across the western counties in the Texas Panhandle. All of the seeding missions were cut short due to NWS severe thunderstorm warnings. July was dominated by high pressure, but the weather that did occur was due to normal summer daytime heating with the combination of some mid-level dynamics to create scattered afternoon thunderstorms. All of the weather systems that moved through the area during August were dominated by slow-moving, heavy rainfall thunderstorms. Therefore, some seeding missions were ended due to flash flood warnings issued by the NWS. All of the rain in September occurred on or before the 12th due to three cold fronts and a stationary front, and the rest of the month was characterized by high pressure. In combination with the monthly changes in weather patterns, we also saw more continental clouds this year that consisted of smaller than normal volumes of supercooled water, which also affected our seeding results.

Table 1 shows the number of seeding and reconnaissance missions, flares used, and time flown during the 2008 seeding season.

Table 1: *Weather Modification in PGCD in 2008*

Month	Seeding Flights	Recon Flights	Hours Flown (H:M)	Flares Used
April	1	1	3:44	8
May	3	2	8:30	21
June	5	1	13:10	54
July	6	0	16:55	53
August	10	2	23:55	95
September	1	0	1:45	7
Totals	26	6	67:59	238

3.2 Seeding Operations and Atmospheric Research (SOAR)

Cloud seeding operations in the SOAR project area were not as busy as in 2007. Overall for the year, 20 days saw clouds being seeded within the tri-county area. In May, the eastern parts of the target area saw above normal rainfall while the western areas were drier than normal. Cloud seeding occurred on three days during the month with two additional days of reconnaissance flights. Wetter than normal weather was experienced in June; this happened to be the busiest month of the season. Eleven days of cloud seeding were recorded with an additional four days where reconnaissance flights took place. Drier weather resulting from high pressure parked over the area in July yielded only two days where seedable clouds were treated, and a further two days of reconnaissance flights. August, like May, saw variable rainfall across the target area with the central third seeing above normal rains while the northern and southern areas were drier. Two days during the month offered clouds that were treated, with one reconnaissance day. Septem-

ber ended up being the last month of operations for the SOAR project, with two days of seeding taking place. It was also a wet month for all but the far northwestern corner of the target area, mainly attributed to a very wet period at mid-month when a flow of tropical moisture across western Texas resulted in a train of very heavy rains. For the entire season, 58 ejectable and 53 burn-in-place flares were used, totaling 3280g of AgI.

3.3 Trans-Pecos Weather Modification Association (TPWMA)

The TPWMA's cloud seeding program, under guidance from SOAR, continued in 2008 with their sixth year of operations. The past year was comparable to 2007, with 17 seeding days recorded versus 21 in 2007. The program's first day of seeding occurred in June, where a total of four seeding days were recorded along with an additional four days of reconnaissance flights. The regular occurrence of orographic convection to the lee of the Davis Mountains resulted in a zone of above normal rains over the far eastern target area. This pattern continued into July, with more widespread above normal rains along and to the east of the Davis Mountains. July was the busiest month of the season for Trans-Pecos, with seven seeding days and four reconnaissance days. The presence of tropical moisture helped with the orographic convection, with some enhancement late in the month by the remains of Hurricane Dolly. August, with four days of seeding and three days of reconnaissance, was drier than normal for all but the far eastern portions of Jeff Davis County. September saw a return to above normal rainfall to the lee of the Davis Mountains, primarily resulting from the mid-month intrusion of deep tropical moisture from the Pacific. Despite this, only one day of seeding took place along with three reconnaissance days. October saw the final seeding mission of the year. Overall, 106 burn-in-place flares were used for seeding, amounting to 4240g of AgI.

3.4 West Texas Weather Modification Association (WTWMA)

2008 West Texas seeding operations started on March 17th and ended on September 24th with 38 operational days. Three days were classified as experimental due to the limited moisture or suppressed vertical structure which hindered sufficient inflow. 77 clouds were seeded with 1,431 flares during 57 flights. Eight reconnaissance flights were flown while making an attempt to find seedable clouds on marginal days and pilots flew 150 flight hours.

Changes to the data format created some problems with the Thunderstorm, Identification, Tracking, Analysis, and Nowcasting (TITAN) software used in the Texas project. The National Weather Service Offices installed a new software package called Build-10 with super-resolution capabilities. The software update required manipulation to the Local Data Manager (LDM). The LDM data stream is what TITAN uses to receive and process radar data. One day (June 13) was completely lost while the new code was written. Weather Decision Technologies (WDT) worked hard to provide the new data stream through the month of June. New issues continued to crop up through the summer associated with the change. Several instances of lost radar hindered operations at various times.

2008 was a rather dry year. The annual rainfall, 19.00 inches, at San Angelo was below normal by 1.91 inches. Record rainfall at the San Angelo Regional airport on September 8th and several days in August where Mathis Field received plentiful rains does not show accurately the amount of rainfall seen by the majority of the target area. August was the most active this season with 15 operational days. Precipitation and percent of normal maps show that much of Texas was well below normal except for March which had mainly one rain event. Another event occurring in September west of the Pecos River and over western Crockett County was also noteworthy.

Table 2: *Weather Modification and average rainfall in WTWMA in 2008*

Month	Days	Flares	Rainfall (Avg.) In inches
March	1	27	2.43
April	2	90	0.64
May	4	95	0.65
June	7	267	2.24
July	7	253	0.43
August	15	707	3.37
September	2	17	2.47
Total	38	1456	12.23

Table 3: *Comparison of operational data analysis from 2002-2008 in WTWMA*

	Seeded Clouds	Operational Days	Flares	Increase Million ac-f	Annual Rainfall
2002	285	47	3024	0.78	14.41
2003	265	50	3184	0.76	19.76
2004	109	46	1140	1.35	30.48
2005	133	39	1524	1.26	20.4
2006	157	53	1810	1.7	17.65
2007	95	46	1166	1.19	32.05
2008	78	38	1420	1.18	19.00

3.5 Southwest Texas Rain Enhancement Association (SWTREA)

The 2008 operational season for the Southwest Texas Rain Enhancement Association was one that could be termed as a "flip-flop" season. 2008 marked the tenth operational season for the SWTREA. The season was below normal flight-wise but much more active than 2007. Most of the spring months were very slow and not until later in the summer, during July and August, did operations peak. Usually, operations peak in May and in September with the two precipitation maxima that occur over south Texas. May was about normal precipitation-wise but not operationally. As well, September turned out to be very slow compared to normal. The wettest month of the operational season was August, with a total of sixteen seeding flights on eleven seeding days. September saw a drop in flight activity, as did October when activity usually drops off. The spring months over the southwest Texas area were active in terms of severe weather, with a total of six hail suppression flights taking place in May and April.

The project's first flight usually takes place in March but this year did not take place until the beginning of April due to lack of convection across the area. A recurring problem during the 2008 operational season involved the quality of clouds that were observed. On a number of occasions, convection present in the target area was characterized by low tops, warm rain processes, and weak echo returns. This was the case mostly during the summer months and greatly impacted operations as seen in Table 4.

There was a stark contrast in rainfall over the target area from north to south. While the northern parts of the target area received very little rainfall during the summer months, southern parts of the target area saw heavy rainfall. August was an especially wet month for the two southern counties, LaSalle and Webb, as a series of upper level lows were situated over southwest Texas and eastern Mexico. These same counties also received ample rainfall from Hurricane Dolly, which moved across the lower Rio Grande Valley in July.

Operationally, there was an addition of a new pilot that served both the SWTREA target area and the SWTMA target area. The STWMA is the eastern border of the SWTREA project, so this only increased operational efficiency in south Texas. As well, the project experienced data

Table 4. *Weather Modification in SWTREA in 2008*

Month	AgI used	Number of flights	Rain Enhancement	Hail Suppression
April	5360	5	1	4
May	5760	5	3	2
June	4600	6	6	0
July	4760	7	7	0
August	9160	16	16	0
September	5080	5	5	0
October	560	1	1	0
Totals	35400	47	41	6

issues during the summer months due to the Build-10 upgrade that the National Weather Service made operational in all radars around the state.

3.6 South Texas Weather Modification Association (STWMA)

2008 marked STWMA's twelfth year of cloud seeding operations in south-central Texas and the seventh year of operations for the Edwards Aquifer Authority's (EAA) tri-county area. While the year as a whole was dry, there were a few months where above normal rainfall fell within the target area, notably July and August, the heart of the seeding season. March was also wet for some parts of central Atascosa County, but this was attributed to a supercell thunderstorm that dropped nearly four inches of rain. The remaining months were quite dry across the STWMA target area, with far northern parts of the area classified as being in exceptional drought by year's end. Overall, 104 clouds were seeded over a total of 41 days in 2008, almost twice as many days as in 2007.

The season's first seeding flight took place on March 18th, the only day of seeding during the month. A storm system with impressive dynamics moved across the state, generating a line of convection over the eastern counties. This was the first flight for our new pilot, Matt Pope, who trained throughout the year with Craig Funke. This was the only day of seeding in March. Given the past history, one can expect a day with seedable clouds in March about every third year. April gave the STWMA no seeding missions as much of the area received only 25-50% of their normal rainfall. May was much drier than normal, with eastern areas only receiving 10-25% of their normal rainfall. This was not good, as May is typically one of, if not the wettest month of the year. Only two days saw cloud seeding take place, both of which occurred during the latter half of the month. In both cases the seeded convection appeared to do quite well, continuing past sunset while other untreated convection dissipated. The dry pattern continued into June, with all of the target area receiving less than 50% of the average monthly rainfall and many areas receiving less than 5%! Oddly enough, this was one of the busiest months of the year, with nine days of cloud seeding taking place. The vast majority of clouds in June, however, were small and short-lived. One exception was on June 20th, when a seeded cloud in the eastern target area tracked southwestward into the southern target area with an average rainfall of 1-1.5 inches along the track. July brought welcome rains to the area, with all but far western Bandera County receiving above normal rains, a good chunk of which fell on the 23rd-24th when a weakening Hurricane Dolly impacted the area. Eight days saw cloud seeding take place in July, the majority of which occurred during the first week. The wet pattern continued into August, with much of the area seeing well above normal rainfall, although there were a few locations that missed out and received below-normal rains. The month was quite active, with 16 days of cloud seeding recorded. Four days in September saw cloud seeding take place, near the start of the month and also towards the end. September, unfortunately, saw a return to very dry conditions despite the presence of tropical moisture. Hurricane Ike impacted the area as it made landfall at Galveston on the 13th, but instead of bringing us rains, the circulation around Ike brought scorching heat, with many locations in the target area topping out between 100-105°F. Our final day of seeding took place on October 14th, the only day of the month that operations took place.

3.7 Edwards Aquifer Authority (EAA)

The South Texas Weather Modification Association and the Southwest Texas Rain Enhancement Association participate in a precipitation enhancement program over a small portion of the Edwards Aquifer located in south-central Texas. Both the above mentioned projects have been seeding in the EAA target area for the last seven years. For 2008, a total of twenty-two seeding flights were flown in the EAA target area.

In 2007 at the request of the EAA, the STWMA began a multi-year experiment within the EAA target area counties of Bandera, Bexar and Medina where randomized seeding would take place. 2008 provided even less randomization opportunities than 2007, with one randomized case overall, and that was in the SWTREA target area. The primary problem stemmed from potential candidates being too close to larger clouds, which did not satisfy the existing protocol. The upcoming season in 2009 will hopefully bring many more opportunities for the experiment to continue.

4. 2008 STATE EVALUATION BY ACTIVE INFLUENCE AND SCIENTIFIC MANAGEMENT

Since 2000, Active Influence and Scientific Management (AISM) has been performing a yearly analysis of all seeded clouds in the state of Texas. Individual analyses of each project are also conducted. The analysis involves looking at a seeded cloud as identified by the TITAN software which uses WSR-88D data from radars covering the various target areas in the state. WSR-88D data has been ingested into TITAN since 2004. The evolution of the identified seeded cloud is then compared to the evolution of a control cloud that best matches the seeded cloud in its early life. Several factors are compared between seeded and control clouds such as lifetime, area, volume and precipitation mass. Each cloud is put into one of the three categories and is either classified as a small cloud, large cloud, or a type B cloud depending on its lifetime and size. Small clouds are those defined as clouds with radar-derived precipitation mass values less than 10,000 kilotons. Large clouds are those with precipitation masses greater than 10,000 kton. Type B clouds are those clouds, large or small, that were not seeded until they were at least an hour old as seen on radar. In this section we will look at the results of all seeded small clouds. Note that this analysis does not include data from both the SOAR and TPWMA projects.

Table 5 shows the results of the AISM analysis of all seeded small clouds in the state of Texas. 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 618 flares were used in this sub-sample with an excellent timing (88%) for an effective dose near 80 ice-nuclei per litre, which might have reached slightly higher levels in some individual cells. An increase of 121% in precipitation mass together with an increase of 51% 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 (48%), area (44%), volume (51%), volume above 6 km (64%) and precipitation flux (53%) are notable. There are slight increases in maximum reflectivity (1%) and in top height (2%). The seeded subsample seemed 45% more efficient than the control sub-sample. Results are evaluated as excellent for this sub-sample.

An increase of 121% in precipitation mass for a control value of 1124.2 kton in 119 cases means:

Δ_1 = 119 x 1.21 x 1124.2 kton = 161,874 kton = 131,279 ac-ft

Large clouds that were seeded in Texas produced an additional **1,760,470 ac-ft** of water, and Type B clouds that were seeded in Texas produced an additional **463,850 ac-ft** of water as determined by the AISM analysis. The apparent total water produced by all seeded clouds in Texas was **2,355,599 ac-ft** in 2008 (Ruiz-Columbié 2008).

The AISM analysis results are comparable to results from research that has been conducted in the state of Texas in the past. Most notably of which was an evaluation of the Texas Cloud Seeding Programs for Seeding Effect during a 2002-2006 time period (Woodley and Rosenfeld 2007).

For many people, the increases in precipitation mass of over one million acre-feet is rather incomprehensible. Annually, a single person consumes 265 gallons (.008 acre-feet) of water. Household water uses on average is 50-100 tons which is equivalent to .445 and .885 acre-feet respectively. Additionally, water used to irrigate crops for making clothing and the food we eat is estimated at 1500-2000 tons or 13.27-17.70 acre-feet (Pearce 2007). Collectively, a single person uses on average 18.6 acre-feet each year. In the State of Texas, the cost of water ranges greatly from $300-$1,200 but for the purposes of this explanation we will use an average value of $750 per acre-foot. Using these values, the cost of water per person is $13,950 per year. The average state-wide budget for weather modification operations is $1.6million. AISM estimated the total increases in precipitation at 2,355,599 ac-ft in 2008 yielding a cost of one acre-foot of water at $1.47.

Table 5. *Seeded Sample versus Control Sample (119 couples, averages)*

Variable	Seeded Sample	Control Sample	Simple Ratio	Increases (%)
Lifetime	65 min	40 min	1.63	63 **(48)**
Area	88.0 km^2	57.8 km^2	1.52	52 **(44)**
Volume	253.2 km^3	157.0 km^3	1.61	61 **(51)**
Top Height	7.9 km	7.6 km	1.05	5 **(2)**
Max dBZ	50.7	49.3	1.03	3 **(1)**
Top Ht of max dBZ	4.3 km	4.3 km	1.00	0 **(0)**
Volume above 6 km	25.1 km^3	12.7 km^3	1.98	98 **(64)**
Precip Flux	695.6m^3/s	415.8 m^3/s	1.67	67 **(53)**
Precip Mass	3150.6 kton	1124.2 kton	2.80	180 **(121)**
Cloud Mass	223.5 kton	131.7 kton	1.70	70 **(51)**
η	14.6	9.0	1.62	62 **(45)**

5. SUMMARY

During the 2008 season, many clouds were seeded in the state of Texas. Six of the seven projects in the state saw a below-average number of flights as drought conditions affected a majority of Texas. Some locations in southwest Texas and the Panhandle did receive substantial rains for parts of 2008 but overall, drought was the story for the year. AISM's annual analysis concluded that even that the majority of seeded clouds were in the small category, all cloud seeded cloud categories yielded increases in precipitation mass, with almost 2.5 million acre-feet of water produced in the state's target and surrounding operational areas.

6. REFERENCES

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