Operations Summary

TEXARC
1996

A SUMMARY OF WEATHER-MODIFICATION OPERATIONS

in support of the

1996 **T**exas **E**xercise in **A**ugmenting **R**ainfall through **C**loud-Seeding (**TEXARC**) Research Project

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EXECUTIVE SUMMARY

In the spring of 1996, a group of eight counties organized the West Texas Weather Modification Association and used this entity as a mechanism for planning and funding an operational cloud-seeding program in a 7.2-million acre region of West Texas between Midland and San Angelo. The program was launched on May 25, 1996 and continued through September 1996.

To help the Association assess the efficacy of its 4-month cloud-seeding program, the Texas Water Development Board provided funds during a 6-week period in August-September 1996 for a research component to be added to the program, an effort known as the Texas Exercise in Augmenting Rainfall through Cloud-Seeding (TEXARC) Project. An instrumented aircraft, with various sampling capabilities, was deployed during an assortment of research missions to detect the presence of a tracer (SF_6 gas) and to measure various properties of clouds being seeded with hygroscopic material and similar clouds left unseeded. Funding from the Board for the field work was devoted solely to the collection of useful cloud-physics data, to be used in a subsequent analysis of the response of those clouds to seeding. This Operations Summary describes all aspects of the research missions conducted in August-September in the vicinity of San Angelo. Analysis and interpretation of the substantial body of data collected are dependent upon funding not yet identified.

TEXARC '96 was launched on August 5 and continued, uninterruptedly, until September 13, 1996, thereby providing a potential of 40 days for cloud-seeding flight operations. A total of 48 hours of flight time, and 95 hygroscopic flares, were expended by the researchers. The bulk (31.3 hours) of the flight hours and hygroscopic flares (69) were consumed in August, when rainfall throughout the 8-county target area exceeded the normal by a factor of 2 to 4. At least six dates (Aug. 15, 18, 19, 20 and Sep. 3 and 8) are believed to have yielded appreciable data with which to conduct "case studies" to gain new insight on the response of growing cumuli to seeding with hygroscopic material.

Though a scientifically-based recommendation must await a thorough and careful assessment of the cloud-physics data, it does appear from an initial inspection of the data that an operational program, like that of the WTWMA, has sufficient and sound justification for using hygroscopic seeding for rain enhancement under the right circumstances. The pending analysis should produce a "decision tree" to help those conducting operational seeding programs determine when, and under what atmospheric conditions, hygroscopic flares should be preferred over silver iodide seeding. In fact, the research work in 1996 hints at the efficacy of using, on some select occasions, both hygroscopic and glaciogenic (silver iodide) seeding on the same convective clouds.

1.0 BACKGROUND

The need for increased rainfall in semi-arid west Texas was never more obvious than the severe-to-extreme drought that afflicted all of the state through mid-summer of 1996. Not surprisingly, some areas initiated weather-modification programs, using the latest in cloud-seeding technology, to deal with the shortage of fresh water. As the drought worsened and spread, interest in using rain-enhancement technology, for both short-term relief from the drought and for long-term water management heightened substantially.

This growing need for adequate fresh-water supplies in arid and drought-stricken parts of Texas has focused renewed attention on alternative and innovative ways of conserving existing water resources and on procuring additional water by tapping into an abundant supply of moisture available in the Earth's atmosphere. Passage of the Texas Weather Modification Act by the Texas Legislature in 1967 was a tacit acknowledgment that the use of cloud-seeding technology had earned a measure of acceptance within the water-management community in Texas. At the same time, the law recognized that many uncertainties remained with respect to the effectiveness of various forms of cloud seeding. Hence, the need to regulate the level of human intervention in cloud processes to protect the interests of the public, and to promote the development of a viable and demonstrable technology of cloud seeding, was addressed by that legislative act.

To attain the objective mandated by the Texas Legislature to develop and refine cloud-seeding technologies, the State of Texas took a first step by linking up with the U. S. Bureau of Reclamation in 1973 to devise and demonstrate a viable cloud-seeding technology. Since then, an on-going, though often spasmodic, research effort has ensued to corroborate and quantify the effects of timely seeding of convective clouds. Despite limited funding over the years, substantial progress has been made in pursuit of this goal.

Even though operational cloud seeding has been performed in the South Plains region of Texas in virtually every growing season since the Colorado River Municipal Water District (CRMWD) first began rainfall-enhancement activities in the summer of 1971, cloud seeding experiments--the kind required to develop fully the technology and vouch for its efficacy and cost-effectiveness--have been performed sporadically only since 1986. Data collected during the late summers of 1994 and 1995, coupled with data collected during brief periods of experimentation carried out in the summers of 1987, 1989, and 1990, have been analyzed thoroughly. The results from these studies strongly suggest that cloud seeding can be used to enhance rainfall. A summary of this work is presented in the next section.

It is the success achieved to date with developing a viable cloud-seeding technology that prompted plans for additional experimentation in the vicinity of San Angelo, Texas during the late summer of 1996. The welcome infusion of funding from the Texas Water Development Board, along with some residual funds from NOAA's Atmospheric Modification Program (AMP), enabled a team of researchers to gather in San Angelo, Texas on August 5, 1996 to seed convective clouds and monitor the clouds' behavior, not only with ground-based, Doppler radar, but also with an airborne cloud-physics measuring platform.

The key component to the 1996 research involved an assessment of the effectiveness of cloud-base seeding with hygroscopic material. In addition, the research afforded the opportunity to determine whether the cloud-base seeding approach is effective in placing the seeding agent (either hygroscopic flares or silver iodide) into the desired sectors of the clouds being treated. The 1996 research is a continuation, and expansion, of the work launched in the summers of 1994 and 1995, referred to as the **Tex**as **Ex**ercise in **A**ugmenting **R**ainfall through **C**loud-Seeding (**TEXARC**) project.

2.0 A RECENT HISTORY OF CLOUD-SEEDING RESEARCH IN TEXAS

Texas' first step in scientifically investigating the value of cloud seeding technology for increasing water supplies was a cooperative effort with the U.S. Department of the Interior that was launched in 1973. The High Plains Cooperative Program (more popularly known as HIPLEX) was a part of "Project Skywater" that was designed to formulate an effective technology of rainfall enhancement to help supplement the Nation's fresh-water supply.

The Texas HIPLEX Program was designed as a long term multi-phase research effort to develop a technology to augment West Texas summer rainfall. Due to Federal funding cutbacks, Texas HIPLEX was limited to its initial phase (1975 through 1980), which included the collection, processing and analysis of meteorological data in order to better understand the typical summertime cloud systems of west Texas. The data collected during the six summer field programs included surface and upper-air observations, and cloud physics, radar, satellite and rain gage data.

Much of these data have been analyzed and insights into the physical processes responsible for convective rainfall in West Texas have been gained (see Riggio et al., 1983; and Matthews, 1983). These results indicate that most of the summer rainfall is produced by the larger, more efficient storms. More importantly, they indicate that a rain enhancement technology for West Texas ultimately must either address this type of storm or induce smaller, less efficient cloud systems to grow into their larger, more efficient counterparts. Jurica et al. (1983) were also led to the conclusion that multiple-cell convective systems offer more promise for significant rainfall enhancement than do isolated cumulus congestus.

The next link in the evolving progression of understanding the role of weather modification in enhancing rainfall was the Southwest Cooperative Program (SWCP) of Texas and Oklahoma. The SWCP was envisioned as a joint effort to develop a scientifically-sound, environmentally-sensitive, and socially-acceptable, applied weather modification technology for increasing water supplies in the semi-arid southern High Plains. The primary initial focus was the testing of dynamic seeding concepts and procedures for the enhancement of rainfall. The sponsors of the Texas SWCP effort were the Texas Water Commission, the U.S. Bureau of Reclamation, the Colorado River Municipal Water District (Big Spring), and the City of San Angelo, Texas. Experimentation was conducted from a base in San Angelo, Texas during 1986, 1987, and 1989 and from a base in Big Spring, Texas in 1990.

All experiments were carried out in accordance with the SWCP Design Document (Jurica and Woodley, 1985) and SWCP Operations Plans (Jurica et al., 1987) over an area centered on Big Spring, Texas. In every case, the experimental unit was the small multiple-cell convective system within a circle having a radius of 25 km and centered at the location of the convective cell, which qualified the unit for treatment. The selection criteria are discussed extensively by Rosenfeld and Woodley (1989). The treatment decisions were randomized on a unit-by-unit basis and all suitable convective cells within the unit received the same treatment -- silver iodide (AgI) in the case of a seed (S) decision or simulated AgI in the case of a no seed (NS) decision.

During the actual randomized experimentation during the summers of 1986, 1987, 1989, and 1990, suitable supercooled convective cloud towers within the convective cells received either simulated AgI treatment or actual AgI treatment near their tops (typical top heights of 5.5 to 6.5 km and top temperatures -8°C to -12°C). The seeding devices were droppable flares that produced 20 gm of AgI smoke during their 1 km free-fall through the upper portion of the cloud. Between 1 and 10 flares normally were ejected during a seeding pass, but more were ejected in a few instances in especially vigorous clouds. The flare ejection button was pressed approximately every second while the cloud liquid water reading was greater than 0.5 g/m^3. In the simulated seeding passes no flares were actually ejected when the button was pressed, but the event was still recorded in the aircraft data system. Some treatment passes were made over the top of the rising cloud tower after it had been verified by actual cloud passes that the cloud population was suitable for seeding.

In the SWCP design, therefore, the treatment units are the convective cells, which contain cloud towers that meet the liquid water and updraft requirements. It is the cell that receives the treatment, and any effect of seeding should manifest itself first on this scale before it is seen in the experimental unit that contains the cells. The results of the SWCP through 1987 have been published by Rosenfeld and Woodley (1989).

Subsequently, Rosenfeld and Woodley (1993) analyzed the convective cells that lived and died within the small mesoscale convective clusters (i.e. the experimental units) that were obtained during the course of the randomized experimentation. This analysis of the individual cells for seeding effects was limited to the 24 experimental units (12 S and 12 NS) obtained in 1987, 1989 and 1990, because individual control cells were not identified in the 10 experimental units obtained in SWCP 1986.

2.1 Results from Randomized Cloud Seeding (1987-1990)

A total of 183 cells (93 seeded and 90 non-seeded) were identified and their properties computed through analysis of three-dimensional, volume-scan, C-band radar data using cell tracking software. The results indicate that AgI seeding increased the maximum heights by 7%, the areas by 43%, the durations by 36%, and the rain volumes of the cells by 130%. Cell merger occurred nearly twice as often in the AgI-treated cases. The rainfall and merger results are significant at better than the 5% level using re-randomization procedures. Additionally, it was found that AgI-treated cells produced more rainfall than untreated cells of the same height.

Time-height reflectivity composite cross-sections for the S and NS cells revealed stronger reflectivities aloft immediately after seeding for the AgI-treated cells. This region of enhanced S reflectivities expanded and descended with time, reaching the earth's surface by 40 min after initial seeding.

The next step focused on the areas surrounding the treated cells. A new and improved "focused area" approach, involving calculations for radii of 7, 10, 15, 25, 50 and 100 km around each treatment position, was developed and applied. The rainfalls from the S cells exceeded the rainfalls from the NS cells at radii < 10 km early in the treatment period, and this apparent effect spread to larger radii with time. These results are consistent with a positive effect of AgI treatment on rainfall that begins on the cell scale, where the seeding takes place, and spreads outward with time.

Analysis of the 34 (17 S and 17 NS) small mesoscale convective clusters (i.e., the experimental units) obtained to date produced ratios of S to NS mean rainfalls of 1.37, 1.27, 1.37, 1.26, and 1.27 for the time periods 0-30, 0-60, 0-90, 0-120, and 0-150 min, respectively, after initial seeding. None of the results has strong P-value support due to the small sample size. The ratios are larger and more significant, when the five experimental units that failed to meet the qualification criteria are eliminated from the sample.

The value of these results lies not only in the apparent rainfall increases, but in the insights that they have provided, which are now manifest in the revised dynamic-seeding conceptual model that is discussed by Rosenfeld and Woodley (1993). Not only have these results provided new understanding of the physical processes that are likely operative in west Texas clouds, they have provided the basis for continued experimentation.

Until 1993, funding had not permitted intensive investigation of the microphysics of west Texas clouds. All results, reported by Rosenfeld and Woodley (1993), had been made using a C-band volume-scan radar and a minimally-instrumented seeder aircraft; no other state-of-the-art instrumentation had been available to the effort due to a lack of funding. With the entry of the State of Texas into the NOAA Federal/State Cooperative Program in Atmospheric Modification Research, however, an additional, substantial, and much-needed source of funding materialized. As a consequence, in the summers of 1994 and 1995, the State of Texas took its first steps in implementing the research program recommended both by Rosenfeld and Woodley (1993) and in a multi-year proposal submitted to the Atmospheric Modification Program (AMP) of NOAA. This new research was done under the acronym of TEXARC.

2.2 Conclusions from Intensive Cloud-Physics Investigations (1994-1995)

Weather modification research advanced to the next level of investigation with the TEXARC programs conducted in the late summers of 1994 and 1995. With the use of an instrumented cloud-physics aircraft, it became possible to document the physical processes that are operative within vigorous supercooled convective towers before, during, and after treatment with silver iodide. While the effort, begun in 1986, of conducting randomized seeding operations on convective clouds and complexes continued, the thrust of research began moving away from a mere assessment of **how much** additional rain volume was being yielded from seeded clouds to an understanding of **how** these rain increases were taking place. The radar-determination, and comparison, of various cloud properties, including rain volume, reflectivity, cloud-top height, cloud area, and cloud duration, of both seeded and unseeded clouds had given added credence to the viability of the conceptual model (Rosenfeld and Woodley, 1993). Further research, involving internal cloud-microphysical measurements, was now needed to investigate additional links in the conceptual chain.

From the analysis of the 1994 and 1995 data sets it was learned that the internal cloud structure is apparently strongly dependent on the cloud-base temperature (CBT). When the cloud bases are high and the CBT is cool, very few rain drops are found at temperatures ranging between -5°C and -10°C and glaciation proceeds rather slowly. When the cloud base is low and cloud-base temperature is warm, the west Texas clouds are more tropical in character with the presence of rain drops at temperatures of -5°C and -10°C. Glaciation appears to proceed rapidly in such clouds via drop freezing and accretion, leading to large graupel particles that continue to accrete the cloud water.

Furthermore, cloud debris found at temperatures of about -5°C often contained high concentrations of ice crystals. These crystals were likely formed in clouds that glaciated at colder temperatures and then subsided to warmer temperatures near the base of a temperature inversion. This glaciated cloud debris provides a mechanism for the natural seeding of cloud towers that grow through it.

It was also found that on-top seeding of supercooled cloud towers in "continental" clouds did not produce appreciable growth but the cloud did harden briefly in appearance. Seeding did appear to produce more ice particles in agreement with the earlier results of Sax et al. (1979), but they were usually not of precipitation size. As glaciation proceeded, the reflectivity of the cloud increased briefly relative to the clouds in its environment but then the cloud usually died. On the other hand, on-top seeding of clouds with warm cloud bases (i.e., CBT $\geq$ 15°C) appeared to result in rapid glaciation, the formation of large graupel particles and strong cloud growth. This is consistent in what has been observed elsewhere in such clouds.

The TEXARC 1995 cloud microphysical results appear to depend on whether the cloud contained supercooled rain. In clouds without supercooled rain it was observed that graupel grows at a rate that is too slow to convert cloud water into precipitable size particles (i.e. > 500 microns diameter) during the lifetime of the updraft except for the most vigorous and vertically developed clouds. This slow glaciation also does not produce a significant dynamic response in the clouds, rather the cloud normally glaciates during its collapse, accelerating its dissipation and leaving holes in the cloud field.

In clouds with supercooled rain, seeding leads to rapid freezing of the supercooled rain and its continued growth as graupel. This graupel appears to grow faster than supercooled rain drops under the same condition in accordance with theoretical calculations (Sednev, et al., 1996). The seeding also increases cloud buoyancy and further invigorates the updraft, while the cloud is still in a position to use it to support the growth of large precipitation particles and, in some cases, greater vertical growth of the cloud.

A major result of the 1995 investigations was the finding that there is no major difference in mean ice particle concentrations between seeded and non-seeded clouds as a function of time relative to first seeding. Only after partitioning by cloud draft were differences noted. In clouds seeded with silver iodide there was a greater concentration of ice particles in the updraft regions than in clouds that did not receive treatment. This coupling between ice concentrations and updrafts in seeded clouds is consistent with the expectations of the dynamic seeding conceptual mode.

These TEXARC results emphasize the importance of when and where the various cloud microphysical processes take place within the cloud and when and where the seeding takes place that is intended to alter these processes. Both the Rosenfeld/Woodley conceptual model and these new results suggest that, when seeding for rain enhancement, it is crucial to produce glaciation artificially within the vigorous supercooled updraft region of the cloud. It is in this region that large artificially-nucleated precipitation-sized particles can be grown most efficiently because they have a greater cross-sectional area for accretion of cloud water than water drops of the same mass. In addition, graupel particles also have a lesser density than water drops and fall slower (Johnson, 1987), giving them a longer residence time in the cloud for the sweepout of cloud water.

Producing glaciation in the updraft region of the cloud requires great care in the placement of the nucleant either in the updraft directly near cloud top or in the strong inflow region at cloud base in well-developed convective systems. It is important that this be kept in mind by anyone conducting seeding operations for rain enhancement.

2.3 Updated Results for the Cells and Experimental Units through 1994

Four new experimental units (one seeded case and three non-seeded cases) were obtained during TEXARC 1994 and the results were analyzed and combined with those published previously for Texas (see Rosenfeld and Woodley, 1993). A total of 38 experimental units (18 Seed and 20 No-Seed) have been obtained in west Texas since experimentation began. In addition, 213 cells (99 Seed and 114 No-Seed) have been subjected to analysis (209 for the "short track" analysis). The results were provided for both approaches for all of the data and for cells on days on which the cloud-base temperature (CBT) $\geq$ 15°C.

The examination first of the overall short track and long track rainfall results suggests that the S cells produced more rainfall than the NS cells by virtue of covering more area and having greater durations (long track only) and larger rain volume rates. The results for rain volume and merger are significant at the 5% level for both approaches. The area and duration results are also significant in the long-track analysis. The ratios of the mean S to NS rainfalls for the short- and long-track analyses are 1.69

and 2.63, respectively. The apparent rain increases took place without an appreciable increase in the mean echo heights of the cells.

This also was the case in Thailand (Rosenfeld and Woodley, 1994). A possible explanation of these results is the magnitude of the seeding-induced buoyancy in relation to the hypothesized increased water mass, mostly graupel, that must be supported in the updraft following seeding. If the buoyancy increase is fast and large as would be the case in glaciating rain drops (Lamb et al, 1981), the buoyancy might well be large enough to support the increased precipitation load and still fuel extra cloud growth. If the seeding-induced increased buoyancy is slower and smaller, however, all of the buoyancy might be used in overcoming the hypothesized increased precipitation loading.

The next step in the analysis by Woodley and Rosenfeld (1996) was to examine only those cases having warm cloud bases, when coalescence would be more active and rain drops would be present in vigorous updrafts above the freezing level. This was done for the short and long-tracked cells, respectively, for those cases when the cloud-base temperature (CBT) was ≥ 15°C. It was noted immediately that the apparent effects of seeding are larger within this partition, especially for echo heights where a sizable effect up to +29% (for the long-track analysis) is now indicated. This result is consistent with the conceptual model. The ratios of mean S to NS rainfalls are 2.37 to 3.46 for the short- and long-track analyses, respectively.

Further insights into the apparent effect of seeding was obtained by examining the mean seed and no seed rainfalls within 1-km height intervals as obtained from the long-track analysis. It was found that the mean seed rainfall exceeds the mean no seed rainfall over the entire range of echo heights. This is compatible with the notion that seeded clouds of a given height contain more precipitation mass than non-seeded clouds. This can only happen if cloud buoyancy is enhanced for the support of this increased loading.

The rainfall results for the 38 experimental units (18 seed and 20 no seed) obtained in the Texas experimentation to date are also provided by Woodley and Rosenfeld (1996) for the mean rainfall by 30-min interval and for the cumulative rainfall in 30-minute intervals to 150 minutes after initial seeding. For the rainfall by interval, the mean seed rainfall exceeds the mean no seed rainfall in all but the 90-120 minute interval. When the wettest case in each sample is deleted as a sensitivity test, the S to NS ratios by interval increase to 1.71, 1.71, 3.26, 1.16 and 1.20 for the periods 0-30, 30-60, 60-90, 90-120 and 120-150, respectively.

The mean cumulative rainfall, by interval, suggests a seeding effect on the order of 45 percent (i.e. S/NS = 1.45) by the end of the analysis period (i.e., 2.5 hours after initial seeding). When the wettest case in each sample is deleted, the apparent effect by the end of the period is +77%. This suggests some sensitivity to outlier values, in this instance favoring the no seed sample.

3.0 THE DESIGN OF TEXARC 1996

In view of the highly positive results for the individual cells and for the experimental units, the emphasis in the research has now shifted to include, not only intensive cloud-physics investigations that will help shed light on why and how cloud seeding with silver iodide works in west Texas to increase rainfall, but the use of hygroscopic seeding material as a viable seeding agent for those clouds that do not appear to be responsive to seeding with an ice nucleant.

The TEXARC cloud microphysical studies suggest that some convective clouds in west Texas are not amenable to seeding with glaciogenic material such as the often-used silver iodide. Some convective clouds are so highly continental in nature that their cloud droplets are too numerous and too small for rain to form within them. Unless the clouds are especially vigorous and organized, silver iodide seeding of continental clouds with high bases and cool base temperatures does not appear to develop precipitation-sized particles before the clouds dissipate. Moreover, some clouds do not even grow tall (and thus "cold") enough to become supercooled below 0C, where silver iodide can become effective. Thus, some other approach is needed for such clouds.

This approach must be effective in producing larger liquid drops in the cloud that can grow large enough during its lifetime to reach the ground as rain. This approach, known as hygroscopic seeding, is really nothing new. It has been attempted for many years with varying degrees of success. What is new is the seeding agent, which is dispensed below cloud base from flares in racks affixed to the wings of an aircraft. The tiny particles produced by the flare are activated preferentially over the many, even smaller, natural cloud condensation nuclei (CCN) as they enter the base of the cloud. Condensation on these new larger nuclei produces cloud drops that have a "head start" on the natural cloud-drop population such that they grow to rain-drop size within the cloud under conditions that would not have produced rain drops naturally.

When this process is working properly, some of the tiniest, natural CCN are never even activated at all. The larger artificial nuclei monopolize the cloud water, so they grow to rain-drop sizes. The cloud is made more efficient by the seeding in that more of the water vapor ingested by the cloud ultimately reaches the ground as rain.

Testing of this new hygroscopic seeding flare has been carried out in South Africa. The results so far have been quite promising, with rain apparently being produced in clouds that had no chance of producing rain naturally. It was decided, therefore, that the time had come to test hygroscopic flare seeding in west Texas clouds that apparently are not responsive to silver iodide seeding. These initial investigations were completed successfully during TEXARC 1996 thanks to the support of the Texas Water Development Board and NOAA. This document is an operational summary of that field effort.

4.0 OVERVIEW OF TEXARC 1996

4.1 Overall Goal and Objectives

The overall goal of the TEXARC Project has been to lay the scientific foundation for cloud seeding as a viable and cost-effective technology for enhancing rainfall in arid, semi-arid, and drought-stricken areas of Texas. The objectives addressed in TEXARC 1996 in the context of this overall goal were:

a) Document the physical processes that are operative within suitable convective clouds before, during and after treatment with hygroscopic material, using a research aircraft to make the internal cloud measurements of drop size and radar for the estimation of rainfall and other cell properties.

b) Document the dispersion of minute quantities of inert sulfur hexafluoride (SF_6) tracer gas concomitant with the release of the hygroscopic seeding agent in order to determine whether the hygroscopic nuclei reach the targeted core region of the convective cloud.

4.2 Resources

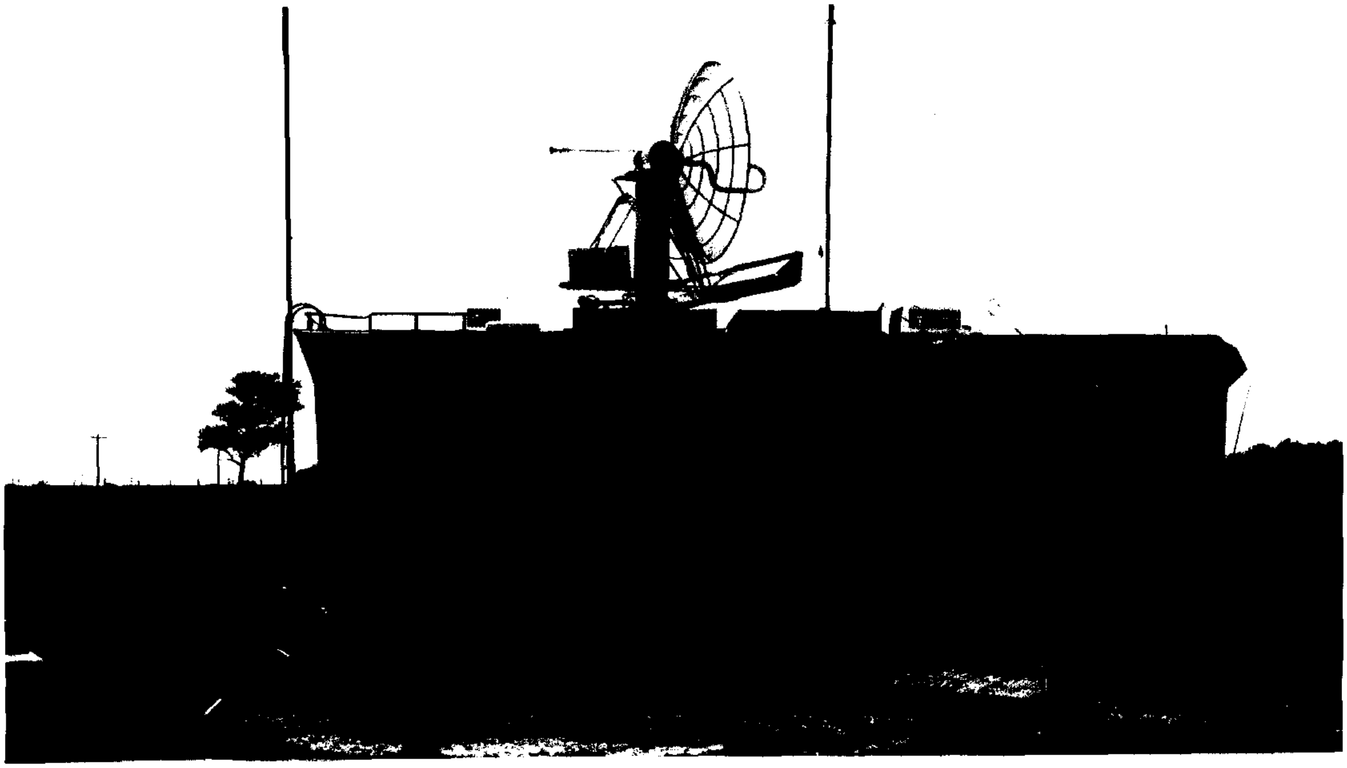
In addition to highly skilled pilots, meteorologists and technicians, the project resources included pressurized, twin-engine Beech Duke for cloud physics measurements and a Piper Seneca for seeding at cloud base (Figure 1). The Seneca had wing-mounted racks for hygroscopic flares provided either by Cloud Quest in South Africa or by Atmospherics, Inc. in Fresno, California (Figure 2). It also carried tanks of SF_6 tracer gas for release during the burning of the hygroscopic flares (Figure 2).

Shown in Figure 3 (top) is the Project Control van that housed the C-band weather radar and the computers for documenting echo development, for tracking the project aircraft and for access to the Internet for real time weather data. All software needed to accomplish the project tasks was also provided. The internal space in the van provided a nice work area for personnel to accomplish their project tasks (bottom of Figure 3).

The Beech Duke was equipped with temperature and cloud water probes throughout the program (Figure 4, top). It also had a dew

Fig. 1. The Beech Duke (top) and Piper Seneca (bottom) aircraft used in TEXARC 1996.

Fig. 2. The Seneca aircraft with wing-mounted racks of hygroscopic flares, produced either by Cloud Quest of South Africa (top) or Atmospherics Inc. of Fresno CA (bottom). Tanks of SF_6 gas are shown in the bottom photograph.



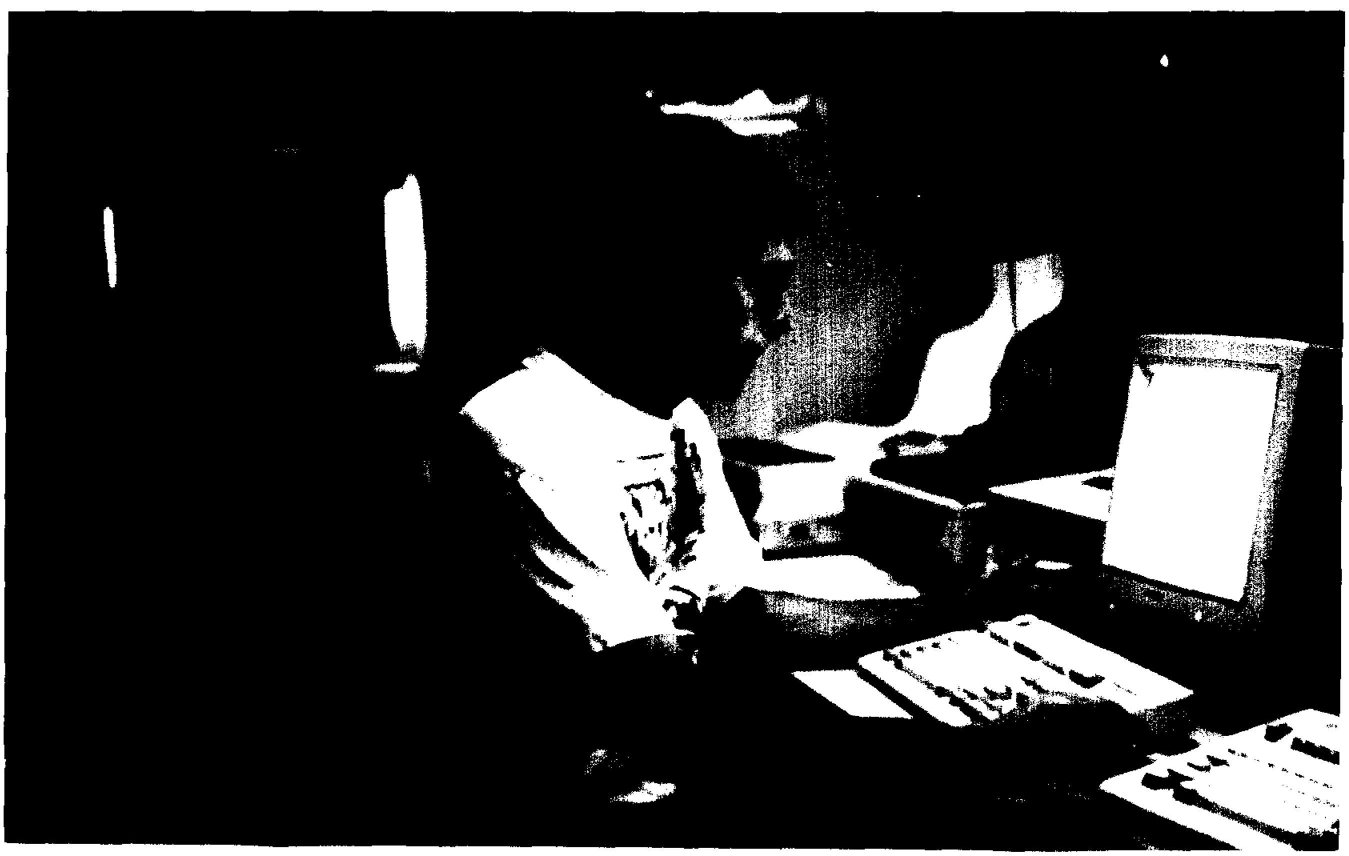


Fig. 3. The project radar control van with C-band radar affixed to its roof (top). The interior of the van provided a work area for project personnel (bottom).

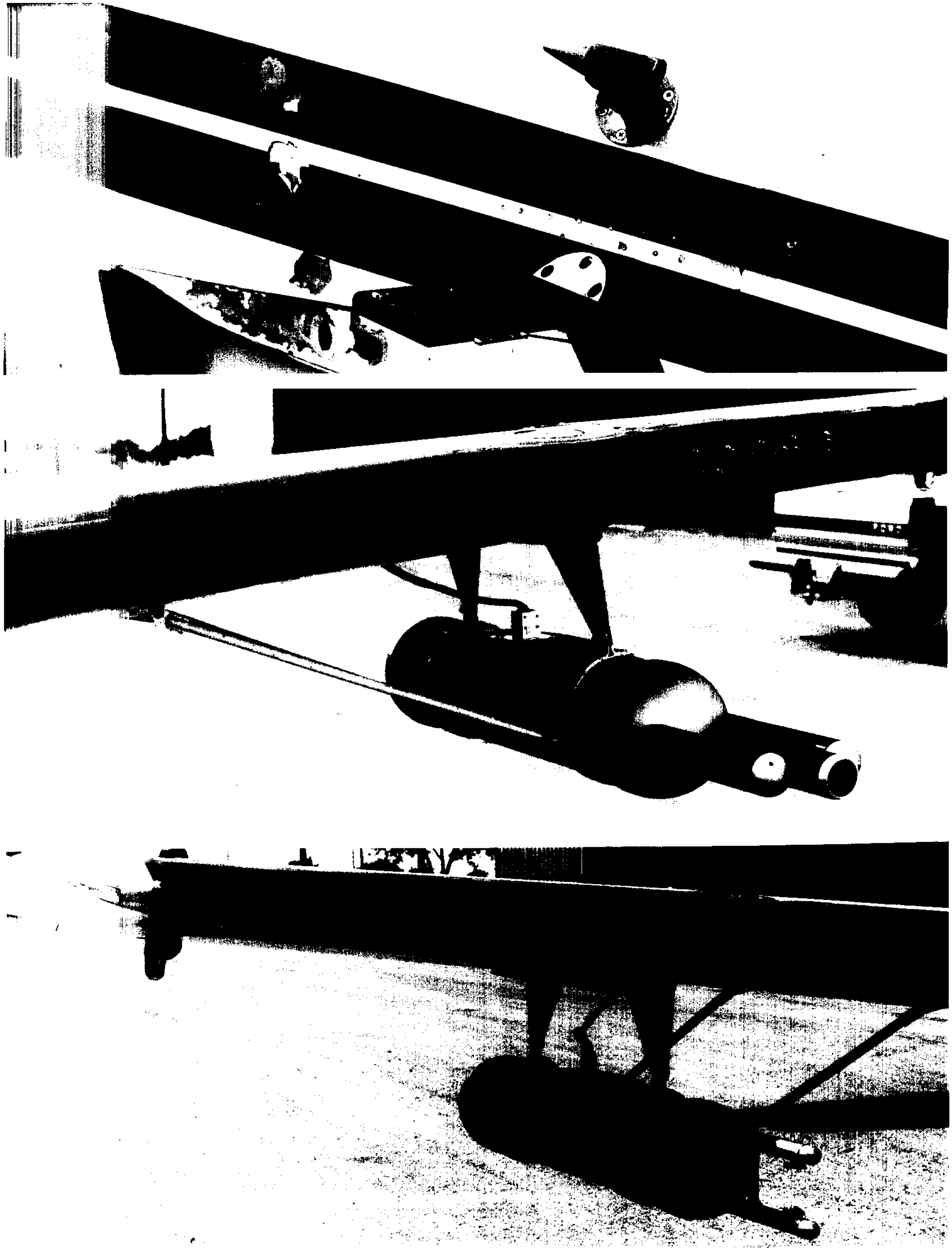


Fig. 4. Rosemount temperature and cloud-water probes mounted on the right front nose of the Duke (top). The PMS, FSSP, and 2D-C PMS probes, mounted under each wing of the Duke, are shown in the center and bottom photographs, respectively.

point instrument. During the research effort it had PMS FSSP and 2D-C cloud probes on pylons under each wing (Figure 4, center and bottom, respectively).

In addition to the work space in the van, ample office space was obtained in the old National Weather Service offices shown in Figure 5. Note the tower and dome for the old WSR-74 S-band radar in the background. It was operative throughout the program as a backup to the newly commissioned WSR-88D NEXRAD radar that was located on Mathis Field near the new NWS offices about 1 n.mi. north of their old quarters. Some of the internal work space in the old NWS offices is shown in the bottom photograph of Figure 5.

The radars to be used for quantitative measurements and evaluation will be the new WSR-88D NEXRAD radars operated in a continuous volume-scan mode by the National Weather Service offices in Midland and San Angelo, Texas. The San Angelo NWS office and the tower and radome for its radar are shown in the top and bottom photographs of Figure 6, respectively. The work console for the radar is shown in the third photograph.

4.3 Personnel

TEXARC 1996 personnel included Dr. William L. Woodley, Chief Scientist, Dr. Daniel Rosenfeld, co-Principal Investigator, and Mr. George Bomar, Project Director. Other key personnel included radar meteorologist Dr. Tony Grainger, the electronics technician/computer specialist Kelly Bosch (on right in top of Figure 6) and the pilots of the research aircraft, Mike Douglas for the Beech Duke for cloud physics measurements (bottom of Figure 7) and Tom Promersberger for the Piper Seneca (on left in top of Figure 7) that was operated at cloud base for seeding and for the release of SF_6 gas. Mr. Yaron Segal (bottom of Figure 7), who arrived in San Angelo on August 21st, replaced Dr. Rosenfeld, who left the project to return to Israel on August 26, 1996. Mr. Segal worked with TEXARC 1996 until September 11, 1996. After the official end of TEXARC 1996 on Saturday, September 14, 1996, Dr. Woodley served as the project meteorologist/radar controller and occasional flight scientist with the operational seeding effort through September 24, 1996.

5.0 EXPERIMENTAL PROCEDURES DURING TEXARC 1996

On days identified as suitable for cloud-base hygroscopic flare seeding the cloud base (Seneca) and cloud physics aircraft (Beech Duke) took off in a search for suitable clouds. On some occasions the Duke flew first to identify an area of suitable clouds. The Seneca, carrying 24 hygroscopic flares and tanks of SF_6 tracer gas, was then scrambled to join with the Duke and the meteorologist on the Duke identified specific cloud targets, noting the GPS position of the prospective base seeding. At this point the meteorologist on the Seneca looked for hard dark cloud bases with

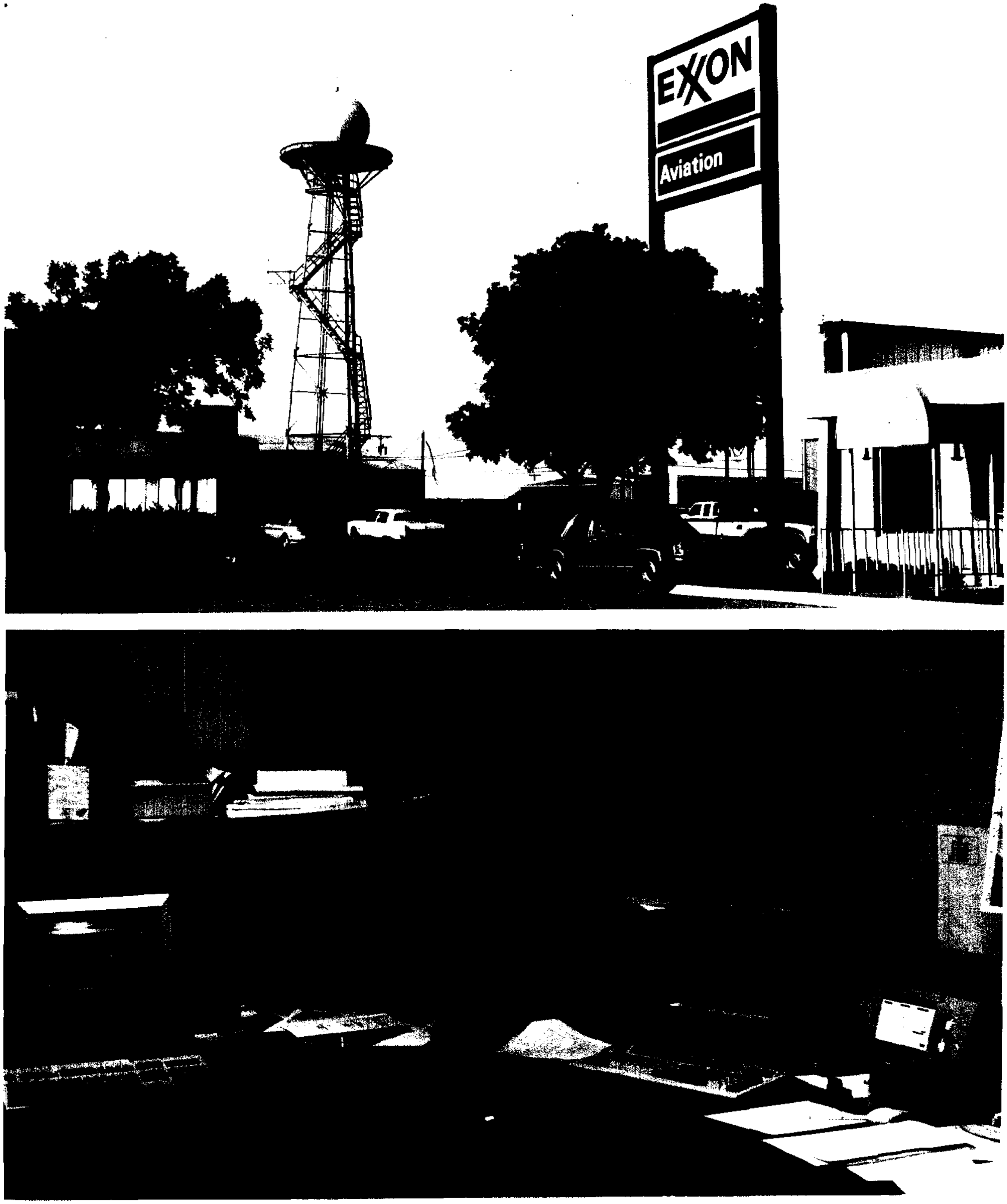


Fig. 5. Vacated office of the National Weather Service, used as TEXARC '96 project headquarters. The tower and radome are parts of the WSR-74 S-band radar formally used by the NWS. Some of the internal office space at the headquarters is also shown (bottom).

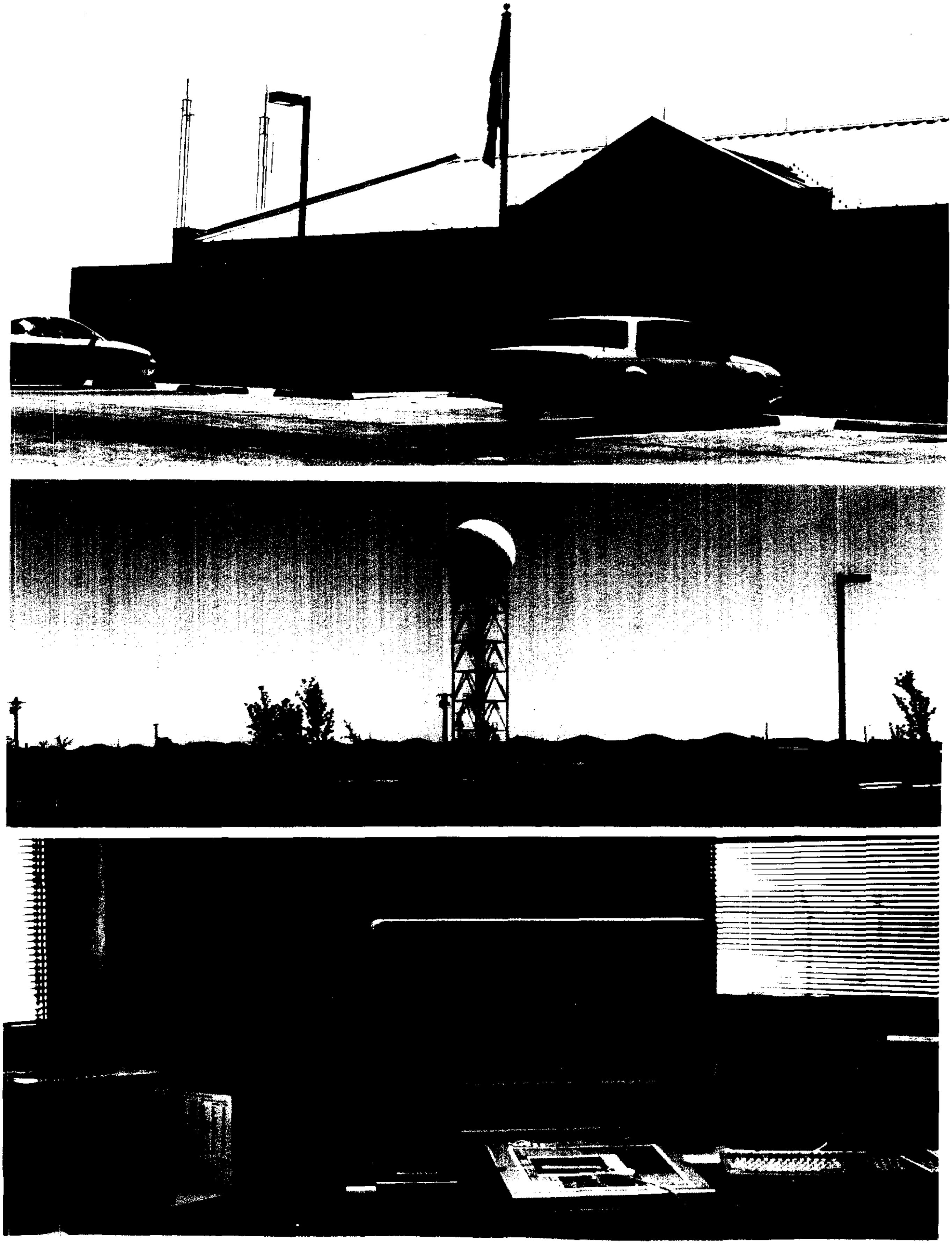


Fig. 6. New office of the National Weather Service in San Angelo (top). The tower and radome of the new WSR-88D Doppler radar are nearby (center). The work console of the radar is also shown (bottom).

Fig. 7. Some of the personnel participating in TEXARC '96: Kelly Bosch, electronics technician/computer specialist/aircraft mechanic (right, top) and Tom Promersberger, pilot (left, top); Mike Douglas, pilot of the Duke (left, bottom); and, Yaron Segal, visiting aircraft scientist from the Hebrew University, Jerusalem, Israel (right, bottom).

updrafts of at least 500 ft/min. When this was done, an experimental unit was declared. The treatment decision was not randomized.

When seeding was done, two hygroscopic flares, one on each wing, were ignited as the aircraft flew in a tight orbit in the updraft. Simultaneous with the seeding was the release of SF_6 gas to be used as a tracer for the hygroscopic material. The calibrated release rate ranged between 1/3 and 2/3 liters per sec. As long as the updraft at cloud base persisted, the treatment continued up to a maximum of 48 minutes since each flare burned an average of 4 minutes and a maximum of 12 pairs of flares were burned per unit. If the updraft at the initial center point waned, the seeding continued at the base of a new tower immediately upshear of the first. The new treatment position was provided to the meteorologist on the cloud physics aircraft.

The Duke cloud physics aircraft monitored the tower being seeded using cloud traverses either within 1 km of cloud base or at levels between the 0°C and -5°C isotherms. The performance of the Beech Duke aircraft did not permit it to sample at both cloud base and near cloud top. The focus was on the detection of the SF_6 gas. When a SF_6 spike was noted, its position was entered into the GPS navigation system and the aircraft was flown relative to that position. It is expected that the treated volume at cloud base would contain cloud-droplet spectra that had been altered by seeding. The expectation for observations made in the supercooled portion of the cloud was for more and larger rain drops than the cloud volume that does not contain the hygroscopic material.

The intent of the initial studies, therefore, was to look for seeding signatures in both the cloud microphysical data and in the simultaneous volume-scan radar observations of the clouds. Because hygroscopic seeding is thought to produce large rain drops where none would have occurred naturally, it is reasonable to expect that a significant radar reflectivity signature would accompany the anticipated cloud microphysical signature.

6.0 THE OUTCOME

6.1 The Weather of TEXARC 1996

The weather of TEXARC 1996 was different from that of TEXARC 1994 and 1995. August 1994 and Augsut 1995 were generally dry with high cool cumulus bases and little in-cloud coalescence under the influence of upper-level high pressure and subsidence. In August 1996, however, the upper high pressure and subsidence backed off farther to the west, allowing weak upper-level disturbances to enter the project area from the northwest. These disturbances served as triggers for the convection such that only a few days were without clouds suitable for glaciogenic seeding. Early in the month it was hot and relatively dry but unstable due to cool temperatures aloft. By the third week of August, however, tropical moisture was working its way into west Texas from the southeast. The initial moisture burst occurred at the time that hurricane "Dolly" entered the Mexican east coast south of Tampico. Although the moisture entering west Texas initially was not directly in the circulation of Dolly, it was associated with the moisture surge from the east accompanying Dolly that extended from the western Caribbean northward into the central and eastern Gulf of Mexico.

With the entry of the tropical moisture into Texas the rains increased even though the atmospheric stability increased. Most of the rain was highly tropical in nature with active coalescence, maximum reflectivities low in the clouds and heavy showers. The shower activity was especially heavy in west Texas between August 25th and August 30th and in the San Angelo area late on August 28th until early afternoon on August 29th. Five to eight inches fell in this area in less than 18 hours, producing minor flooding, especially to the south of San Angelo near Christoval, which prompted the National Weather Service to issues a series of flood statements and warnings. Overall, this period of tropical rainfall was highly beneficial, increasing the lake levels and greening everything, seemingly overnight.

The tropical moisture continued in the project area on the last day of August and the first day of September, but there was very little attendant shower activity. These few days of unsuitable weather coupled with the preceding days of heavy rain allowed most project personnel to take some time off for well-deserved rest and relaxation. On September 2nd showers formed early in Glasscock and Sterling counties but then dissipated. Stronger storms formed W and SW of Midland putting out a large canopy over the entire target. On September 3rd shower activity to the E of San Angelo gradually developed to the immediate SE of San Angelo and into Schleicher and Sutton counties in the evening producing a dazzling lightning display that could be seen from the airport. Showers formed early on September 4th and tracked W in small clusters through the target. The most concentrated activity was in south-central Crockett county.

The most intense and extensive shower activity on September 5th was in Schleicher and southern Irion counties in association with operational seeding activity. There were a few other showers scattered about the operational target but none of them were suitable for research operations. The shower activity decreased further on September 6th as upper ridging and subsidence moved into the area. A cold front was moving through Colorado toward the Texas Panhandle late in the day.

The front from the N had little effect on the local shower activity as it dissipated on its trek through the area. The shower activity was isolated to widely scattered on September 7th, 8th and 9th except in the old frontal boundary which had become stationary to the S of the operational area. A second frontal boundary passed into the operational area on September 10th, enhancing the shower activity in a NW-SE band through the center of the target. The cooling and drying with the passage of this boundary resulted in no shower activity in the target area on September 11th, although showers were noted to the distant S-W in the region where the frontal boundary encountered the flow of tropical moisture from northern Mexico.

By September 12th the tropical moisture was affecting the research area with thick middle and upper cloudiness and patches of light to moderate rain. This activity was associated with a weak upper disturbance that was moving from Mexico and extreme west Texas toward the operational area. Meanwhile Hurricane "Fausto", a category 3 hurricane with sustained winds up to 120 mph and a central pressure of 955 mb was tracking to the N toward the tip of Baja California. September 13th had low ceilings and light rain showers associated with the upper disturbance tracking NE through north Texas. It was quite cool with the temperature < 70°F most of the day.

At one point there was talk of extending the research effort even further through Monday, September 16th. Had this been done, this is the weather the research effort would have had:

September 14th began with thick fog as the remnants of Hurricane Fausto were tracking toward west Texas from northern Mexico. Two surges of showers passed through the operational area during the day. The first passed to the N of San Angelo during the afternoon and affected the target counties N of a WSW-ENE line through San Angelo. The second surge was more organized and passed through the entire operational area during the nighttime hours. The weather cleared and dried on Sunday, September 15th. The weather was clear warm and dry on September 16th. As can be seen, nothing would have been gained by extending TEXARC an additional three days.

A day-by-day synopsis of the weather through September 15, 1996 is provided in Table 1.

San Angelo had a mean August temperature of 81.3°F, which is 0.6°F below normal. The highest temperature was 104°F on August 3rd and the lowest was 65°F on August 13th. The precipitation total for the month was 7.66 in, which is 5.73 in. above the monthly average. Eleven (11) days had at least 0.01 in. of rain. The largest 24h total was 4.66 in. spanning August 28th and 29th. This event is discussed extensively in Appendix A. Thunder was heard on 9 days during the month. The peak wind was 36 mph on August 6th.

The month of September was substantially drier than August, and temperatures significantly below normal. San Angelo's rainfall sum of 1.92 in. was a mere 56 percent of normal, with most of that

TABLE 1

SUMMARY OF WEATHER CONDITIONS DURING TEXARC 1996
AUGUST 5 - SEPTEMBER 15, 1996

DATE	Temp.(°c) Min./Max.	Precip.(mm) 07- 07 LT	Weather Information
8/5	100/76	0.15	Hot conditions, TRW+ near SJT
8/6	99/72	T	Hot with isolated shwrs to S & SW
8/7	98/72	0.00	Isltd shwrs dist S-SW late in day
8/8	91/70	T	Wdly scattered showers
8/9	89/70	0.08	Sctrd heavy showers
8/10	96/70	0.01	Seeding & hvy shwrs in Sterling Co.
8/11	92/68	0.88	Seeding & hvy shwrs in Irion Co.
8/12	94/67	0.00	Suppressed cloud conditions
8/13	93/65	0.00	Hazy suppressed cloud conditions
8/14	97/66	0.00	Suppressed cloud conditions
8/15	95/70	0.00	Isltd shwrs, good hygro S case
8/16	94/73	T	Wdly scat shwrs, mainly to S of SJT
8/17	94/71	T	Wdly scat shwrs to W and NW of SJT
8/18	96/76	T	Few shwrs decreasing late in day
8/19	96/74	T	Wdly scat shwrs in early evening
8/20	94/67	0.00	Shallow clds, isltd shwrs
8/21	93/67	0.00	Isltd shwrs
8/22	90/67	0.00	Supprssd & wndy, shwrs app. from SE
8/23	82/69	0.80	Rain & shwrs, influx of trop mstr
8/24	80/68	0.70	Rain & shwrs, low ceilings
8/25	80/70	0.29	Rain in a.m., trop moisture
8/26	85/67	0.01	Wdly scat shwrs, trop moisture
8/27	88/71	T	Trop moisture, low ceilings
8/28	88/71	2.61	Trop moisture, hvy shwrs by night
8/29	78/69	2.06	Hvy shwrs in a.m., trop moisture
8/30	80/70	0.07	Trop mstr, shallow clds and shwrs
8/31	84/67	0.00	Low ceilings in a.m., isltd shwrs
9/01	82/65	0.00	Low ceilings in a.m., shwrs to SE
9/02	90/66	0.00	Few shwrs in target, dssptd early
9/03	90/68	T	TRW SE-S of SJT in evening
9/04	85/69	0.00	Erly shwr actvty & then anvil cover
9/05	82/65	T	Hvy shwrs in Schleicher & Irion Co.
9/06	85/64	T	Isltd light shwrs
9/07	88/66	0.00	No shwr activity
9/08	89/67	0.00	Isltd shwrs in target, more to E
9/09	89/64	0.00	Few shwrs in extreme S of target
9/10	88/64	0.00	NW-SE line of shwrs in target
9/11	87/59	0.00	Dry & suppressed, no clds
9/12	84/66	0.15	Thick middle & upper cld, RW-
9/13	74/64	0.07	Cool, low ceilings, RW-
9/14	83/65	1.54	Thick a.m. fog, TRW+ at night
9/15	85/66	T	Mostly clear & dry, breezy

6.2 Aircraft and Radar Operations

There were 40 days of potential flight operations for TEXARC 1996 between August 5 and September 13, 1996. A listing of all flights in this period, including those conducted for operations is provided in Table 2. Included also are the flight personnel on the aircraft. A more detailed flight breakout for the TEXARC research effort is provided in Table 3. There were 17 flights on 10 days in August 1996 as summarized in Table 2. During this month there were 9 flights of the Seneca for TEXARC 1996; 4 of the 9 were for hygroscopic flare seeding and the balance of 5 flights were used to test the hygroscopic flares and/or to test the SF_6 detector. There were 7 flights of the Duke in August for TEXARC 1996, 4 for cloud physics measurements and 3 flights in association with tests of the hygroscopic flares and/or the SF_6 detector. On 3 of the 4 flights for cloud physics measurements, the observations were made in clouds with and without cloud-base hygroscopic flare seeding. On one occasion the Cessna 340 was used for photography in support of TEXARC 1996. The flight hours expended by the Seneca, Duke and Cessna 340 for TEXARC during August 1996, calculated from engine start to engine stop, were 15:46, 14:08 and 1:26, respectively. The number of hygroscopic flares charged to TEXARC 1996 in August 1996 were 69 out of an allotment of 150 flares.

In September 1996 there were 4 flights of the Seneca for TEXARC 1996; 3 of the 4 were for hygroscopic flare seeding and the balance of 1 flight was used to test the hygroscopic flares and/or to test the SF_6 detector. There were 4 flights of the Duke in September for TEXARC 1996, 3 for cloud physics measurements and 1 flight in conjunction with tests of the hygroscopic flares and/or the SF_6 detector. On 2 of the 3 flights for cloud physics measurements, the observations were made in clouds with and without cloud-base hygroscopic flare seeding. The flight hours expended by the Seneca, Duke and Cessna 340 for TEXARC during September 1996, calculated from engine start to engine step, were 7:11, 9:40 and 0, respectively. The number of hygroscopic flares charged to TEXARC 1996 in September was 26.

The TEXARC 1996 totals for flight hours for the Seneca, Duke and Cessna 340 were 22:57, 23:48, and 1:26, respectively, for a total of 48 hours 11 minutes out of an initial allotment of 48 hours. A complete breakout of all WMI Texas flight hours in 1996 is provided in Table 4. The number of hygroscopic flares expended in TEXARC 1996 was 95 out of an allotment of 150. In addition, 14 hygroscopic flares produced by Atmospherics, Inc. were burned for test purposes.

Table 2

SUMMARY OF ALL FLIGHTS DURING TEXARC 1996
(Including those for operations)

(Flight Personnel Identified in Parentheses)

DATE	FLIGHTS						COMMENTS
	Piper Seneca		Beech Duke		Cessna 340		
	Y	N	Y	N	Y	N	
8/5		X	X(MD)		X(MR)		C340 for Ops S, BD for checkout
8/6	X(TP)			X	X(MR)		No suit. clds, PS arrives in SJT
8/7		X		X	X(MR)		Ngt flt, could not see clds
8/8		X	X(MD)		X(MR)		Both acft flew twice, BD damaged on 2nd flt
8/9	X(TP,MD,WW)			X	X(MR)		C340 and PS flew for Ops, hygro. S from PS
8/10		X		X	X(MR,W)		Ops S, 86 fl, TRW+
8/11	X(TP,MD)			X	X(MR,WW)		Ops S at top and base AgI and Hygro, TRW+
8/12		X		X		X	No suitable clds
8/13		X		X		X	Hazy & suppressed
8/14		X		X		X	Hazy & suppressed
8/15	X(TP,WW)			X	X(MR)		Op S missions, hygro at cld bse, TRW+
8/16		X		X	X(MR,WW)		Op S, mushy clds
8/17	X(TP,DR)			X	X(MR,WW)		Op S, ontop & cld bse
8/18	X(WW,TP)		X(DR,MD)			X	Research hygro flt
8/19	X(WW,TP)		X(DR,MD)			X	Research hygro mission
8/20	X(WW,TP)		X(DR,MD)		X(MR,CW)		Research hygro mission
8/21	X(WW,CW,TP)		X(DR,YS,MD)		X(MR)		Ops & research flights
8/22		X		X	X(MR)		Ops mission
8/23	X(WW,CW,TP)			X	X(MR)		Ops mission
8/24		X		X	X(MR)		Ops recon
8/25		X	X(DR,MD)			X	Research flight
8/26	X			X		X	Research burn of hygro flares
8/27	X(TP)			X	X(MR)		Three ops missions
8/28	X(TP)		X(MD)		X(MR)		Four ops missions
8/29	X(WW,TP)		X(YS,MD)			X	Research test of SF_6 detector
8/30	X(YS,TP)		X(WW,MD)			X	Research test of SF_6 detector
8/31		X		X		X	All ops down for R&R
9/1		X		X		X	All ops down for R&R
9/2	X(YS,TP)		X(WW,MD)			X	Flt tests
9/3	X(YS,TP)		X(WW,MD)		X(MR)		Res. & Ops flts

Table 2 (Continued)

DATE	FLIGHTS Piper Seneca Y	Piper Seneca N	Beech Duke Y	Beech Duke N	Cessna 340 Y	Cessna 340 N	COMMENTS
9/4	X(TP)		X(MD)		X(MR)		Ops flts
9/5	X(YS,TP)		X(WW,MD)		X(MR)		Res. & Ops flts
9/6		X		X		X	No flts;unsuit. clds
9/7		X		X		X	No suitable clds
9/8	X(YS,TP)		X(WW,MD)			X	Research flights
9/9		X	X(MD)		X		Ops mission in Duke
9/10	X(YS.TP)		X(WW,MD)		X(MR)		Ops missions
9/11		X		X		X	No suitable clds
9/12		X		X	X(MR)		Cld recon mission
9/13		X		X		X	Low clds, cool
9/14		X	X(MD)		X(MR)		Limited to Sh,Su & Cr
9/15		X		X		X	Clear, dry & breezy
9/16		X		X		X	Clear and warm

Note: TP = Tom Promersberger; WW = William Woodley; MD = Mike Douglas; DR = Danny Rosenfeld; YS = Yaron Segal; MR = Mark Rivard, CW = Christopher Woodley

Table 3 OPERATIONAL SUMMARY FOR TEXARC 1996 HYGROSCOPIC SEEDING PROGRAM
(Flight Operations Based in San Angelo, Texas)
(All Times Are CDT)

DATE	CASE #	TIME TO.	TIME LANDING	FLT DUR. MIN.	CBT °C	TIME 1ST TRMT	POSITION OF TRMT XX	XX.XN	XXX	XX.XW	TIME OF LST TRMT	TRMT DUR	# FL	# MON. PERIOD (min)	# SF_6 HITS	MAX DBZ BFR/AFTR
8/15	1	1552	1820	148S	13	1646	31	27.6N	100	48.0W	1656	10	4	0	0	00/47
8/15	2	1552	1820	---S	13	1715	31	03.0N	100	33.0W	1757	43	19	0	0	23/63
8/18	3	1515	1700	105S	10	1606	31	41.0N	100	58.0W	1620	14	7	-	-	15/30
8/18	3	1419	1700	161D	10	----	--------		---------		----	--	-	?	1	15/30
8/19	4	1714	1903	109S	10	1804	31	05.84	100	40.04	1840	36	17	-	-	—/—
8/19	4	1713	1905	112D	10	----	--------		---------		----	--	--	?	?	—/—
8/20	5	1558	1846	168S	10	1643	30	34.89	100	26.38	1655	12	6	-	-	—/—
8/20	6	1558	1846	---S	10	1734	31	06.03	101	02.17	1741	4	2	-	-	—/—
8/20	7	1558	1846	---S	10	1759	30	59.66	100	49.06	1808	9	4	-	-	—/—
8/20	5-7	1602	1900	178D	10	----	--------		---------		----	--	--	-	-	
8/20	-	1608	1734	86C	--	Cessna 340 used solely for photography										
8/21	-	1655	1830	95S	11	Seneca used to photo the burn of 4 hygroscopic flares										
8/21	-	1701	1835	94D	11	Duke used to photo & sample the Seneca flare burn from behind										
8/23	-	1645	1730	105S	20	Seneca used to photo 3 flares										
8/25	-	1603	1736	93D	17	Duke used to measure the cloud droplet spectra										
8/25	-	1635	1724	49S	18	Seneca fired 4 AI hygroscopic flares							4H			
8/29	-	1653	1902	129D	19	Duke used in test of SF_6 detector										
8/29	-	1700	1824	84S	19	Seneca used in test of SF_6 detector						-	6	-	-	—/—
8/30	-	1650	1811	81D	19	Duke used in test of SF_6 detector						-	-	-	-	—/—
8/30	-	1657	1820	83S	19	Seneca used in test of SF_6 detector						-	4	-	-	—/—
9/2	-	1426	1530	64S	--	Seneca used in test of SF_6 detector						-	4H	-	-	—/—
9/2	-	1421	1525	64D	--	Duke used in test of SF_6 detector						-	-	-	-	—/—
9/3	8-9	1533	1825	172D	15	Duke used to monitor hygro cases						-	-	14/11	1/1	—/—
9/3	-	1530	1831	181S	15	Attmpt to measure size dist of AI hygro fls							5H	-	-	—/—
9/3	8	1530	1831	---S	15	1633	31	07.53	100	13.09	1644	11	5	-	-	—/—
9/3	9	1530	1831	---S	15	1748	31	05.13	100	10.87	1756	8	4	-	-	—/—
9/5	-	1532	1708	96S	18	Cloud recon for research mission, no suitable clouds										
9/5	-	1414	1656	162D	18	Cloud recon for research mission, no suitable clouds										
9/8	10	1505	1807	182D	14	----	--------		---------		----	--	--	67	0	15/59
9/8	10	1607	1737	90S	14	1650	31	07.95	100	13.85	1722	32	22	-	-	15/59

Notes: Two of the eight flares used on August 20th were for photography and not for the case. The flights on August 21st were solely for the purposes of photography. The treatment duration is the time of extinction of the last flare minus the time of ignition of the first flare.

Table 4

WMI FLIGHT HOURS IN TEXAS IN 1996
OPERATIONAL AND RESEARCH PROGRAMS
(May 26th through September 14th)

Month	Duke		Cessna 340		Seneca	
	Ops.	Res.	Ops.	Res.	Ops.	Res.
May	3:13	-	6:40	-	-	-
June	41:59	-	52:35	-	-	-
July	26:22	-	26:11	-	-	-
August	17:35	14:08	65:29	1:26	9:16	15:46
Sept.	18:48	9:40	16:53		3:37	7:11

The radars performed well in TEXARC 1996. The WMI project radar was operative on all days. The side-by-side PPI presentation and the GPS tracking of the aircraft made flight coordination a relatively simple matter for the radar controller. The only problem was the difficulty that the radar had in seeing echoes > 60 n.mi. away to the west. This was likely due to a combination of factors including, spreading of the 2° beam, attenuation of the radiated C-band energy during precipitation episodes, occasional operation of the radar at too great an elevation angle and the interception of the radiated energy by nearby ground targets when the radar was operated at low elevation angles.

The source of the radar data for analysis of the hygroscopic cases will be the volume-scan data from the WSR-88D radars at Midland and San Angelo. It appears as though these radars were in continuous normal operation during TEXARC 1996, so the radar data required for analysis of the TEXARC 1996 cases should be readily available from the National Climatic Data Center in Asheville, NC.

6.3 Chronology of Important Events during TEXARC 1996

A detailed daily journal of the events in TEXARC 1996 prepared by William Woodley is provided in Appendix A. The highlights are presented in this section.

All project personnel were in place as of August 5, 1996. The Piper Seneca arrived on August 6th to join the Beech Duke and Cessna 340, which were already in operation for the West Texas Weather Modification Association. The Beech Duke was damaged on the second operational seeding flight on August 8th and it was down for repairs until August 18th. In the interim some test hygroscopic seeding was done at cloud base from the Seneca, most noteworthy was the operational test on August 15th during which one vigorous cloud was seeded with hygroscopic flares and a comparable near neighbor was seeded from on-top with AgI flares. About 10 miles to the west another vigorous cloud received no seeding at all. This cloud triad should be examined carefully in order to assess apparent seeding effects. The NEXRAD radar data will be crucial for that study.

Research operations were conducted using the Seneca and Duke aircraft on August 18, 19 and 20, which will permit the derivation of drop-size distributions (i.e., median volume diameters and concentrations) as a function of height. The SF_6 tracer gas released during the burns of the hygroscopic flares was detected in the wake of the seeder aircraft but only one definite "hit" was detected above cloud base. The base line of the SF_6 detector was found to vary with time and with altitude, making unequivocal hits of the SF_6 gas hard to discern.

In the period August 19th through August 24th video photography was made of project activities by Christopher Woodley with the focus on the hygroscopic seeding component of the effort. He and his father William Woodley made the video "Harvesting the Skies of West Texas" during TEXARC 1995 that has been shown to thousands of Texans subsequently. The intent of the new video taping was to prepare a 3 to 5 minute addition to the original tape to update it with respect to the hygroscopic seeding.

By August 25th tropical air had entered the project area from the SE, bringing an increase in clouds and shower activity. The conditions initially were good for glaciogenic AgI seeding but they deteriorated late on August 28th through August 29th when very heavy rain occurred in eastern Irion, western and southern Tom Green and southern Schleicher counties. The cloud mass from which at least a portion of this rain storm evolved had been seeded intensively at cloud base at cloud top near 21,000 ft over several hours prior to the episode of heavy rain. The NEXRAD radar data should be examined to determine what role, if any, the seeding played in this heavy rain event.

All project operations were down on the Saturday, August 31st and Sunday, September 1st just prior to Labor Day at the request of the West Texas Weather Modification Association. The operational effort was down on Labor Day Monday, September 1st as well. The research component was back in operation on Labor Day in order to test equipment, particularly the SF_6 detector.

On August 29th and 30th and September 2nd the attention of the research effort focused on the SF_6 detector. Jim Rydock, the developer of the instrument, was in San Angelo to service it. During his time in San Angelo, he managed to steady the base line but could not explain why the instrument was not as sensitive as he thought it should be. Before he left on September 1st, it had been concluded that the instrument pump was not bringing enough air to the detector unit. Mr. Rydock made several modifications that he thought should increase the flow rate to the detector just before he left and these were tested during flights on September 2nd.

The flight test on September 2nd resulted in such strong SF_6 hits that the instrument appeared to saturate. This occurred after turning the sampling intake into the wind in one instance and also by taking air through the aircraft pressurization system in another. The instrument was flown the next day in a research mission.

Two hygroscopic seeding cases were obtained on September 3rd and one definite "hit" of the SF_6 gas was noted in each case. These cases will have to be examined to determine whether any change in the cloud droplet spectrum was noted at the time the gas was detected. The weather conditions were not suitable for research flights on either September 4th or 6th. Research flights of the Duke and Seneca aircraft were conducted on September 5th, but the prospective clouds weakened and dissipated before any hygroscopic cases could be qualified.

A good hygroscopic seeding case was obtained on September 8th. After the drop-size distribution was documented as a function of height to the west of San Angelo, a hygroscopic unit was qualified about 20 n.mi. to the east of San Angelo in an area of vigorous clustered convection. Large rain drops > 5 mm diameter were observed in the seeded clouds about 18 minutes after commencement of base seeding with hygroscopic flares. No SF_6 gas was detected by the detector on the Duke flying 11,000 ft above its release.

September 8th was the last flight day for TEXARC 1996. The balance of the revised research period from September 9th through September 13th had highly disturbed conditions with clouds that were unsuitable for hygroscopic seeding.

7.0 PRELIMINARY FINDINGS AND INTERPRETATIONS

An initial quick look at the data from TEXARC 1996 indicated that the hygroscopic seeding was not producing a noticeable change in the FSSP droplet spectrum near and at least 2 km above cloud base. Daily plots of the median volume diameters and droplet concentrations were made as a function of height on all days of hygroscopic seeding in 1996 and for August 20, 1995 when hygroscopic seeding was done with the South African flares. Measurements definitely made in the plume of the hygroscopic seeding material were identified by detecting the SF_6 gas that had been released simultaneously with the burn of the hygroscopic flares. These droplet measurements were contrasted with comparable measurements made outside the plume. No obvious differences were noted. The case in 1995 is especially noteworthy because of the repetitive strong "hits" of SF_6 without changes in the droplet spectrum.

The initial joint flights of the Piper Seneca cloud-base seeder and the Beech Duke, after it returned to service on August 18th after 10 days of repair for damage suffered during on-top seeding, had concentrated on relatively small clouds. This was done to ensure sampling the seeded volume as determined by hits of SF_6 gas. After August 21st, however, the emphasis shifted to cloud-base seeding of strong updraft cores for the production and the detection of rain drops in the cloud tops between the levels of 0°C and -10°C.

The case obtained on September 8th is especially noteworthy. A cluster of vigorous cumuli were seeded at their bases with 22 1-kgm hygroscopic flares over 32 min while the cloud physics aircraft sampled the towers growing from this region at about the -5°C level. No rain drops were detected initially in the clouds. After 20 minutes, however, large rain drops began to appear, some reaching over 10 mm in diameter. The maximum radar reflectivity reached 59 dBz, which appears to be the highest measured anywhere on this day. Detailed studies of non-seeded clouds on this day must be completed, however, before this behavior can be ascribed unambiguously to the hygroscopic seeding.

Two other cases of interest were obtained but they did not have the benefit of simultaneous cloud physics measurements. One occurred on August 15th during which a vigorous convective cloud was seeded with 19 1-kgm hygroscopic flares over 43 minutes. The cloud became a thunderstorm achieving a maximum low-level reflectivity of at least 63 dBz. The second case was obtained during the course of operational seeding on August 11, 1996. A total of 23 hygroscopic flares were burned at the base of a convective line over the course of 99 minutes. The cloud towers in this line were being seeded at the same time from on-top by another aircraft using ejectable AgI flares. **This may be the first time this has been done anywhere in the world.** A careful analysis of these two additional cases should provide additional insight into the effect of hygroscopic seeding in west Texas.

8.0 PROBLEMS AND THEIR SOLUTION

As in most cloud seeding experiments, the weather posed the biggest problem in 1996, because it was out-of-phase (as usual) with the desires of the researchers. In TEXARC 1994 and 1995 clouds containing an abundance of rain drops were desired for the testing of dynamic seeding concepts. Instead most clouds contained a minimum of rain drops. In TEXARC 1996 clouds with a minimum of coalescence and resulting rain drops were desired for the testing of the effectiveness of hygroscopic flares in generating rain drops artificially. Instead, many of the clouds contained rain drops naturally. Despite these problems enough of the desired clouds did occur to make some inferences about the effect of seeding.

The other problems centered on the cloud physics effort and were man-made. The first was the performance of the Beech Duke that did not permit it to climb from cloud base to cloud top during a hygroscopic seeding mission. This meant that each mission had to concentrate on either the bottom or top of the clouds but not both. It was not possible to follow a rising bubble with the Duke aircraft.

For whatever the reason, the SF_6 detector was a major disappointment in TEXARC 1996 unlike TEXARC 1995 when a different detector was used. For about half of the time allotted to TEXARC 1996 the base line of the detector varied with time and altitude such that small excursions in the trace could not be ascribed unambiguously to the detection of the SF_6 gas. After that problem was corrected, two small hits of the SF_6 were noted at and just in cloud base during hygroscopic seeding events. Their amplitude was much smaller than expected, however, even though much larger hits were noted when flying the Duke behind the Seneca as it released SF_6 gas. In the big hygroscopic seeding event on September 8, 1996, no SF_6 gas was detected even though the Duke was clearly being flown repetitively through cloud towers that were being seeded with hygroscopic seeding material from below.

The second problem was the loss of the Beech Duke cloud physics aircraft between August 9th and August 18th due to the mishap during a cloud pass that occurred late on August 8th. Although the lost days were added to the September period, resulting in program termination on September 13th rather than September 5th, the lost days were in a period when in-cloud coalescence was at a minimum. These clouds would have been more suited to hygroscopic seeding experimentation than the clouds that formed during the added days in September during which in-cloud coalescence processes were at their maximum. No one is to blame for this circumstance; it just happened as a consequence of the damage to the Duke on August 8th.

9.0 RECOMMENDATIONS

9.1 TEXARC 1997

In view of the great progress that has been made in TEXARC in understanding cloud processes and their alteration by seeding, the most obvious recommendation is that TEXARC continue in 1997. Only a month of study was available in each of the three previous TEXARC years. If resources permit, the annual period of experimentation and study should be increased to two months or more. The major cost in any experiment is in getting everything in place and returning it to its home base. When a program runs only one month, a disproportionate percentage of the funds is paid for start-up and take-down rather than on the research activity itself. A longer program, although it will cost more, is more efficient in terms of utilization of the research dollar.

TEXARC 1997 should address both glaciogenic and hygroscopic seeding, since the scientific issues are not resolved totally in either area. More cold-cloud, randomized, experimental units and additional high quality cloud physics cases are needed to increase the significance of the rainfall results and to further our understanding of how on-top AgI seeding acts to increase rainfall. Emphasis should be put on those clouds thought to be most responsive to silver iodide seeding.

The TEXARC hygroscopic studies have just begun. Cloud physics case studies are needed in which the sampling aircraft begins at cloud base and ascends with the rising parcel, containing the hygroscopic nuclei and the tracer gas. **A randomized hygroscopic seeding experiment should begin.** The initial skeleton design of such an experiment is presented in Appendix B.

Which experiment should be conducted should be dictated primarily by the weather conditions. Based on our past TEXARC measurements and experience, it makes no sense to do on-top AgI seeding of convective clouds that have high cool (CBT < 15°C) cloud bases. Such clouds do not appear to respond well to cold-cloud seeding. On the other hand, hygroscopic seeding of such clouds is expected to produce a major (reflectivity) seeding signature and probably more rainfall. Conversely, hygroscopic seeding of clouds with low warm cloud bases (i.e., CBT $\geq$ 15°C) should not be as effective as seeding with AgI because such clouds often contain rain drops that were produced naturally. The hygroscopic seeding signature should, therefore, be smaller in such clouds. AgI seeding, on the other hand, should be effective in warm-based clouds in releasing large quantities of latent heat and increasing cloud buoyancy. This enhanced buoyancy is needed to support the growing graupel mass that results from the seeding-induced freezing of the rain drops.

A high performance aircraft with four hours on station up to 20,000 ft is needed for TEXARC 1997, regardless of which experiment is conducted. This is especially crucial when conducting the "Lagrangian" hygroscopic seeding case studies in which the aircraft follows the parcel from cloud base to cloud top following commencement of seeding. The Piper Cheyenne performed exceptionally well in TEXARC 1995. It or its equivalent is the aircraft of choice for TEXARC 1997.

9.2 The Operational Seeding Program

The concern of the operational effort sponsored by the West Texas Weather Modification Association is the enhancement of the natural rainfall through cloud seeding. The most immediate question is whether hygroscopic seeding can be used operationally to augment the rainfall from clouds that would not otherwise be responsive to seeding with AgI. <u>Although definitive answers must await the complete analysis and interpretation of the data obtained in TEXARC</u>

1996, the initial evidence is strong enough to warrant our recommendation that hygroscopic seeding be incorporated into the operational program.

If this recommendation is accepted, it is recommended further that TEXARC scientists and the officials of the West Texas Weather Modification Association work together to reach three objectives:

1. Develop a decision protocol that will specify when either hygroscopic and/or AgI seeding should be used operationally for the enhancement of the precipitation. This specification will likely depend on the weather and cloud conditions. There may be days on which both seeding approaches should be used.

2. Stipulate how the hygroscopic seeding is to be done as a function of the initial conditions. This stipulation must include when, where and in what quantities the flares are burned.

3. Specify how the operational hygroscopic seeding is to be evaluated and by whom. Although the hygroscopic seeding will not be randomized, it is quite possible that the seeding signature will be strong enough to allow for the evaluation of the seedings. The data provided by the NEXRAD WSR-88D radars at San Angelo and Midland likely will be used in such an evaluation.

10.0 ANALYSIS PLANS FOR THE TEXARC 1996 DATA

10.1 Data Resources

An impressive data set was obtained during TEXARC 1996, including complete cloud physics data within subject clouds along with NEXRAD radar data from San Angelo and Midland. These data will be used in the proposed analyses. Complete operational documentation for TEXARC 1996 has been provided by Woodley et al. (1996) in this document.

10.2 Objectives of the Proposed Analyses

The overriding goal of the proposed analyses is to determine the potential of cloud-base hygroscopic seeding for the enhancement of rainfall in Texas, especially its semi-arid and arid western half. To reach this goal will require achievement of the following objectives:

a) Analysis of all cloud-physics cases obtained in 1996 in order to formulate a cogent depiction of convective-cloud structure and behavior as a function of such factors as cloud-base temperature and initial drop-size distribution; moreover, any changes observed in the treated clouds as a result of the introduction of hygroscopic material will be documented;

b) Analysis and interpretation of all WSR-88D Doppler weather-radar data obtained from the Midland and San Angelo sites that are of relevance to the cloud-physics cases; and the incorporation of information obtained from such procedures in the cloud-physics studies;

c) Analysis of those case studies in which sulfur hexafluoride gas was released from the seeder aircraft at the same time hygroscopic seeding material was dispersed.

Achievement of these objectives during the course of the proposed analyses will make it possible for Texas decision-makers to decide whether the hygroscopic flares should be used during the conduct of the operational seeding program. Attainment of these objectives will also make it possible to design the next phase of the research effort.

10.3 The Research Plan

The research plan consists of an intensive, highly-focused series of analyses, evaluations and interpretations of cloud-physics and weather-radar data and information obtained during the conduct of the 1996 TEXARC experiments in the vicinity of Midland-San Angelo, Texas. The planned series of analyses by Drs. Woodley and Rosenfeld will be done in Texas, Colorado and Israel and exchanged via the Internet. In addition, face-to-face work sessions will take place during the 6-month research effort.

To reach the objectives identified in Section 10.2 (above), the work will consist of the following specific tasks:

a) Analysis of the deliberate seed cases on August 15, 1996 when two storms side-by-side were seeded, one with AgI from on-top and the other at cloud base with hygroscopic flares. There was also another comparable storm farther to the W that was not seeded.

b) Analysis of the operational seeding case on August 11, 1996 when both AgI and hygroscopic seeding was conducted in the same clouds and at the same time.

c) Calculation of the FSSP cloud droplet distributions (concentrations and median volume diameters) on all days as a function of height.

d) Documentation of hygroscopic seeding signatures in the FSSP droplet spectrum simultaneous with hits of SF_6.

e) Comparison of the cloud droplet distributions (concentrations and median volume diameters) in tropical air with those in more continental air.

f) Calculation of the droplet concentrations as a function of FSSP channel, looking especially at the tail of the distributions.

g) Documentation of a hygroscopic seeding signature by looking for the presence of rain drops in the supercooled portions of seeded clouds as compared to unseeded clouds.

h) Calculation of the particle concentrations as a function of size for the hygroscopic flares.

i) Analysis of the radar observations of the hygroscopic seeding cases to assess whether the behavior of the subject cloud is different from non-seeded clouds. The altered behavior may take the form of earlier echo formation, lower first-echo heights and greater maximum reflectivities.

In addition to these 9 tasks of relevance to the hygroscopic seeding, the following important task of relevance to glaciogenic seeding with silver iodide is identified:

a) Analysis of the heavy rain episode in the San Angelo area beginning the evening of August 28th and ending mid-afternoon on August 29, 1996. It is important to look especially at the role that seeding may have played in enhancing the rainfall.

These tasks will be completed and the Final Report written within six months of the initiation of the analyses. This should allow for a spring completion in enough time to incorporate the results of the analyses into the design of the TEXARC 1997 program.

10.4 Significance of the Proposed Analyses

Operational cloud seeding for precipitation enhancement has been a reality for over 40 years even though many would contend that scientists have not proven unequivocally that it works. Texas has been the host of at least one rainfall enhancement program within its borders in all but one of the last 23 years. Another operational rainfall-augmentation program, covering 7,000,000 acres in west Texas, began in May 1996. It is vital, therefore, that TEXARC scientists continue their efforts to put the practice of cloud seeding for precipitation augmentation on the strongest possible scientific foundation.

The continuing west Texas research, which is based on the experience gained by Woodley and Rosenfeld in Florida, Texas and Thailand, has enormous potential for advancing this discipline further. The results of their research to date suggest that AgI seeding as practiced in this program is effective in producing substantial increases in rainfall in this semi-arid region. Their physical/statistical analyses are continuing.

Not all Texas clouds respond to silver iodide (AgI) seeding with increased precipitation. The focus in TEXARC 1996 was on whether cloud-base seeding with hygroscopic flares stimulated the production of rain drops in clouds that could not produce them on their own. Such clouds are not very responsive to AgI seeding.

Analysis of the data obtained during TEXARC 1996 will make it possible to determine whether hygroscopic seeding should be pursued further for rain enhancement in West Texas. This is important both to the continuing program of scientific research in Texas and to the operational cloud seeding program that is being conducted under the auspices of the West Texas Weather Modification Association. The Association needs to know at the earliest possible time whether hygroscopic seeding should be incorporated into their rain augmentation program.

The proposed research is, therefore, highly significant in the step-wise scientific process leading to a demonstrated, beneficial, rain-enhancement technology for Texas. What is planned must be accomplished before additional steps can be taken.

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APPENDIX A

TEXAS SCIENTIFIC JOURNAL

August 5 to 13 September 1996

By

William L. Woodley

August 5, 1996

My wife Marlene and I arrived by rental car at about 2100 CDT on August 4, 1996. A line of Cbs that was being worked by the WMI Cessna 340 could be seen to the distant west. The echoes were moving slowly from the S. The temperature at 2100 CDT was 98°F.

The minimum temperature overnight was 76.6°F and the morning dawned with scattered to broken middle cloudiness. It was somewhat hazy. The temperature climbed rapidly into the mid-90's and the maximum by late afternoon had been 102°F. The cumuli in the local area had not shown much development by early afternoon, but they grew rapidly to TCU with a few Cbs by late afternoon. Thunder was heard at the airport by 1700 CDT and a heavy shower was in progress at 1707 CDT.

The WMI Cessna 340 was airborne between 1630 and 1700 CDT intending to work clouds in the operational area to the W. Meanwhile, the WMI Duke was airborne with Mike Douglas, Kelly Bosch and a person from Lyle Lillie's office in order to test the data system and instrumentation. The Piper Seneca from WMI, which will serve as the hygroscopic seeder, arrives tonight.

August 6, 1996

It was clear and breezy in the morning and hot in the afternoon, with the temperature in San Angelo reaching a maximum of 100°F. The first cumuli had formed by early afternoon and there were TCU and a few isolated showers and Cbs by late afternoon, especially to the S and SW.

The Cessna 340 flew late in the day for an operational mission, but the clouds were not particularly suitable. Most shower activity had dissipated by sunset.

The Piper Seneca arrived today complete with racks for the hygroscopic flares, 12 to a side. The only obvious problem was the lack of a GPS unit on this aircraft. We will need it for an accurate position of the hygroscopic seeding and SF^6 gas release so that the Beech Duke can find the relevant cloud at its flight temperature around 0°C. Without such a position from the seeder aircraft, it will be like looking for a needle in a haystack.

<u>August 7, 1996</u>

Today began as it had yesterday with clear skies and light winds, which increased from the E during the day. There was no echo activity in the local area, but there were echoes in the Texas Panhandle in association with a weak front that was moving slowly S through this region. I could see at least two Cbs to the distant NNW of the Midland Airport where I had driven my wife to make a plane connection for her flight to visit her parents in north Florida.

Once again the first cumuli did not form until around noon and it wasn't until late afternoon that they had attained any depth. By an hour or so before sunset a few cumuli to the distant SE-S had reached towering stature and become small Cbs shortly thereafter. The Cessna 340 flew to this cloud region which was in Schleicher and Sutton Counties. Mark Rivard tried to work this area, but it was now dark. The rise of the quarter-moon had not yet taken place and there was very little lightning, so it was very difficult to work this region and he returned to base. Occasional lightning could still be seen to the distant SW at midnight as the clouds tracked to the NW. The high for the day was 99°F.

We are still making preparations for our first flight. Kelly Bosch, the WMI technician, has been setting up the data system and the display of the data, while Mike Douglas, the Duke pilot, has been working on the right engine, which has not been developing its normal power when at seeding flight altitude. Pat Sweeney arrived in San Angelo by mid-evening and he promised to obtain a hand-held GPS for the Piper Seneca.

<u>August 8, 1996</u>

It was clear in San Angelo this morning with the exception of scattered cirrus and altocumulus clouds, becoming broken to the ENE. The winds were light from the E. The altocumulus castellanus clouds were moving from the ENE. The visibility was still quite good although there was a light haze over the area. The temperatures and dew points were in the low 70's and mid-60's, respectively. The National Weather Service is calling for a 20% chance of showers in the local area today, tonight and tomorrow.

The middle cloudiness increased through the mid-morning and cumuli began forming below the broken to overcast middle cloud by late morning. A few of the cumuli had reached TCU and Cb stature by noon and the Cessna 340 was airborne and doing operational seeding between 1230 and 1300 LT. The Beech Duke was airborne shortly thereafter, flying initially in the western portion of the target.

In the local area the temperature had reached to near 90°F by early afternoon, dropping into the mid and upper 80's by mid-afternoon as the cloudiness and shower activity increased. The anvils of the Cbs were shearing to the W, making the E side of the cloud masses the upshear side. Some new towers also grew up into the anvils on the W side of the cloud masses, making it difficult to reach them with the aircraft. Echo motion was to the WNW.

The two aircraft each made another seeding flight later in the afternoon. The Beech Duke returned with its engine cowlings appearing to have been wrenched on their mounts. Mike Douglas reported that he was doing on-top to just in-top seeding when his aircraft "hit a bump" and then pitched over in a steep dive. He dropped from 21,000 ft to 13,000 ft before he could get the aircraft out of the dive. Mike reported that the aircraft was iced at the time and I would guess that the tail stalled and this pitched the aircraft into the dive. It is doubtful that the aircraft will be able to fly again in the near future. What we do about that remains to be seen.

August 9, 1996

San Angelo had scattered to broken cloudiness this morning, consisting of cirrus, altocumulus and thin patches of low cloud. The altocumulus clouds were drifting from the NE. The surface winds were light from the NE and the temperatures were in the low to mid 70's and the dew point was in the upper 60's. We appear to be set up for another round of extensive shower activity in our target.

Inspection of the Beech Duke was more encouraging than our first impressions yesterday. The cowlings on both engines were destroyed and have to be replaced and the electrical generators must be sent out for inspection and maintenance. Otherwise, no additional damage from the dive and pullout yesterday is obvious to the naked eye. A licensed FAA inspector, who works for WMI, will arrive today from Fargo, ND to inspect the aircraft.

The events of yesterday show the importance of doing most of the seedings over the top. I want to fly further with the pilots to give them additional training in how best to do the over-the-top seedings. They must find a way to avoid the heavy icing from these clouds while still doing the job expected of them.

Cumulus clouds began to develop by mid-morning and a few had reached towering and Cb stature by 1230 CDT. The Cessna 340 took off at around 1230 CDT and the Seneca was put in a standby mode for a cloud base hygroscopic mission. I will fly that mission along with Tom Promersberger and Mike Douglas.

The day is not optimum for hygroscopic seeding because of the low cloud bases and warm temperatures which should guarantee coalescence and warm rain. Nevertheless, we need to try out our new seeding procedures now that we have a hand-held GPS for locating our seeding positions. I will have to record the positions manually, since we do not yet have a recording capability.

By 1300 CDT there were echoes everywhere in the target. It looked to be a messy situation at cloud base, but we will have to make the best of it. Cloud bases were at 4,500 ft MSL, which will mean a ground clearance of only about 2,000 ft. Finding good hard bases in all of the low cloud may prove to be a serious problem.

Danny Rosenfeld is toying with the idea of going to Montclova, Mexico while the Beech Duke is down for repairs. I intend to stay here to meet my obligations with the various projects. Besides doing the cloud bases mission, I intend to fly with the on-top Cessna 340 seeder to work with Mark Rivard on over-the-top seeding.

I later talked to Dan Breed of NCAR, who is working on the hygroscopic seeding project in Monclova, Mexico. He indicated that Danny would be welcome to visit but that there really wasn't much for him to see. The cloud physics data exist on tape and disk and no one has had the time to look at it, so there was not much that Danny could learn by visiting. Further, the Project Office in Montclova will not be open on Sunday, so Danny would not have much to do. In view of all of this, Danny decided to stay in San Angelo and make the best of the situation here.

I took off in the Piper Seneca with Tom Promersberger and Mike Douglas as pilots at 1452 CDT. Cloud base was at about 5,500 ft, which is pretty low for west Texas. I sat in one of the seats that face to the rear and I noted immediately that I could not see very well if I stayed in that position. I then disconnected my seatbelt and got on my knees between the two rearward facing seats and tried to cope with my notebook, clipboard, GPS unit and microphone and with the turbulence. It was not long before I was feeling squeamish in this position.

We flew into NW Schleicher County and tried to find hard suitable cloud bases for seeding. I was not very comfortable in doing so because of the few heavy tropical showers in the area. I was wondering just what good hygroscopic seeding would do under these circumstances of active coalescence. Nevertheless, we did seed in this general region beginning at 1524 CDT with the ignition of two flares. Initially the maximum updraft was around 500 ft/min and the plume of smoke behind the aircraft did not appear to be rising into cloud base. The plume did ascend into cloud base later when the maximum updraft was > 1,000 ft/min.

We continued hygroscopic seeding until 1612 CDT when the last flare burned out. We had expended a total of 13 flares, 6 from the right side and 7 from the left, leaving a total of 11 flares remaining on the aircraft. We skipped over one flare on the right either because of a poor connection or because of a bad flare. We will not know until we check it out. The flares burned an average of only 4 minutes, which was about 2 minutes less than I had expected. The minimum burn time was 3 minutes and the maximum was around 5.

It rained in the general area of seeding, but it would be hard to ascribe it to seeding in view of the many showers around. We began our return to the airport at 1615 CDT and landed at 1641 CDT after flying around a large thunderstorm which was to the immediate S-W of the San Angelo Airport. It had an awesome appearance just before it reached maturity. Although it produced very heavy rain, it remained virtually dry at the airport. After this thunderstorm had died, however, a general light rain began, apparently from the extensive anvil.

According to the research of Danny Rosenfeld, this precipitation results from general ascent in the anvil that has been produced by the earlier convection and this ascent produces the growth of ice particles by deposition. Some of the resulting ice crystals aggregate and then fall, resulting in rain drops. Only the largest survive the long fall to the ground such that the rain consists of mainly large drops in low concentrations. Because of these large drops, a general convective Z-R relationship will overestimate this anvil rain because of the sensitivity of the radar reflectivity to the sixth power of the drop size. A unique Z-R equation, specific to this anvil stratiform rain, is needed for accurate radar estimation of this rainfall.

I think that the flight was worthwhile today, but I am embarrassed that I almost became sick on the aircraft. Once Tom Promersberger is comfortable in the aircraft we probably should put the scientist in the right seat next to him and move the SF_6 bottles forward so that they can be operated by the scientist from the copilot's seat. I recommend against further hygroscopic seeding under such circumstances, because I cannot defend such seeding when there is so much natural coalescence and rainwater. On-top AgI seeding still seems to be the best approach under these circumstances.

By 1800 CDT the target area consisted of mostly cloud debris although there were some nice clouds to the distant S. Light showers were occurring at the airport at the time. The Cessna 340 was making a second flight at this time, but it returned to the airport, having expended only 4 flares.

August 10, 1996

San Angelo had broken altocumulus clouds and light southerly winds early this morning. The temperature was in the low to mid 70's and the dew point was in the low 70's. The middle clouds and the high surface dew points suggest that there is deep moisture in the region. This combined with intense surface heating should have us another round of showers today. If I get my other chores done during the morning, I plan to fly with Mark Rivard in the Cessna 340 to develop further our on-top cloud seeding procedures.

Our shipment of SF_6 gas did not arrive as scheduled yesterday. I will have to track it down. Danny and I also have to find the time to work with Kelly Bosch to develop a check list for the operation of the instrumentation and data system on the Duke, so that we will be ready to go when it is again ready to fly, now scheduled for Tuesday, August 13th.

To use the Seneca for cloud base seeding and simultaneous release of SF_6 gas, we will have to put the scientist in the co-pilots seat and find some way of releasing the SF_6 gas remotely from the co-pilot's seat. A tube, running from the gas bottles mounted in the back of the aircraft, a flow meter and release valve will be necessary to release the gas remotely from the co-pilot's seat. I can't see any other way of doing it, unless one wants to strap the gas bottles to the back of the co-pilot's seat.

The first cumuli formed in the local area by late morning and had reached towering stature by noon, especially to the NW of San Angelo. A few of these clouds were approaching Cb stature by 1300 CDT. I took off in the Cessna 340 with Mark Rivard at the controls at 1308 CDT. Cloud base was noted at 7,000 ft MSL as we climbed slowly to the W. About 40 n.mi. to the WNW were there were a few echoes oriented in a SW-NE line.

Our first seeding was at 1347 CDT to the WNW of San Angelo at 39 n.mi. We continued seeding in this general region from W to NW of the radar from 44 n.mi to 27 n.mi until 1551 CDT for a seeding duration of 124 minutes. We attempted to fire 90 flares on 31 seeding passes, but 86 actually left the rack for an average of 2.77 flares per pass. In Thailand we are averaging about 5 flares per treatment pass. Some of the clouds looked quite hard and they appeared to be responsive to the seeding with strong growth and glaciation. By mid-afternoon the strongest and virtually only echo mass was the one were seeding. Everything else appeared to be suppressing with time.

We were down to our fuel reserve by 1555 CDT when we began our return to San Angelo. There were still several hard clouds that could have been seeded had we been able to stay airborne. Most of the good clouds, however, were well to the N and NW. Cloud base had risen to 8,500 ft. We landed at 1605 CDT. By 1700 CDT all of the good echoes were concentrated in the NE quadrant of the radar scan. Some of the clouds were quite beautiful against the clear deep blue sky.

I rank today's flight as successful in terms of operations and in terms of the apparent response of the clouds to seeding. The Cessna 340 did not give us much performance at altitude, especially when it was loaded with ice. I had to ignore several really hard impressive clouds because we would have had to penetrate them in order to seed them. That would not have been good for the aircraft.

The high in San Angelo was 97°F, which was higher than I had expected. The dew point had dropped to 61°F at 1700 CDT. This agrees with the drying evident in the clouds in the local area. By late afternoon we might have had conditions suitable for hygroscopic seeding. I mention this for academic interest only since cannot yet conduct hygroscopic seeding operations. We still have to track down the SF_6 gas and we have to get the Beech Duke in working order as well.

By early evening an area of cumulus clouds had developed W-N-E of San Angelo and a few of the clouds were precipitating. They were not very impressive and not very deep. After midnight and before dawn, however, we had a thunderstorm in San Angelo with heavy rain. The showers were not limited to San Angelo since heavy rain occurred in the trans-Pecos region well to the west of San Angelo.

August 11, 1996

San Angelo had broken to overcast middle and upper cloudiness this morning and light winds. The satellite image showed cloudiness over much of west Texas, especially in a WSW-ENE line through San Angelo. The temperature was in the low 70's and the dew point was in the upper 60's. The rain total overnight was 0.89 in., bringing the August total to 1.12 in.

The first cumuli had formed in the local area by 1100 CDT and they had reached towering stature by 1300 CDT. A small Cb was evident to the SE of San Angelo. There was little activity from WNW-N-NE.

I took off in the Cessna 340 with Mark Rivard as pilot at 1513 CDT. We found cloud base at 7,000 ft at an uncorrected temperature of 19°C as we headed to the SW toward the NW end of the line of TCU and Cbs that lay on a NW-SE line to the SW of San Angelo. The Piper Seneca took off shortly thereafter with the intention of practicing a hygroscopic seeding mission on the NW edge of the line.

The Cessna 340 completed its climb while flying on the S and SW side of the line where the new towers were growing. Many of them were shrouded in debris so it was hard for us to get at them. Just as we completed our climb the Seneca lit its first flare at cloud base on the NW edge of the line. We followed with on-top AgI seeding at 1555 CDT at the SE end of the line. The clouds in this region were not particularly good, so we flew W and NW along the line. As we flew W the line took an abrupt turn to the N and from this point and then to the N the clouds were fantastic in appearance.

We continued our seeding in this area and then gradually worked our way farther N and NW along the broken line, trying to fill in the gaps by seeding vigorous clouds in this region. Meanwhile the cloud-base aircraft was continuing its hygroscopic seeding beneath us along the line, which was growing strongly as the convective elements within it merged into an organized mass.

We continued our seeding for 103 minutes and expended all 102 flares in the rack on 31 cloud passes. Upon inspection of the rack later, however, I determined that 7 of the 102 flares had not fired, giving an ejected total of 95 flares. A total of 23 hygroscopic flares had been burned aboard the Seneca. They had stopped seeding 10 minutes before us. Between the two of us we had done seeding in Irion, Crockett, Reagan, and Schleicher Counties.

The rain was obviously quite heavy in the line. It is too bad that we do not have any systematic rain measurements in our target area. A few point totals were likely quite large beneath some of the cores in the line. I hope that it will be possible to put together a cooperative rain gage network in the area by the start of operations next year.

After we returned to the airport the line began to decrease in extent and intensity. Although we were prepared for a second flight, it did not seem necessary. From this point onward, the clouds continued to decrease until by sunset there was no shower activity within view. The high for the day had been 94°F and the dew point was still 67°F at 1830 CDT.

August 12, 1996

Today dawned with clear skies except for some altocumulus clouds to the E and calm winds. The temperatures and dew points were in the upper 60's. No shower activity is forecast for today.

If today turns out to be as dry as predicted, it may present us with the opportunity of doing a hygroscopic seeding experiment late in the day when the boundary layer is most organized. It will give Tom Promersberger more experience in the cloud-base aircraft and it will at least allow us to examine the response of the cloud on radar. Until the Beech Duke is back in service, which now may take until Friday, August 16th, we are limited to only the radar component of the hygroscopic experiment. When the Duke is back, we will be able to do the cloud physics component.

The first cumuli had formed in the local area by 1100 CDT, but they had not grown much by mid-afternoon. The surface wind was from the NE at 10 to 15 kts and the dew point slowly dropped into the mid-60's. By 1600 CDT a lone mushy Cb could be seen to the distant SSE in Kimble County, which is out of the operational area to the E of Sutton County.

I canceled flight operations for the hygroscopic seeding experiment at 1700 CDT and indicated to Tony Grainger that we would not use the aircraft for operations tomorrow. The forecast is highly unfavorable with the upper high at 500 mb predicted to intensify and expand into our area. The WMI people here need a break, and this looks like a good time to give it to them. I can't see keeping them standing by tomorrow when we will have a greater need for their services later this month.

Hans Ahlness arrived from WMI this afternoon to take charge of the repairs that will be necessary to get the Duke back in the air. Hans discovered a bent elevator on the Duke into addition to the damaged cowling. It apparently will have to be replaced.

Pat Sweeney leaves for Bangkok, Thailand early tomorrow morning, carrying the WMI response to the Thai aircraft tender with him. I hope that all goes will with his trip.

<u>August 13, 1996</u>

Today began with clear but smoky conditions due to a fire of unknown location. The temperature and dew point was in the mid-60's. There were no echoes and no clouds over all of west Texas and none are forecast for today. We can use the down time today to work on getting the aircraft ready for our next mission opportunity.

It stayed clear but hazy through 1230 CDT when cumuli formed on the southern horizon. These clouds had achieved towering stature with at least one Cb core by 1330 CDT. The strongest echo was about 170 km SSE of the radar outside of the operational area to the E and S. I had to admit that I was surprised to see such clouds so early in the day. We are down today regardless of what happens.

George Bomar returned today and we spent the morning discussing the project. The SF_6 gas is due in today and the special computer arrived for our viewing of the project data. Hans Ahlness is more optimistic about getting the Duke back up by as early as Friday.

After a barbecue lunch here at Southwest Aviation I left for Midland to pick up Marlene. The weather en route and back was hazy with a few small cumuli. The area of TCU and Cbs to the distant SSE of San Angelo never did enter into the operational area, but it is possible that we might have been able to operate on them had all of the aircraft been available.

During the evening hours I talked with Dan Breed in Montclova, Mexico about the possibility of our bringing down the Seneca cloud-base aircraft for their use in their hygroscopic seeding experiments. They do not yet have the services of a cloud-base seeder because the flare racks provided by WMI have not been installed properly. Dan was quite receptive to our coming and I indicated that Danny and I wanted to fly on both the cloud base and the cloud physics (Cheyenne) aircraft and that we wanted to examine the data. I suggested that Dan talk to the other scientists involved from NCAR (i.e., Roelof Bruintjes, Roy Rasmussen and Brant Foote) to see how we might collaborate if we bring down the Seneca. He promised to do so and get back to me later.

August 14, 1996

Today began clear but hazy due the continuing presence of smoke from the fires elsewhere in the country. The temperature and dew point was 71°F and 62°F, respectively. There were no echoes anywhere in the area.

Hans Ahlness and Mark Rivard left around 0830 CDT today to go to Dallas to pickup cowlings from the Beech Duke. He is also looking into the purchase of a new elevator for the Duke since the old one was bent in the pull out from the dive. A new one costs about $17,000 which strikes me as absurdly expensive and reminds me once again why I quit flying for myself. I just can't afford it.

While I was taking Marlene to Midland Airport this morning for her trip back to Denver, the first cumuli formed in the Midland area by late morning. The cumuli were not much larger in the San Angelo when I returned to the area at 1430 CDT. There were, however, TCU and a couple of Cbs about 170 km to the SE. The intervening clouds looked to have potential for growth and we were contemplating flying the Seneca for a cloud physics mission.

The clouds to the distant SE stayed in place through the afternoon and no significant cloud developments occurred closer to San Angelo. In view of the unsuitable weather and the work that still had to be done on the aircraft, we canceled all flight operations. In the interim the SF_6 gas arrived and we busied ourselves getting the tanks of gas connected to a pressure gage, flow meter and release valve.

August 15, 1996

Today began as yesterday with hazy calm conditions. There were a few patches of cirrus and altocumulus clouds that moved into our area from the NW during the night. These clouds were debris from a blowup of convection in SE Colorado, NE New Mexico and W Oklahoma last evening. The early morning temperatures were in the low 70's and the dew point was in the mid 60's.

At this point we do not expect much convection, but we are hopeful for enough high based convection to do a hygroscopic seeding experiment for monitoring by radar. Microphysical measurements are not possible until the Duke is once again ready to fly. This morning we will go to a welding supply place so that we can purchase the tubing and gages for the SF_6 tanks.

By mid-morning we had all of the gages and tubing in place for the release of the SF_6 gas thanks to the efforts of the men at J&T Welding Supply in San Angelo. We returned to the airport and Danny and I had lunch while the first cumuli were forming in the local area. By the time that we returned a few of the cumuli were approaching congestus stature and we began planning for a hygroscopic seeding flight that would serve as both a training flight and as a case study for radar evaluation.

I took off at 1609 CDT in the Piper Seneca with Tom Promersberger at the controls. We had broken to overcast cumuli of various sizes and altocumulus clouds that were being formed by the spreading out of the cumuli. A few of the cumuli were towering into the altocumulus debris and had pileus caps on them. The sky was not particularly pretty due to the haze and all of the cloud debris.

We commenced a slow climb to the SW, finding cloud base at 9,000 ft at an uncorrected temperature of 13°C to 14°C. None of the clouds was particularly impressive at their bases initially as we flew N to S and S to N about 20 n.mi. to the WNW-W-SW of San Angelo.

Our first deliberate hygroscopic seeding took place at an 280° at 17 n.mi. from San Angelo at 1646 CDT. The treatment duration was 10 minutes during which 4 flares were burned, two at a time, one on each wing. The cloud base did not hold together for too long, resulting in an early end of this case. Some rain was noted from the cloud at its base, with the maximum reflectivities reaching 47 dBZ. Considering the short time between seeding and the rain, I did not seriously consider this to be an effect of seeding.

The second case involved a much more vigorous cloud. The first seeding took place at 1715 CDT at 184° at 19 n.mi. from San Angelo. The cloud appeared to be at least 20,000 ft at the time of seeding and the new growth with pileus was on the N and NW side of the main tower. The Cessna 340 was also in the vicinity and I asked that it not seed this cloud, so that we might make some inferences regarding its behavior after only hygroscopic seeding. Tony Grainger at the operational radar agreed and he directed Mark Rivard in the Cessna 340 to do on-top AgI seeding on a cloud about 5 n.mi. to the E of our cloud.

The seeding in our cloud complex continued for 43 minutes with the burning of 19 flares (total of 23 for the day; position 2 in from the right on the right rack did not fire again today). The cloud grew dramatically during the seeding, reaching Cb stature with lots of lightning and a maximum reflectivity of 63 dBZ, which struck me as quite high considering the high cool cloud bases. An RHI scan revealed that the high reflectivity was concentrated at low levels, suggesting that it was produced by large rain drops and not hail.

The shower below cloud bases was quite impressive visually with strong outward bending of the rain shaft as it neared the ground due to strong outflow. We did not penetrate the core of the rain shaft due to its high intensity but we did encounter some large rain drops at the edge of the shower on its N and NW sides where the new towers were growing. These drops were likely falling through the updraft region where we were seeding.

Our cloud was the strongest and had the longest duration of the day. One unseeded cloud about 10 n.m. to the NW did reach 59 dBZ for a brief time, but then it dissipated. The maximum echo height of the seeded cloud is not known, but it apparently exceeded 35,000 ft on one of the few RHI scans that were taken during the operation. By 1802 CDT we had expended all of our flares and we began our return to the airport, landing at 1818 CDT. Meanwhile, the Cessna 340 moved in for AgI seeding near the tops of the new towers but no AgI seeding was done on this cloud.

The cloud began to decrease as soon as we left it. Consequently, Mark did not have much success with his on-top seeding. (He expended a total of 20 flares during his flight.) In less than an hour after termination of treatment the cloud had dissipated. It had been an impressive case that was clearly suggestive of the potential of hygroscopic seeding when conditions are not right for the cloud to develop rain drops on its own. We are clearly on the right track. It is crucial, however, to make some microphysical measurements in hygroscopic seeding cases. Only if the seeded clouds contain rain drops in sizes and concentrations that are different from neighboring unseeded clouds will I be convinced of the effectiveness of hygroscopic flare seeding. I am impressed by what I saw today, but much more remains to be done.

Because we were not in a position to do cloud physics studies, Tony Grainger classified our flight as an operational mission today. We will not, therefore, be charged for the flares and the flight hours. Considering the outcome of the seeding, it is not hard to justify it as an operational activity.

The case today should be added to the list of cases to be analyzed using the San Angelo NEXRAD data. Comparing the two seeded clouds, one with AgI and the other with hygroscopic material, should be interesting. Then both clouds can be compared to the non-seeded clouds in the area. That the hygroscopic case was not randomized should not detract from what we learn physically during the study.

August 16, 1996

Today began differently from the past days with overcast conditions and widely scattered light showers from multiple layers of thick middle cloud. The rain was in a NE-SW band of showers toward Abilene where the shower activity was heavier and more extensive. The shower area appeared to be tracking to the SE. The temperature and dew point was in the mid 70's and mid 60's, respectively. The winds were SE up to 15 kts.

I expect this activity to continue into mid-morning with new convection developing later in the afternoon. We may be in a position to fly the Duke today, although tomorrow is more likely. We will clearly be in a position to fly another cloud base mission provided the clouds do not produce rain drops on their own.

By mid-morning we still had overcast moist conditions with the dew point rising into the upper-60's. There were numerous breaks in the overcast and high-based cumuli and/or large altocumulus castelanus were evident through breaks in the overcast. By noon it was still mostly overcast and the temperature had risen into the low 80's.

AT 1400 CDT there was still broken to overcast altocumulus clouds, which had thinned considerably since mid-morning. Cumuli were forming all quadrants, but none of them were very tall due to the lack of surface heating.

By 1600 CDT there were a few showers on the scope, especially to the S of the radar. In many ways the pattern was similar to that of yesterday. In fact, the main cloud, echoing up to 54 dBZ, was within 5 n.mi. of our main seeded cloud of yesterday. In view of these developments, Tony Grainger called for an on-top seeding flight and I was preparing to fly with Mark Rivard.

We took off at 1700 CDT and headed S with the intention of eventually working suitable clouds on the flanks of the existing echoes. There was broken to overcast altocumulus clouds at the time and the few cumuli within sight did not look particularly strong. Nevertheless, a heavy shower could be seen to the distant S in the same general area as our cloud of yesterday. Cloud base was noted at 9,500 ft at an uncorrected temperature of about 16°C as measured by the sensor on the Duke.

We had reached 17,500 ft when we made our first cloud pass and our first AgI seeding took place at 1734 CDT at an azimuth of 192° at 47 n.mi. from the radar. The cloud was on the W flank of the existing mushy Cb and there was a field of potential seeding candidates in the region. Two cloud areas, separated by about 10 n.mi., were seeded in this general area. Both grew in a mushy mode to Cb stature with the N original cloud the taller of the two. I would estimate that it reached a visible top between 35,000 ft and

40,000 ft with a maximum reflectivity > 50 dBZ. This was not very unusual, however, since one or two unseeded clouds near the radar were claimed to have reached 60 dBZ. Considering that I did not find any rain drops in the clouds today, I am surprised by the high reflectivities.

We made our last seeding pass in the original cloud area at 1826 CDT and moved to the N closer to San Angelo for more seeding. Although these clouds also looked rather mushy, we began seeding at 1851 CDT 20 n.mi. to the SW of San Angelo. I frankly did not see much of a cloud response in this area. We ceased seeding here at 1908 CDT and left the area, landing at 1932 CDT. The total seeding duration had been 94 minutes during which we expended 41 flares on 15 seeding passes. The flight duration had been 152 minutes.

It had not been a particularly auspicious day. The initial clouds had appeared to respond to the seeding, but in a weak mushy growth mode. Nevertheless the radar suggests that they produced heavy precipitation for a time. The other seeded clouds rained too, but I would have a hard time ascribing much of their rain to our seeding.

<u>August 17, 1996</u>

Today began as it had yesterday with broken to overcast middle and upper clouds and a scattering of mostly light showers over much of west Texas. The showers were moving generally from the NW. The temperature was in the low 70's and the dew point in the mid 60's. The winds were light from the SE.

By mid-morning the middle clouds had decreased somewhat and both the temperature and dew point had risen into the low-80's and upper 60's, respectively. The middle clouds continued to decrease into the afternoon, but the cumuli were slow to grow in the area, reaching towering stature by mid-afternoon. The dew point dropped to near 60°F. The first significant echoes formed to the NW-NNW out of our operational area.

Since the Duke was not ready to fly, I decided to go on an on-top operational seeding mission once again in the Cessna 340. Mark Rivard and I took off at 1656 CDT and proceeded westbound toward an area of echoes 35 to 40 n.mi. to the W of San Angelo. Cloud base was noted at 9,500 ft at an uncorrected temperature of 16°C. The actual cloud-base temperature was likely closer to 14°C, considering that the local dew point was about 15°C when we took off.

We completed our climb near the anchor Cb about 35 n.mi. to the W of San Angelo and began seeding in a cloud to the S of this anchor at 1717 CDT at an azimuth and range from the SJT VOR of 257° at 35 n.mi. (264° at 33 n.mi from the airport). The seeded cloud looked very mushy and had only weak updrafts. The second seeding was on the ENE of the anchor in clouds that would ultimately feed into the larger parent. While this was going on, new clouds were forming parallel to the older NW-SE line of echoes. Our third seeding was in one of these new clouds.

We continued our seeding until 1903 CDT for a duration of 96 minutes, expending 56 flares on 15 treatment passes. The Piper Seneca with Tom Promersberger and Danny Rosenfeld aboard joined us in the area of growing clouds. They began base seeding at 1810 CDT and continued until 1907 CDT for a seeding duration of 57 minutes during which they burned 19 flares. Some of the clouds that they seeded had been seeded earlier from on top from our aircraft.

The clouds were nothing special today. They had weak updrafts and no rain drops and the older specimens had mostly small graupel. Some of the seeded clouds grew to > 10 km, but the growth mode was slow and mushy. Some of the clouds produced maximum reflectivities > 50 dBZ. Even so, I saw nothing that really impressed me as an effect of seeding.

Dr. Rosenfeld's Account of His Flight on the Piper Seneca

On take off the conditions were: Wind 170/10, T=34, DP=14.5. The NW quadrant was filled with cellular echoes that were poorly organized in a NW-SE orientation. No particular area seemed to be better than the other. The smaller clouds were sheared badly from the NW. Once they developed above about 15 kft there was not that much shear. I decided to concentrate on the NW side of the clouds for base seeding.

We took off at 17:48 with Tom Promersberger as the pilot. Tony directed us to the WNW, an area that Bill was already working with Mark Rivard as the pilot. The best clouds appeared to be those that Bill was already seeding. They were already precipitating quite heavily, so we decided to take the SE continuation of that cloud line, which looked firm and was not precipitating. Cloud base was at 10 kft, and we seeded at 9 kft. The seeding log, with GPS respective of San Angelo (Azimuth from San Angelo to the aircraft) is:

18:10	304/33	Ignited 2 flares, heading NE
18:15	309/33	Turning SW, continue burning 2 flares.
18:18	306/37	Turning E, continue burning 2 flares.
18:22	308/32	Turning NW, continue burning 2 flares.
18:25	308/38	Turning E, continue burning 2 flares.
18:29	314/33	Turning W, continue burning 2 flares.
18:31	312/31	Turning SE, continue burning 2 flares.
18:37	310/31	Turning SE, stop burning.

This cloud was seeded on its north side, which was a reasonably organized inflow, with updraft of 500 ft/min for about 1/3 of the time, no downdrafts. No strong updraft bumps. The best updrafts were mostly along the leading edge of the cloud. The cloud with the seeding position propagated slowly northward. A good rain shaft developed in the cloud, which initially did not precipitate.

18:42	307/30	Turning E, burning 1 flare.
18:45	306/31	Seeding
18:47	309/29	Stop seeding.

Turning under a new cloud base to the SE of the previous activity, which started to precipitate and cloud bases not as good any more. The cloud started precipitate and we stopped seeding when rain occupied most of the cloud bases.

18:56	320/37	Start seeding 2 flares
19:00	320/37	Seeding
19:04	324/34	Seeding
19:07	320/38	Stop seeding

Returned to the north edge of the cloud. It had already weak towers, but Bill said that they are strong with pileus. It turned out that it was not the same cloud. The base started to disintegrate, and we stopped seeding.

19:26 Landing.

<u>August 18, 1996</u>

Today dawned with broken to overcast altocumulus clouds and a scattering of virga and light showers. The temperatures and dew points were in the mid-70's and mid'60s, respectively. The winds were 10 to 15 kts from the SSE.

The weather had not changed much by late morning as Danny and I went through a dry run of the data system in the Duke, which is now ready to fly. We plan a test flight immediately after lunch. Once that is over we will have a look at the data and then work with Kelly Bosch to install the forward-looking video camera and VCR. Once that has been accomplished and if there is suitable weather, we will fly a two-aircraft hygroscopic seeding mission. Danny will be in the Duke with Mike Douglas and I will be in the Seneca cloud-base seeder with Tom Promersberger.

By 1300 CDT the altocumulus had decreased to broken and the first cumuli had formed. We were preparing for our 1330 CDT test flight of the Beech Duke. The surface wind had increased to 15 to 20 kts from the SSE. By 1330 CDT, however, the cumuli to our immediate W and NW had attained some depth and we were considering a flight that would serve as a test <u>and</u> as an actual scientific seeding mission.

The Duke tookoff at 1437 CDT and flew to the W and NW into our target area, finding cloud base at 10,000 ft MSL at a temperature of 10°C. There were several towering cumuli in the area at the time with larger TCU and a few Cbs from NE-SE. Upon reaching 12,000 ft and making a few cloud penetrations to determine that the data system was working, the Piper Seneca was scrambled to rendezvous with the Duke.

I took off in the Seneca with Tom Promersberger at the controls at 1520 CDT. We also found cloud base at 10,000 ft. We rendezvoused with the Duke at 1530 CDT and began an actual coordinated seeding case with the ignition of 2 flares at 1606 CDT at 123° at 32 n.mi. to San Angelo as measured by the GPS hand-held device on the aircraft. Dr. Rosenfeld on the Duke also had an identical GPS instrument. The position of the initial seeding to the nearest minute was 31° 41′ N, 100° 58′ W. The cloud base at the time was fairly uniform and moderately dark over a relatively small area.

Immediately after the ignition of the two initial flares I crawled to the back of the plane and began the release of SF_6 gas at a rate of 60 ft^3/hr, which is a little greater than 1/3 l/sec when calibrated for the SF_6 gas. (Although the flow meter readings are for argon gas, we calibrated it for the SF_6 gas by relating the flow-rate reading to the rate of expansion of a balloon that was receiving SF_6 gas. This process is described elsewhere.)

Hygroscopic seeding continued in an orbit beneath the cloud base until 1620 CDT for a total seeding duration of 14 minutes during which 7 flares were burned. The cloud base was barely detectable on radar at the initiation of the seeding and reached a maximum of about 30 dBZ subsequently. The updrafts at seeding had averaged about 500 ft/min, but the reached a momentary maximum of 1,000 ft during the seeding. The cloud base had begun to disintegrate by 15 minutes after the initial seeding, which explains why the seeding was terminated after the extinction of the last flare at 14 minutes after the initial seeding.

We then moved farther to the SE toward San Angelo in a search for additional suitable clouds. Meanwhile the Duke continued its repetitive passes through the seeded clouds. Early in the monitoring process one apparent hit of SF_6 was noted but there was no corresponding change in the FSSP droplet distribution.

The new area of clouds closer to San Angelo did not prove to be suitable as the clouds began to suppress in our area. Both aircraft then returned to the airport with the Seneca landing at 1655 CDT and the Beech Duke at 1659 CDT, giving flight durations of 95 minutes and 142 minutes, respectively.

A more detailed look at the data obtained by instrumentation on the Duke showed a slow increase in the median volume diameter from about 7 microns at the cloud base of 10,000 ft to 17 microns at the highest Duke flight level of 17,000 ft. The FSSP concentrations tended to be lower when the drop sizes were largest. Although the few instances of weak SF_6 signatures had corresponding MVD values of 17 microns, there were other points without SF_6 signatures that had drops of the same size.

August 19, 1996

This morning was mostly clear except for a few scattered altocumulus clouds. The temperatures were in the mid-70's and the dew points were in the mid-60's. The surface winds were 10 kts from the SSE. The main band of cloudiness on the satellite image this morning stretched from northern Mexico into New Mexico and Colorado. An area of cloudiness in the west-central Caribbean has developed over night and it could develop further into a tropical storm in a day or so as it tracks WNW toward the Mexican Yucatan Peninsula.

Today will have less cloudiness than yesterday but more heating. The weather should be suitable late in the day for our plan to obtain a relatively shallow but vigorous cloud in which we can look for a change in the droplet spectrum simultaneous with a hit of SF_6.

The first cumuli formed in the local area by 1300 CDT and by 1530 CDT there was a field of small cumuli with some vertical development. The temperature was 94°F and the dew point was 60°F and the wind was from the SE at 10 to 15 kts. We were planning a 1630 CDT takeoff of both the Duke and the Seneca for a flight to the SE within 50 n.mi. A few small echoes were noted beyond 100 km to the SE of the radar.

When we actually rolled out the aircraft, Tom Promersberger decided that the main landing gear on the Seneca needed air. Upon putting air in the left main, the retaining ring popped out and could not be reinstalled. This resulted in a delay while the problem was being addressed. I pointed out to Tom that the aircraft should have been pre-flighted this morning and air added to the tires at that time. This would have resulted in an early discovery of the problem and (presumably) an early solution, allowing us to fly this afternoon as we had scheduled.

Tom and I finally took off in the Seneca at 1719 CDT and the Duke with Danny and Mike on board took off at 1724 CDT. We found cloud base at 9,000 ft at a temperature of 11°C and the Duke found cloud base at 9,500 ft at a temperature of 10°C. By the time that the Duke reached its highest altitude of 16,500 ft the clouds were showing much more development in the general area than we had expected. The first was a small cloud that achieved Cb stature about 3 n.mi. N of Mathis Field in San Angelo. It had a line of growing clouds to its SW. There was another line of TCU oriented NW-SE to the WSW of San Angelo that captured our attention.

We began the hygroscopic seeding experiment at 1804 CDT at 198° at 20 n.mi. There was a shower to the N of our cloud mass. The updraft under our cloud initially was about 500 ft/min with a maximum of 1,000 ft/min. As the seeding continued we moved farther to the NW in the line. The echoes were moving to the SW and the development was on the W side as well, accentuating the apparent movement to the W. The updrafts beneath the clouds seemed to decrease as we moved NW.

The seeding continued until 1840 CDT when the last flare went out giving a seeding duration of 36 minutes. The region immediately below cloud base seemed to get progressively more hazy from the smoke from the flares. By this time the updrafts below cloud base had weakened and we left the cloud for the airport, landing at 1858 CDT.

The Beech Duke stayed with our initial cloud mass as we moved slowly NW. No obvious SF_6 hits were noted in real time on the aircraft. Later in the monitoring period the Duke moved farther to the WNW to the region where we had finished our seeding. A look at the data after the flight revealed some large rain drops at temperatures of about -2°C. These must have come from below since they could not have originated as melted graupel at that temperature.

The Cessna 340 was flying to our west doing operational on-top seeding in the target area. Some of the clouds grew quite well, one to the S of San Angelo in northern Schleicher County and the other to the SW near Mertzon. A total of 51 AgI flares were expended from this aircraft. Mike Douglas joined the Cessna 340 in the Duke a little later and also did some seeding. Both aircraft were returning to the airport as of 2100 CDT.

August 20, 1996

Today began with broken to overcast stratocumulus clouds that had decreased to scattered by 0900 CDT, revealing broken to overcast cirrus clouds that were moving from the NE. The winds were light and the temperatures and dew points were in the mid-70's and mid-60's, respectively.

The West Texas Weather Modification Association met in our office space this morning to discuss the progress on the operational weather modification program here in west Texas. I gave a briefing on a number of items of relevance to the effort.

The first cumuli formed in the local area by 1130 CDT and they had not achieved appreciable depth by 1330 CDT. We are planning a three-aircraft mission for hygroscopic seeding and photography. The plan is to fly the Seneca under a relatively small but active cumulus cloud and ignite two flares in the updraft. The Duke is to follow behind us and sample the plume of smoke from the Seneca, measuring particle size with the FSSP and sensing the SF_6 gas. The video camera on the wing of the Seneca will photograph the burning flares and smoke plume while the video camera on the Duke will photograph the same process from behind. The Cessna 340 will fly abreast of the Seneca and be video-taped by Christopher Woodley.

By early afternoon the cumulus clouds had grown only slightly in depth but we were still planning a three-aircraft mission by late afternoon. By this time it was obvious, however, the video cameras would not be installed on both the Seneca and Duke in time for the flight.

I took off in the Piper Seneca with Tom Promersberger at the controls at 1610 CDT. The Duke with Mike Douglas and Danny Rosenfeld aboard followed a few minutes later and the Cessna 340 with Mark Rivard and Christopher Woodley followed the Duke. We all flew to the SE and rendezvoused about 50 n.mi. from San Angelo. The coordination went very well as the Duke came in behind us and the Cessna 340 flew abreast and off to our right.

Our first case came at 1643 CDT on the 168° radial from San Angelo at a distance of 46 n.mi. with the ignition of two hygroscopic flares beneath cloud base. The Duke came in behind us and sampled the plume, obtaining several SF_6 hits, and then climbed up into cloud base. The Cessna 340 was to our right for photography as planned. Two more pairs of flares were ignited under the cloud, giving a total burn time of 12 minutes. Although it appeared to be a rather shallow cloud at the time I selected it, rain drops were detected at cloud base by the Duke at the time of initial seeding. This made the case unsuitable for our purposes. Two additional flares, ignited one at a time, were burned for photography. The Cessna 340 then returned to San Angelo and we continued our experimentation.

The second case was initiated at 1734 CDT with the ignition of two flares. The cloud was not very suitable with only weak updrafts. The seeding duration was 4 minutes.

The third case was the best of the three, beginning at 1759 CDT at a radial of 030° to San Angelo at 26 n.mi. To increase our chances of finding the SF_6 gas and hygroscopic plume, I increased the gas flow to the maximum possible, which could have been as high as one liter of gas per second. This is my estimate since the flow rate was off scale on our flow meter.

I burned two pair of flares in this case for a total burn time of 9 minutes. The updrafts were quite weak initially, increasing to 500 ft/min at 1809 CDT, about 10 minutes after initial treatment and 1 minute after the flares had burned out and the gas flow was shut off. The Duke continued monitoring this cloud through 1826 CDT, reporting that several apparent SF_6 hits had been obtained. We did not, however, detect any change in the FSSP droplet spectrum.

August 21, 1996

It was clear, hazy and warm with light winds early this morning. There were a few isolated patches of altocumulus clouds to the N. The morning satellite and radar images showed cloudiness and echo activity in the Texas Panhandle around Lubbock. Its origin and cause was not known at this writing. Tropical storm Dolly was still drifting W over the Yucatan Peninsula.

The first cumuli formed in the local area at 1030 CDT and developed slowly into the afternoon. The temperature had climbed into the low 90's and the dew point had dropped to 60°F. The winds were 10 kts from the E and it was hazy.

By 1600 CDT the Seneca and Duke were being pulled out for flight. The plan was to rendezvous at a point and light two flares and release SF_6 gas. The flare burn will be photographed at close quarters from a small camera mounted on the nacelle on the Seneca and from the nose camera that has been mounted on the Duke. The Duke will fly behind the Seneca in and out of the smoke plume from the flares. Yaron Segal, who arrived from Israel today, and Danny Rosenfeld will fly on the Duke with Mike Douglas. Christopher Woodley and I will fly on the Seneca for photography and for the release of the gas and the burning of the flares.

After this initial work, the Duke will fly a wind box for the calibration of the pointer on this aircraft. It will then climb and work with us on the Seneca for the selection and seeding of a large cloud for the purposes of rain enhancement. This will be coordinated with Tony Grainger at the WMI radar.

I took off in the Seneca at about 1700 CDT and climbed on a SE-bound heading to the cloud base altitude of 9,000 ft where the temperature appeared to be about 11°C. The Cessna 340 had taken off about a minute ahead of me for an on-top AgI seeding mission. Mark Rivard's estimate of cloud base was 9,500 ft. The Beech Duke took off several minutes later for a rendezvous with us about 35 n.mi. SE of San Angelo.

The convective clouds appeared to reach their peak in development between 1600 and 1700 CDT and were decreasing in number, depth and intensity as we climbed to altitude. After our rendezvous with the Duke we turned westbound with us in the lead. After the Duke had closed tightly on us from the rear we ignited four hygroscopic flares over the course of about 10 minutes, beginning about 1750 CDT. The flare burn was photographed from our aircraft by the miniature video camera mounted on the nacelle of the left engine and from the rear by the forward-looking video camera on the Duke.

We completed the photography under the bases of some large cumuli that were being worked from above by Mark Rivard on the

Cessna 340. Showers were just commencing on the western edge of the cloud mass. I asked Tony Grainger whether he wanted us to stay for an operational mission but he declined stating that the one on-top aircraft had everything well in hand. I had to agree. We returned to San Angelo, landing at 1824 CDT. Meanwhile Danny Rosenfeld, Yaron Segal and Mike Douglas flew a couple of wind boxes for calibration of the pointer system. Then they also returned to the airport. Later still, the Cessna 340 landed after having expended 10 flares during its on-top seeding.

<u>August 22, 1996</u>

Today dawned clear except for some cirrus and altocumulus clouds along the eastern horizon. The winds were light from the E. The temperature and dew point was 68°F and 63°F, respectively. Tropical storm Dolly has emerged into the Gulf of Campeche as it drifts WNW. It may reach minimal hurricane strength before its expected landfall to the S of Tampico, Mexico. It is not expected to affect the United States.

The first cumuli formed in the local area by 1030 CDT and increased in size and number into the mid-afternoon. The altocumulus and cirrus clouds noted on the eastern horizon also gradually moved into our area from the E. The maps and models indicate that a disturbance in the easterlies is moving into our area. If the models are correct showers and rain should commence late this afternoon and continue until late tomorrow.

Danny and Yaron spent the morning and afternoon attempting to account for the changing base line of the SF_6 detection instrument. They plotted the base line readings (in volts) as a function of aircraft altitude and as a function of time from when the instrument was first turned on. Meanwhile, Pat Sweeney is attempting to contact the individual from whom the instrument was rented to brief him on the problems that we are having with the detector. Pat intends to get him here in San Angelo as soon as is possible to address the problems that we have documented with the detector.

The plan for the day is to fly the Seneca and Duke in an operational mode if weather conditions warrant. We would attempt to identify a strong cloud with good feeders and seed them with hygroscopic materials and to attempt to identify a seeding signature in the form of anomalous rain drops near a cloud top of -5°C to -10°C. Unless we solve the problem with the SF_6 detector, we will not disperse SF_6 during this experiment. We will pay for the flight hours, but use the last of the operational SF_6 flares as long as we are doing an operational experiment. If not, we will pay for the flares as well if we do the experiment.

By late afternoon the cumulus clouds had not grown further as the middle clouds cut down on the heating. The winds were easterly at about 20 kts with stronger gusts. The temperatures had dropped into the upper 80's and the dew point held in the mid 60's. The Cessna 340, which had been launched in mid-afternoon, returned to base after the ejection of a few flares in the SW portion of the target. We then cancelled all other flight operations for the day.

Since we were down for the day, I contemplated renting a pontoon boat for a pre-sunset cruise on Lake Nasworthy with all project personnel for relaxation and munchies. The winds were too strong and the water too choppy, however, to enjoy the cruise. It would have to wait for another day.

By early evening an area of showers was advancing toward San Angelo from the E. The clouds could be seen growing up into the altocumulus clouds.

<u>August 23, 1996</u>

San Angelo had low overcast conditions, light to moderate rain and drizzle early this morning with light E winds and a temperature and dew point of 70°F. The radar showed a patchy area of level 1 and 2 echoes from San Angelo to the W and SW. The absence of reflectivity cores suggests that these clouds are rather shallow. This area moved into our area from the E during the night. A larger scale look at the weather suggests that the rain is more extensive from the SE-SW.

Tropical storm "Dolly" became a minimal hurricane with central pressure about 990 mb during the night and was entering the Mexican E coast this morning. Our tropical moisture influx during the night is not directly associated with this hurricane but it is associated with the general westward movement of tropical moisture into much of Texas and northern Mexico.

At this point it is doubtful that we will fly any hygroscopic seeding missions today since the coalescence processes are already highly enhanced. It might be interesting, however, to see how the cloud droplet spectra have been altered in the tropical air relative to previous drier days.

It stayed overcast in San Angelo the entire day, although the ceiling lifted, cumuli formed beneath the overcast and showers were scattered around the area. The Cessna 340 was airborne at 1620 CDT for operational seeding. He started out on top but could not find suitable clouds due to the overcast, and at my suggestion he came down to the cloud base of 3,800 ft for AgI seeding with the acetone burners. He seeded for 30 minutes in the NE quadrant of Irion County and then returned to the airport.

I was airborne in the Seneca at 1653 CDT along with Christopher and Tom Promersburger. We flew only long enough to photograph the burn of three hygroscopic flares from a camera that was mounted on the tail of the Seneca. It was from my perspective at cloud base that I had suggested that Mark in the C340 come down to cloud base for seeding. We landed in the Seneca at 1728 CDT.

Tony Grainger left the project as of 1700 CDT today and I assumed his duties at the radar van. I frankly feel somewhat overwhelmed with my dual responsibilities as chief scientist for the research effort and as the project meteorologist for the operational seeding program. Somehow I will work things out with the assistance of the other personnel. Kelly Bosch has been a big help to me in many areas since I arrived, and he has agreed to assist me in the radar when I am flying research missions and/or flying on the aircraft for operational seeding missions.

August 24, 1996

It rained heavily in San Angelo overnight and the day dawned with low overcast conditions, occasional drizzle or light rain, and light ENE winds. The temperature and dew point was 68°F. The early morning radar scan showed only very light showers in our area and the satellite image showed extensive cloudiness. The remnants of hurricane Dolly are still in Mexico and hurricane Edouard is at about 14°N well to the east of the Lesser Antilles.

Today should be an active one for the operational project, provided we get enough clearing for solar heating. We are incredibly moist from the surface into the upper troposphere and good heating should generate some large clouds.

By 1300 CDT we still had overcast conditions in the San Angelo area, but the cloud base had lifted slightly and some cumulus towers could be seen towering up into the overcast. I asked for the Cessna 340 to be pulled out for cloud-base AgI seeding and I also requested that the Seneca with the flare rack that accommodates the fixed AgI flares be pulled out for possible seeding later in the afternoon. The plan was to fly the Duke for the measurement of the FSSP cloud droplet spectra. It is doubtful that any aircraft will be able to break out on top of the overcast at 20,000 ft.

I spent my afternoon in the radar van for the first time this year in service of the operational project. The weather was totally unsuitable for research operations, so I concentrated on the possibility of flying for operational seeding. I had scrambled the Cessna 340 by late afternoon and Mark spent less than an hour trying to figure out a way to seed some convective cells that were intensifying in Schleicher County. I had suggested that he seed below cloud base with the acetone silver iodide burner, but the bases were too low to allow such seeding. The clouds were embedded, so I did not ask him to climb for on-top seeding.

I then asked him to return to the airport and suggested that he hurry to avoid a line of showers that was moving in from the E.

Fortunately, he did manage to land before the heavy rain began.

The rest of the day and evening consisted of thick overcast conditions with light rain and embedded showers. No flights were contemplated overnight because of the low ceilings and fog.

August 25, 1996

It remained overcast with low clouds during the night and there were occasional periods of light rain. The pavement in the local area was beginning to dry by early morning but light rain begin again after 0800 CDT. The radar scan showed a large patch of light rain to the E of San Angelo. The temperature and dew point was 70°F and the winds were light from the E.

By 1300 CDT the rain had stopped and the sky had lightened. There were broken to overcast cumuli and nimbostratus with a few breaks evident in the upper overcast, revealing a blue sky. The echo mass to the E was weakening but a new mass had moved into Crockett Count from the S. The fuzzy edges of this mass suggested that any convective clouds that existed were embedded.

The weather never did improve enough for operational seeding, but there was enough of a break in the clouds over and just to the W of San Angelo to permit a research flight to measure the cloud droplet spectra in the growing cumuli nearby. Danny Rosenfeld and Mike Douglas took off in the Duke at 1614 CDT, made a succession of cloud passes up to 19,000 ft and then returned to the airport at 1734 CDT for a flight duration of 80 minutes. The only significant echoes at the time were around and to the E of San Angelo and into the NE corner of Irion Counties northwestward into Sterling County.

It was still overcast in the local area at sunset and there was a scattering of echoes on the radar scope.

August 26, 1996

It did not rain overnight but the day dawned overcast with at least two layers of cloud. It continued very moist with the temperature and dew point in the upper 60's. The wind was calm. The local radar scan was virtually free of echo and the statewide scan had a scattering of echoes, mostly in the SE portion of Texas.

By 1300 CDT the temperature was in the low 80's and the dew point was 69°F. The sky was broken to overcast and a few cumuli were growing beneath the upper clouds. I was hopeful at this point that suitable clouds would develop later in the day.

Through the rest of the afternoon there were a few small relatively weak echoes and most of these were to the N-E-S of the radar. There were very few echoes in the target.

By 1630 CDT I had decided to take a brief flight in the Seneca with Tom Promersberger to test 4 of the Henderson hygroscopic flares. We took off at 1644 CDT and headed S to cloud base at 5,400 ft at a temperature of 18°C. We ignited the first flare at 1657 CDT and it burned for 4 minutes until 1701 CDT. We then lit another flare at 2203 CDT and after a few seconds the next flare inboard of it also ignited. Both flares burned for 4 minutes. The last flare was ignited at 2208 CDT and had burned out at 1712 CDT, again a burn time of 4 minutes. All of the burns were smooth and uniform and did not seem to differ from the South African flares. It should be mentioned, however, that the Henderson flares consisted of 500 gms of hygroscopic material while the South African flares contained 1,000 gms.

The weather did not change much into the early evening. There was still a scattering of small showers in the area and most of them stayed E of a N-S line through San Angelo. Some of these clouds appeared to have glaciated tops that were streaming to the SE as the showers themselves moved NNW. We likely would have worked this cloud mass for some time had it been in our target area.

August 27, 1996

San Angelo was overcast with multiple layers of cloud again today. There were breaks in the low and middle clouds to the E and SE and the overcast was thicker and darker SW-W where the radar showed a scattering of weak echoes. We had occasional sprinkles at the airport. The wind was from the SSE at 5 to 10 kts. The temperatures were in the low 70's and the dew point was near 70.

Meanwhile the tropics continued to be fairly active with hurricane Edouard about 300 miles NE of the northern Lesser Antilles and a tropical depression to its E being slung SW under it.

By 1000 CDT conditions had not changed too much. The area of weak echoes had shifted to the NW quadrant of the scope and the low deck had developed a few darker spots indicating that a few of the clouds had increased somewhat in depth. All clouds were moving from the S, so the echo motion should be from the S as well.

By 1300 CDT the clouds had developed enough for the launch of the Cessna 340 and he was in the air at 1322 CDT with the intention of working clouds in Irion and Sterling Counties. Mark encountered several layers of cloud in the climb to altitude and had difficulty finding suitable clouds. He managed to make one cloud pass and drop two flares. He then flew into Glasscock and Reagan Counties in a search for suitable clouds after which he returned to the airport, landing at 1450 CDT for a flight duration of 78 minutes.

By 1600 CDT a broken line of echoes oriented ENE-WSW was developing to the NW of Glasscock and Sterling Counties. Although the cell movement was to the NNE, it looked to me as though the line itself might move toward the area from the WSW. At this point I scrambled the Duke with Mike Douglas as pilot with the intention of scrambling the Cessna 340 once again if conditions warranted.

Between 1700 CDT and 1720 CDT Mike Douglas was in Seed 1 (the Duke) near the S end of runway 18 running up the engines because he did not feel that the aircraft was ready to fly. I learned later that he was suffering an unexplained power loss in the right engine. By the end of the period he had decided that the aircraft was not safe to fly, so he taxied back to the ramp.

I then scrambled Seed 2 (Cessna 340) for on-top seeding in the target; he was airborne at 1802 CDT. Both Mike Rivard and I were doubtful that he would be able to work the clouds from on top because of thick cirrus blow off into the target area from clouds in the line. When he finally did reach altitude, our suspicions were confirmed. There was too much thick middle and upper cloud to reach the clouds from on top. He then descended to cloud base and began base seeding at 1850 CDT with the AgI/acetone burner.

The situation appeared to be reasonably good for seeding at cloud base in that the clouds showed some organization and inflow. Maximum cloud-base updrafts in the line initially were about 1,000 ft/min and they decayed to 500 ft/min later in the seeding period. Over the 122 minutes Seed 2 seeded from the northern third of Upton County into SW Glasscock and NW Reagan County. Our radar showed this area as a relatively weak band of echoes, but the Midland and San Angelo radar depictions suggested that the echoes were much stronger. This finding agrees with my earlier impressions that our radar does not see the echoes well in the W portion of its scan. Regardless of the actual echo intensities, rain was produced for an extended period in the seeded area.

There was also another weaker and less organized echo mass in NE Sterling County and I scrambled Seed 3 (the Seneca) to work this area at cloud base using the fixed burn-in-place AgI flares. Tom Promersberger took off in Seed 3 at 1854 CDT and landed at 2025 CDT for a flight duration of 91 minutes. He burned only 3 flares during this period and frankly had little to show for it. The clouds were just not suitable in this area.

By 2130 CDT we were shutting all of our equipment down and heading for home. The echoes in the target were now dissipating and there was no prospect of additional suitable clouds during the night. It had been a long but productive day. I hope that Seed 1 will be repaired in time for flights tomorrow.

August 28, 1996

San Angelo had less cloudiness this morning than yesterday morning. We did have broken cirrus and altocumulus clouds that thickened to the NW and N. The temperature was in the low 70's and the dew point was 70°C and the winds were light. The radar showed a band of echoes stretching from N of Midland to Lubbock and beyond. This bank stretched from NE New Mexico into the Texas Panhandle and then E to virtually the east coast of the United States. This suggests that a weak synoptic feature, such as an old front is organizing the convection.

The tropics continue to be active. Hurricane "Edouard" has weakened and is still tracking WNW well to the NE of Puerto Rico. Meanwhile, tropical depression 6 to the SE has intensified to warrant its naming as tropical storm Fran. Because it is currently at 15°N, Fran likely will traverse the northern Lesser Antilles in a couple of days. There is also another depression farther to the SE of Fran, so it looks as though we will be watching tropical storms well into September.

The first cumuli had formed in the local area by mid-morning and they were concentrated primarily to the W and NW. Strong solar heating was taking place to the S of an E-W line through San Angelo. The cumuli looked as though they were going to develop early as one of them had towered up into overcast by noon. By 1300 CDT, however, the target was still clear of echo, although there was an echo to the N of San Angelo.

Heavy rain continued through the morning from NW-N-NE of Midland and by 1320 CDT the National Weather Service at Lubbock had issued a flash flood watch for many counties in this region of heavy rain. Virtually simultaneous with the watch was a warning for several counties in the watch area.

By 1330 CDT there was a Cb echo along the SE border of Sterling County. Thinking that this was the beginning of echo development in the target, I inquired about the status Seed 1 (the Duke) and its troublesome right engine. I was told that it had been run up extensively and appeared to be OK. When echoes started to develop in Crockett County, I called for the launch of Seed 1.

Mike Douglas was airborne in Seed 1 at 1447 CDT. He found cloud base at 5,500 ft at a temperature of 18°C as he climbed initially toward Crockett County. After he topped the lower cumuli he indicated that there were no seeding targets in Crockett County, so I suggested that he reconnoiter NW Glasscock County. He did so, finding no suitable clouds, and then flew along the N border of Glasscock into Sterling County where a large thunderstorm echo was growing about 10 n.mi. N of the N border of the county. After finding nothing there, I suggested that he return to base. He landed at 1552 CDT.

I continued to watch the target area into the late afternoon. The strongest echo area was a NNW-SSE line of echoes to the NE of San Angelo. The clouds in the line had bright white bubbly tops and inky black bases. They had the appearance of clouds in the deep tropics. The visibility was great. The clouds persisted in this region for some time, extending ultimately into Runnels County.

During the late afternoon, Mr. Jim Rydock, who provided the SF_6 detector for the program, showed up at the radar trailer after his long trip from Arizona by car. He has come at our request to service the SF_6 detector, which has not been much use to us so far, because of its unstable base line and poor sensitivity.

By 1700 CDT, however, a scattering of weak echoes, having a NNW-SSE orientation parallel to the line to the NE of San Angelo, had formed to the W and SW of San Angelo. With a good imagination, one could see the potential for a line stretching from eastern Irion County into Sterling County and then into Glasscock County. At this point I decided to take the chance of scrambling both Seed 1 and Seed 2 with Seed 3 standing by for launch as well. I was certain that if I did not take this action we would still be on the ground when the suitable clouds in the line formed. On the other hand, if I was wrong and nothing developed, I would look foolish for having scrambled two aircraft with nothing to seed.

Seed 1 was airborne at 1733 CDT and Seed 2 took off just behind at 1736 CDT. Because Mike in Seed 1 could only seed on top, I suggested that he concentrate his activities at the S end of the line where the cloud towers likely would be more exposed. Mark was to work farther to the N where we ran the risk of having the new clouds embedded in the upper cloud that had been produced earlier by the heavy convection to the NW and N. As they climbed out, I scrambled Tom Promersberer in Seed 3. Tom took off at 1804 CDT with instructions from me to do fixed AgI flare seeding in updraft regions at cloud base in the portion of the line 20 to 30 miles SW-W of San Angelo.

When everyone finally got to altitude, we put the plan into effect. Seed 2 could not find any exposed cloud towers from on-top so I asked that he seed at cloud base with both AgI burners, beginning in Sterling County along the line and then S and SE into Irion and Schleicher Counties. Meanwhile, Mike was able to work on top of feeder clouds in the line, mainly in eastern Irion County and then S into northern Schleicher County. Tom worked the entire time at the base of the line to the W and SW of San Angelo as planned. It appears, therefore, that the portion of the line in Irion County just to the W of San Angelo had repetitive seedings over nearly 2.5 hours.

The line of echoes organized as the individual echoes drifted to the NE. The portion of the line near San Angelo was drifting into the 10 n.mi dead zone of the radar by 2100 CDT just after Mark in Seed 2 had landed at 2032 CDT. Seed 1 had landed earlier at 2002 CDT and Seed 3 at about 1930 CDT. The flare expenditures during their flights had been 41 for Seed 1, 12 fixed burn-in-place on

Seed 3. The two AgI burners had been on for 2 hours 20 min during the flight of Seed 2.

Yaron and I did not leave the radar trailer until 2130 CDT. It was raining lightly at the time and there was occasional lightning SE-S-W. Heavier rain began in our area later in the evening and continued until just after midnight.

<u>August 29, 1996</u>

The rain that had begun in San Angelo about 2100 CDT as our seeded clouds moved into the area continued until midnight. Then there was an interlude of several hours with little shower activity. By 0600 CDT, however, a new shower area was forming in the same region that had the earlier heavy rain. Whether the new convection formed on outflow boundaries of the earlier seeded convection is not known, but we should do an analysis of Midland and San Angelo NEXRAD data to find out. Judging by the satellite images and radar depictions for the area we were in an synoptic area of enhanced convection, so rain was going to occur without us. Nevertheless, it is quite possible that seeding had enhanced the rainfall in our area.

A total of 2.8 in. of precipitation had been produced as of midnight, bringing the monthly total to 5.72 in, which is nearly 4 inches above the normal. The yearly total as of midnight was 12.82 in., which is 0.33 in. above the normal to date. The surface winds were generally from the E as low scud moved across our area during the heavy showers. The temperature and dew point was near 71°F, dropping into the upper 60's during the heavy rain episodes.

In looking at a morning time-lapse of the echoes in Texas this morning along with the surface winds, it appears as though a circulation exists on an old front or shear line, having its center in central Texas to the SW of Dallas. The surface winds in west Texas were up to 15 kts from the N while those in east Texas were from the S.

Yaron and I also accessed the NEXRAD radar estimate of precipitation for much of Texas over the past 24 hours. The highest rain estimates, amounting to point values of 8 to 10 inches was noted about half-way between San Angelo and Dallas. This area decreased to a minimum of 2 to 3 inches toward San Angelo until the secondary maximum in Tom Green and Irion Counties where we seeded heavily last evening. The maximum in this area ranged between 3 and 5 inches as of 0600 CDT where heavy rain was still falling.

Meanwhile hurricanes Edouard and Fran are tropical storm Gustav are churning WNW in the Atlantic. Both storms appear to be headed ultimately away from land and out to sea. That's fine as far as I am concerned. With the heavy rain in recent days, the last thing we need here is a tropical storm.

It was still raining over the entire area as of 1245 CDT. Some of the showers were quite heavy and flash flood advisories and warnings were being issued for streams in Irion, Tom Green and Crockett counties. We have no plans to fly for operational seeding today even though there are portions of the target that have not had excessive rainfall. It would be too difficult to explain to the local populace why our planes are in the air in view of the local flooding.

The rain had stopped at the airport as of 1315 CDT, although there were still showers scattered around the area. Patches of blue appeared began to appear in the overcast skies and the possibility of flying to test the SF_6 detector were improving. The plan is for Jim Rydock to fly in Seed 1 with Mike Douglas to see whether the instrument is stable. If it is, we may be able to do a two aircraft mission in which I release the SF_6 from the Seneca and it is detected by the instrumentation of the Duke.

By 1530 CDT the sky had cleared further, leaving a magnificent blue sky and a scattering of Cbs with bright white tops and black bases. They did not appear to be overly tall and their anvils were shearing to the ENE.

The new plan was to send the Duke out with Mike Douglas and Yaron Segal for initial measurements with the Seneca right behind. If the instrument checks out, we will attempt to find a suitable cloud for base release of SF_6 from the Seneca and its detection by the Duke. Our main anticipated problem is finding a suitable cloud with a high enough base to allow us to do the test.

Seed 1 took off at 1704 CDT and we in the Seneca were right behind him at 1706 CDT. The weather at the time consisted of overcast anvil cirrus with an undercast of small cumuli. There were TCU and a few Cbs NW-NE and radar was tracking them from 030° at 15 kts, which is an unusual echo motion suggesting that we are on the W side of an upper level disturbance. The sky to the W was mostly clear except for the low cumuli. Cloud base varied from 3,500 ft to 4,000 ft at a temperature of 19°C.

Seed 1 rendezvoused with us to the NE of San Angelo and came up behind us to sniff for the SF_6 gas after we began our flare burn and gas release at 1748 CDT. A large chunk of one of the flares fell off almost immediately and I had Tom light another right away. The other burned completely. Meanwhile the Duke detected the SF_6 behind the aircraft. I turned the gas off at 1754 CDT.

We began another burn of two flares and gas release beginning at 1757 CDT 23 n.mi. to the NE of San Angelo. The cloud was on the flank of a showering system, but it did not have much updraft. Seed 1 detected the gas and then moved up into the cloud. Again a large chunk of one of the flares fell off and fell to the ground. I took two photographs of this flare burning in a field. It is fortunate that this came after a big rain. Otherwise we could have started a fire if the flare had fallen into dry grass.

Once the aircraft was in the cloud, I allowed the last flare to burn out but continued the release of gas. The last release of gas was at 1807 CDT. We then returned to the airport, landing at 1823 CDT for a flight duration of 77 min. Upon inspecting the aircraft flare rack I noted that an additional flare had ignited and burned briefly. Thus, three of the six flares had problems and this may well be due to leaving the flares on the rack for several days. The high humidity may have resulted in their deterioration. We will have to take the flares off the aircraft after each flight if we do not use them.

After looking at the flight data, we discovered that Jim Rydock had indeed stabilized the base line of the SF_6 detector. In addition, we did get a few SF_6 hits but they were comparable to we had detected before. Upon looking at the video tape, however, we noted that Seed 1 had only traversed the plume for a brief period. We do not know, therefore, whether the hits were rather small because of the instrument or because we were not in the plume for an extended period. Jim will make more adjustments of the instrument and we will fly the two aircraft again tomorrow.

By evening there was still a scattering of showers in the local area. For the entire rain event we had obtained 4.85 in., bringing the August total to 7.58 in., which is well above the August normal of around 2 inches. The yearly total to date is 14.68 inches, which is now above the normal to date of 12.59 inches. In flying over the area, I saw a few flooded regions. Overall, however, the area looked fresh and green. This rain has been good for the area. Still, I am happy that it stopped when it did. A little more rain and the entire project could be shut down.

<u>August 30, 1996</u>

It was overcast with at least two layers of low clouds and there were a few light showers in the area. Some impressive Cbs could be seen to the SE through breaks in the overcast. The echoes on the radar scope were moving to the SSW as they were yesterday. The temperature and dew point were in the low 70's and the winds were light.

Yaron got sick again on the Duke yesterday, so today we plan to switch aircraft to see whether that will help. I will fly on the Duke (Seed 1) the cloud physics monitoring aircraft and Yaron will fly on the Seneca (Seed 3).

In the late morning I had a conversation with Dale Bates during which he indicated that he would like to put the operational seeding program down until Tuesday, September 3, 1996. He viewed the heavy rainfall of the past few days as a natural opportunity to give everyone a rest. I agreed. It is obvious too that he is now getting flack about any seeding in view of the recent flooding episode. He likely fears a lawsuit.

Provided the planned test goes OK today, I have no problem with everyone getting at least the weekend off from the research effort as well. The clouds are so tropical that a seeding with hygroscopic material would not prove anything anyway. To keep everyone working when Dale Bates, Scott Holland and George Bomar have ordered that they take the time off would not be too smart on my part. I do, however, plan to bring everyone back for work on Monday, which is Labor Day, a national holiday. If the weather is highly unsuitable, however, I will give everyone another day off. It is very ironic that what is unsuitable this year would have been viewed as highly suitable last year. We are out of synch with the weather.

By 1300 CDT San Angelo had broken to overcast clouds that consisted of tropical-looking cumuli underneath a relatively shallow layer of cloud with maximum tops probably less than 3 km. Even these shallow clouds were producing showers with small drops much as they would in the tropics, especially in Hawaii. The temperature was in the upper 70's and the dew point was 70°C. When we fly today, I hope to make ascending passes through a few of the cumuli so that I can specify the cloud droplet distribution.

During the flight today we will burn a few hygroscopic flares to serve as a tracer for the released gas. I learned later in a telephone conversation with Dale Bates that he had told the newspapers that we will not burn any flares in his area today, so I will have to burn the flares outside the operational area, even though I will do it in clear air without any intent to alter the rainfall. I certainly do not want to cause any public relations problems for the operational project. On the other hand, we brought Jim Rydock here to fix the SF_6 detector and I cannot tell whether it has been fixed unless I fly to release the gas, using a burning flare as the tracer.

After a number of delays, I finally took off in the Duke at 1702 CDT. The sky was messy with low shallow cumuli and low scud. There were a number of showers in the area restricting visibility. The Seneca with Yaron aboard was off 1 minute behind us. We both climbed to the SW and then the SE and E to get above the clouds, topping them at 11,000 ft where there was a stable layer. Once above the clouds, I could see towering cumuli and Cbs to the distant ESE-SSW.

It took awhile but we eventually joined up with the Seneca burning flares and releasing gas in the lead and me in the Duke right behind. We flew in and out of the smoke plume at close range and then back perhaps 100 m or so. We got a number of SF_6 hits with their largest amplitude was just over 1 volt, which was smaller than Jim Rydock expected. I obtained some very good flight video of the test. We also got a few FSSP and 2D-C hits of the nuclei. Yaron and I will try to size them. Some of the particles looked like ash, perhaps from the cardboard binder, while the other particles looked quite regular as small dots on the 2D-C. Given a day or so and we will have some idea of their size distribution.

We burned 4 South African flares today and they all burned smoothly. It is obvious, therefore, that we must remove the flares from the racks after each flight and store them in desiccating material. Otherwise, we will create a safety problem for people on the ground.

After the flight we analyzed our situation, concluding that the problem with the SF_6 detector is not the detector itself but rather the means being employed to get the outside air to the sampler. The clincher for me was when Jim Rydock took a syringe sample of air from the Seneca after the flight and introduced it into the detector. The resulting signature was full scale at 5 volts.

We then cast around for ideas on how to get more air to the sampler while the aircraft is in flight. The two best ideas that surfaced were either to increase the diameter of the intake and turn it into the wind or to sample outside air after it has been through the aircraft compressor. Jim Rydock will make the modifications tomorrow, but we will not be able to test the changes until Monday since everybody but Yaron and I are off for the weekend. By that time Jim will be back in Arizona. If these modifications do not work, we will be on our own to made further modifications.

<u>August 31, 1996</u>

San Angelo had low overcast clouds, light winds and temperatures and dew points in the upper 60's this morning. There was very little echo activity in the local area. There was a large echo mass moving S through the southeastern corner of New Mexico and a few echoes in SE Texas. Regardless of how the weather shapes up, we will not be flying today or tomorrow.

Jim Rydock was here this morning making the modifications to the air intake of his SF_6 detector that are discussed above. He then left for his return trip by car to Arizona.

The weather is forecast to dry out by Monday and continue into at least the middle of next week. The temperatures are forecast to climb back into the 90's, so maybe we will have the type of cloud that we desire for hygroscopic flare seeding.

San Angelo still had overcast cumulus and stratocumulus clouds by early afternoon and these decreased in number during the afternoon such that we had only scattered clouds by sunset. The only echo activity during the day was to the distant NE near Abilene. I would see the Cb cloud mass through the increasing haze during the late afternoon. Even if we had been in operation today, we would not been able to find suitable clouds for our research. It is nice that the brief period of R&R for project personnel coincided with a period of unsuitable weather.

I spent a portion of the day looking at some of the FSSP and 2D-C data that we obtained yesterday in clear air when the Duke was flying close behind the Seneca during a burn on the South African flares and gas release. In no instance did we obtain simultaneous FSSP and 2D-C data, suggesting that we were so close to the Seneca that the plume had not passed over the entire aircraft. The most noteworthy initial findings were the images of almost round exhaust particles between 100 and 300 microns in concentrations of up to about 30/liter. It may be these particles, which in many ways looked like drizzle drops, that are likely responsible for the rain drops noted by Mather in South African clouds.

September 1, 1996

The month of September in San Angelo began with low overcast clouds and fog and light winds. The temperature and dew point were in the mid to upper 60's. I expect the dew point to drop later when the low clouds burn off. The radar scan and the satellite images showed very little activity in Texas, except for a shower area near Dallas-Ft. Worth. Hurricane Edouard is slowly weakening as it tracks slowly northward toward eastern Massachusetts. Hurricane Fran, now a weak hurricane, is expected to intensify today as Edouard moves away. Fran may well pose a threat to the southeastern U.S. in a couple of day.

The low stratus overcast stayed in our area through noon and this struck me as highly unusual for the 1st of September. There were no echoes anywhere on the scope.

By 1400 CDT the overcast had thinned and become broken and a few CU and TCU could be seen SE-SW through breaks in the low clouds. The radar showed an area of echo to the distant SE. The surface winds in San Angelo were ENE at 10 kts and the temperature and dew point were 77°F and 71°F, respectively. I am surprised at how high the dew point has remained.

Not much changed for the rest of the day. The sky cleared further and the TCU and a few Cbs persisted to the distant SSE-SSW. They were rather pretty with their tops illuminated by the setting sun. It would not have been a good day for either the research or operational seeding programs, so it is just as well that we were down today.

September 2, 1996

It was mostly clear early this morning except for some thin scattered to broken cirrus clouds, which were moving from the W. The visibility was restricted somewhat due to a fog and haze. The temperature and dew point were 67°F and 66°F, respectively, and the winds were calm. There was no echo activity on the scope.

Today should be a busy day. Yaron will spend the morning generating more plots of the concentration of droplets (#/cc) as a function of FSSP channel. He will then generate printout of FSSP and 2D-C data that we obtained during our recent SF_6 and hygroscopic flare test in which the Duke flew in the immediate wake of the Seneca. Meanwhile, I hope to work with Kelly Bosch to do the bead test calibration of the FSSP.

After the air intake for the sampling of the SF_6 gas beneath the belly of the Duke has been turned into the wind, we will again fly the two aircraft to see whether this modification has improved the detection of the SF_6 gas by the Rydock SF_6 detector. By a quick change in tubing we are prepared also to take outside air through the aircraft compressor to the detector. It seems that we all agree now --- this is surely a bad sign! --- that the problem is that the sample pump within the detector is not working efficiently against the aircraft pressurization system such that only small air samples are reaching the detector. Turning the air intake into the wind or running the air through the pressurization system is our solution to the problem. We'll see what happens.

Depending on what happens with the test and on how the weather develops, me may conduct a research mission today. I remain concerned about the high dew points and the likelihood that coalescence will be active in the clouds of today. The resultant rain drops could mask any effect of hygroscopic seeding.

We are getting low on SF_6 gas, and we may have to consider buying more from the gas company in El Paso, Texas. If we buy more gas, we will have to pick it up with one of the project aircraft, probably the Seneca. As of today, we have used 13 hours of our 24 hour allotment of flight hours for the Seneca and about 11 hours of our 24 hour allotment of hours for the Duke. Since the cost is the same, the Seneca hours are exchangeable for Duke hours and vice versa. We have also used about 1.5 hours for the Cessna 340, which must be deducted from our 48 hour allotment of flight hours. When all this is done, we have about 22.5 hours left from our 48 hour allotment. If we need more hours, the cost is only $98 per hour, which is a great bargain.

The first cumuli formed in the local area at 1015 CDT and there were a few towering cumuli to the distant W in the operational area at 1100 CDT. By noon several of these clouds had reached Cb stature and by 1245 CDT the echoes associated with this cloud mass sat astride the Glasscock and Sterling County border. The anvil tops of this cloud mass were streaming strongly to the E. There was nothing else on the radar scope. The cumuli in the local area were small and scattered. Clearly, something was forcing this lone mass of deep convection.

On Friday Dale Bates told me (and the newspapers) that there would be no seeding and no burning of flares in the operational area through the Labor Day weekend, so I guess there is no reason to be concerned about the early echo developments of today. Still, it is hard to look at such nice clouds and do nothing. If we do any research tests today, they will have to be done outside the area in order to honor Dale's promise that "no flares will be burned in the operational area during the Labor Day weekend."

We finally did the bead test of the FSSP and my initial impression is that the calibration is OK for the lower channels and up to 5 microns low for the channel 25 to 35 microns. Yaron and I intend to look into this further, before reaching a final conclusion. (When we did, we concluded that dust in the hangar at sizes < 25 microns diameter) were adding noise to the test and that the bead test had confirmed the calibration that we had been provided with the FSSP.)

By 1400 CDT the aircraft were being pulled out for the tandem flight to test the SF_6 detector. There were a few large clouds and Cbs W-NW in the operational area but the cumuli to its E and N were still quite small.

I took off in Seed 1 with Mike Douglas as pilot at 1433 CDT, just behind Seed 3 with Tom Promersberger and Yaron Segal aboard. We climbed out to the E and rendezvoused for a flare burn and gas release. The first time we took air in from the aircraft belly and the second time we took it through the aircraft pressurization system. Both times we had huge gas hits but did not record any 2D-C or FSSP particles. After both hits the baseline seemed to jump to a level 3 to 4 volts above where it started, but it did not come back down no matter what I did to bring it down.

Because none of us had an explanation of what had happened, we returned to the airport with Seed 1 landing at 1523 CDT for a flight duration of 50 minutes. Seed 3 landed a few minutes later. After talking with everyone at the airport and also with Jim Rydock in Arizona we concluded that both time we likely had such strong hits of SF_6 that the system had saturated. Jim said that it is possible to have such a strong hit that it might take days for the instrument to come back down to normal. If everyone is right, then we may have solved our problem of not detecting the SF_6 gas. Jim's advice was to fly the aircraft on a mission in the expectation that the problem has been solved.

I had intended to fly another mission today, but by this time it was too late in the heating cycle and the clouds were beginning to dissipate. I saw no sense in scrambling for another flight if the clouds were on the down trend, so I canceled all flight operations for the rest of the day. Tomorrow I hope to begin our experiments in earnest in the expectation that we have solved our SF_6 problem. We will start at cloud base and work our way upward. If we get good hits along with good microphysical data, we can then turn our attention to the supercooled regions of the clouds in a search for rain drops. We probably have enough flares until our last day on September 10th, so I will not hesitate to give the clouds a good seeding provided they have updrafts to warrant it.

The initial thunderstorm mass in Glasscock and Sterling counties did not last very long into the afternoon. They put out a good cirrus cover but did not appear to have been overly rain productive. Late in the afternoon, however, a larger mass of thunderstorms developed to the distant WSW-WNW from San Angelo well out of our operational area. These were large and strong storms that produced heavy rain and perhaps some severe weather.

By 1800 CDT virtually all of the cumuli in the local area had dissipated. The Cb mass to the distant W was still very strong. Had this been an operational day, we likely would have scrambled one aircraft for operational seeding. Because we were late in getting our first test done, it is doubtful that we would have had a successful second research mission even if we have been allowed to fly into our target.

<u>September 3, 1996</u>

San Angelo had patches of altocumulus and cirrus clouds this morning with light winds. There was a slight haze and the temperatures and dew points were in the low 70's and upper 60's, respectively. There were no echoes on the radar scope. The forecast for today is for isolated thunderstorms.

By 1100 CDT there was a beautiful scattered to broken layer of altocumulus castelanus over much of the sky with small cumuli forming underneath. The dew point was high at 71°F. At 1300 CDT the cumuli in the local area had not increased in size or number, remaining only widely scattered. The broken altocumulus castelanus layer persisted and a small area of Cbs could be seen to the distant NE-E. They corresponded to rather strong echoes on the radar scope.

By 1430 CDT the cumuli had increased in size and number in the SE quadrant of the sky centered on San Angelo. Large Cbs could still be seen to the distant NE and small echoes were beginning to appear at closer range to the E. I am not happy about the tropical conditions, but I will have to make the best of what we have. We can at least do a cloud base experiment and see if we can detect the SF_6 at low levels in the cloud.

I finally took off in the Beech Duke at 1543 CDT. The Seneca with Tom Promersberger and Yaron Segal had taken off a minutes before me. We proceeded to the SE to our rendezvous point with the intention of doing a test burn of Henderson's hygroscopic flares. Cloud base was noted at 7,500 ft MSL at a temperature of 15°C, which was cooler than I had expected based on a surface dew point of about 19°C. Again today, the clouds were sheared badly to the SE such that the projection of the tops of small clouds fell to the SE of the cloud body.

By 1604 CDT we were behind the Seneca while it burned two hygroscopic flares produced by Atmospherics Inc. There was no release of SF_6 gas. My intent was to size the smoke particles from the flare. The test went on for 10 minutes during which Mike Douglas maneuvered the Duke repeatedly into the smoke plume. We measured nothing on the FSSP and 2D-C for reasons that are unclear to me.

I even had Mike pull up into a small cumuli to verify that the FSSP was working. Indeed it was with droplet concentrations approaching 400/cc, which is as high or higher than any concentrations we have measured in TEXARC 1996 so far.

We then came down behind the Seneca to continue our test, which is well documented on video tape, and still no measurement of any particles. You would have to see the video tape to understand my consternation. Later I deliberately had Mike fly into the edge of a rain shaft to check out the 2D-C and the rain drop images were clearly evident on the video monitor.

After the test, we searched for a suitable cloud for cloud base study. The region to the E and SE of San Angelo looked good for our purposes, although a number of clouds were producing showers. The area was slowly organizing into larger clouds, suggesting that Cbs could not be far behind.

I should mention for documentation purposes that the video camera today was reading 2 minutes 19 seconds <u>later</u> than the computer time. This means that 2 minutes 19 seconds must be subtracted from the video time in order to bring it to the computer time. I have asked Kelly Bosch to correct the video time tomorrow.

Our first cloud was nothing special. It had only a weak updraft < 500 ft/min. We began our burn of South African flares at 1633 CDT along with the SF_6 gas. At 16:34:52 CDT we traversed the plume of hygroscopic smoke at the exact moment it was entering cloud base at 7,800 ft. We had a small hit of SF_6 as we entered cloud. I saw nothing in the FSSP data to suggest any change in the droplet spectrum. The concentrations within a few seconds of the hit ranged up to 400/cc and the median volume diameter did not change between 6 and 7 microns.

The rest of this case was nothing special. A total of 5 flares had been burned over 11 minutes and we monitored the cloud over 15 minutes. We had no more hits of SF_6 gas as we ranged up to 9,000 ft in the cloud. I saw no point in climbing higher, since we were not getting repetitive gas hits within 2,000 ft of cloud base. We then moved to the W so I could have a look at our operational area in which a cluster of vigorous clouds was growing. Upon seeing them in Schleicher and Sutton counties, I scrambled Seed 2 via Kelly Bosch, who was taking my place at the radar --- (I have not yet perfected being two places at once.) Seed 2 took off soon after but was not airborne for long, because he could not did get a clearance from traffic control to work in the desired area. This is the first time that this has happened this year.

After our first case we moved into Schleicher and Sutton counties hoping to work the clouds at their bases that Mark could not in Seed 2 work at their tops. By the time that we got there, however, the clouds were dissipating. We then turned back to the E where the clouds looked great at a distance as they grew on the W side of developing Cb clusters. These were the same clouds that we had been watching all day. They were developing westward toward San Angelo even though the upper winds were from the W.

We began our second case of the day at 1748 CDT with the ignition of two South African flares under the bases of towering cumulus clouds on the S side of a taller showering cloud. As best I could tell the seeded area was free of rain initially except for a few drops near the edge of the cloud. A second set of flares was ignited at 1751 CDT and they had burned out by 1755 CDT. Isolated rain drops were detected near the edge of the cloud during this period as well. It should be noted that we hit what appeared to be ash from the flares at 17:51:12 CDT near the edge of the cloud at an altitude of 7,838 ft, which was about 300 ft above cloud base. The maximum particle size was 788 microns. There was no concurrent hit of SF_6 gas.

We monitored the cloud through 1759 CDT, detecting a small SF_6 gas hit at 1752 CDT. The hit was coincident with a sharp drop in the FSSP concentrations but there was no change in the equivalent drop diameter. If this represented an effect of the flares, the equivalent diameter should have increased as the droplet concentrations decreased. More likely we had a temporal misalignment due to what we believe to be a slower response of the SF_6 detector. If one corrects for about a 2 sec delay in the response of the SF_6 detector, the hit then coincides with a maximum in droplet concentrations of at least 425/cc.

We now have at least 4 documented hits of SF_6 in clouds (1 in 1995 and 3 in 1996) seeded with hygroscopic flares burned beneath their bases. None of the microphysical data obtained at the time of these SF_6 hits give us any reason to believe that the South African flares are producing a detectable change in the cloud droplet spectra. If any change is being produced, it must be occurring at larger sizes and at lower concentrations. This is not a new conclusion; I am merely restating it. My opinion is based on the 100 to 300 micron 2D-C particles that we have imaged in clear air behind burning South African flares. In many cases, the particles themselves looked like drizzle drops. I could readily imagine how these particles could become large rain drops high in the clouds.

After the second case, we drew back into formation with the Seneca for yet another attempt to detect SF_6 gas. We had four hits; one had an amplitude of 1.1 volts, the second was 0.75 volts in amplitude and the other two had amplitudes of 0.5 volts. By now the Duke was very low on fuel, so we returned to the airport, landing at 1823 CDT. Meanwhile the cumuli that we had been working to the E continued their development toward San Angelo.

By 1830 CDT some of the clouds and echoes associated with the cloud mass to the E and SE had worked their way into eastern Schleicher and Sutton counties, probably the result of new cloud growth on the outflow from the Cbs to the NE. Although most of the action was still in Tom Green County, there was enough activity in Schleicher and Sutton to warrant the scrambling of Seed 2 for AgI seeding at cloud base. Mark Rivard was airborne in Seed 2 at 1926 CDT and he began seeding in northern Schleicher at 1942 CDT. The inflow and updraft in these clouds had diminished by 2038 CDT and base seeding ceased at 2034 CDT for a seeding duration of 52 minutes. Seed 1 returned to San Angelo at 2038 CDT for a flight duration of 72 min. All this time there was considerable lightning activity to the E and SE of San Angelo and eventually to the S. It would have been a great show if I had had the time to watch it. A brief sprinkle of rain was noted at the airport along with the distant thunder. The main effect of the storms was rapid cooling as the outflow passed through the area. It was as cool as my air conditioned motel room.

As Mark returned to the airport, I went back to our research office to consider the results of our earlier flight. I had not been very pleased with the clouds that we had worked. Once again the updrafts had been rather weak despite their appearance and their proximity to Cbs. We had managed two SF_6 hits but without any obvious changes in the FSSP droplet spectra.

The most perplexing aspect of the flight had been our inability to detect any particles from the AI hygroscopic flares even though the smoke was seen to pass over the aircraft on several occasions. For the record the FSSP is mounted under the left wing tip of the Duke and the 2D-C probe is mounted under its right wing tip. It was necessary, therefore, to S-turn the aircraft from side to side to bring the smoke alternatively over each probe.

From my perspective it is time now to concentrate on larger clouds in a search for rain drops from hygroscopic seeding. Our continuing major problem is the presence of tropical air that is likely leading to coalescence in the clouds. Such coalescence will make it difficult to detect a hygroscopic seeding signature that is said to take the form of large rain drops. On the other hand, I may be a little paranoid. Considering the high cloud droplet concentrations present in the clouds today, maybe the rain drop problem high in the cloud was not as bad as I imagined. It is time to find out.

If conditions look suitable for the hygroscopic seeding mission, the plan is for Mike Douglas and me to go out in Seed 1 in a search for suitable clouds that are growing in clusters under obvious forcing. During the search we will begin near cloud base and make repetitive penetrations at successively higher altitudes through non-precipitating clouds to document the cloud droplet spectra. Depending on conditions, we will stop somewhere between 15,000 ft and 20,000 ft.

When it appears that conditions are going to be right, we will call Seed 3 out with Tom Promersberer and Yaron Segal aboard and have them fly to the region of suitable clouds. After their scramble, we will make cloud penetrations between 0°C and -10°C to document the natural conditions. These penetrations will serve as the controls for our subsequent hygroscopic seeding.

After I have identified a limited suitable area, Yaron and Tom will be tasked with finding a suitable candidate at cloud base. An updraft > 500 ft/min and preferably > 1,000 ft/min will be sought. As soon as an acceptable candidate has been identified, seeding and gas release will begin while Seed 3 flies in tight circles under the subject cloud. A minimum of two hygroscopic flares will be burned at a time. Seed 3 will provide Seed 1 the time and GPS location of the seeding and I will use my GPS to identify which towers should be carrying the seeding material. We will begin sampling all cloud towers coming through our flight altitude within a 3-mile radius of the initial seed position, noting the GPS position of each pass.

I will order two more canisters of SF_6 gas tomorrow at a cost of about $600 per canister. We have less than 1 full bottle left and if I do not order more, we will not have any for the rest of the program. We may have to pick it up in El Paso in one of our aircraft on Thursday.

I should mention that Yaron Segal is doing much better in the Seneca. He has not become sick once and appears to be enjoying the flights. On the other hand, he became sick every time on the Duke to the point where he is said to have become incapacitated. I will take Duke duty until the end of our efforts in 1996.

September 4, 1996

San Angelo had broken to overcast altocumulus clouds this morning with light winds. The early morning temperatures were in the low 70's and mid to upper 60's, respectively. By later in the morning lower stratocumulus layer had moved into the area and I was thinking late afternoon for suitable clouds.

I ordered two more canisters of SF_6 gas, although it is not clear at this point how we will pay for it. I hope George Bomar makes an appearance sometime soon.

By 1230 CDT there were breaks in the clouds E-SE, revealing a large Cb anvil SE with new cumuli growing on its N and W sides. When I saw that these clouds were producing echoes that extended into NE Schleicher County, I immediately scrambled Seed 1 for an operational seeding flight. Because the conditions were totally unsuitable for a hygroscopic seeding mission at the time (the cloud bases were too low), I thought it best that Seed 1 go out first so that it would be available later for a research flight if one is warranted. I had Mark Rivard standing by with Seed 2. I even asked that Tom Promersberger be ready in the Seneca for a cloud-base AgI seeding flight if things get really active.

Meanwhile, Hurricane Fran is intensifying and moving toward the NE Georgia and South Carolina. It has the potential to do some real damage if it continues to intensify.

By 1330 CDT Seed 1 had started its engines and was taxing out for takeoff and I was on my way to the WMI operational radar. After Seed 1 was airborne Mike took it into Schleicher County and began on-top seeding at 1422 CDT and continued to work there and in eastern Crockett County until his last seeding about 1540 CDT. He dropped 46 flares on 21 seeding passes.

Just after Seed 1 got to altitude, I scrambled Mark Rivard in Seed 2. He took off at 1432 CDT and proceeded westbound to survey Crockett County. Finding nothing there, he moved back to the E to share the airspace with Seed 1. It worked out OK, although Seed 1 had to climb to about 21,000 ft to make air traffic control happy and that was too high and too cold for my liking.

Seed 2 seeded clouds in Irion, Reagan, Upton and Crockett counties before he returned to the airport at 1720 CDT. The clouds showed nice development but it did not appear to be overly anomalous when compared to natural cloud growth in the target area. The same could be said of the clouds seeded by Mike Douglas in Seed 1. It was a nice seed day but not one I will remember for all time.

Mike had returned to San Angelo by 1603 CDT and Mark was on the ground at 1720 CDT. I had originally sent Seed 1 out first, knowing that he would have to return to the airport within 2.5

hours. I had entertained the hope of getting in a hygroscopic mission later in the afternoon, but by the time Seed 1 had landed the clouds did not appear to be suitable. They were sheared badly and there was extensive middle cloudiness. The clouds had developed quite early but they did not extend their growth period into the late afternoon.

I also got Tom Promersberger into the act by having him seed with fixed AgI flares on his left wing, since there were 11 flares left in our arsenal. After his takeoff at 1615 CDT he flew to the WNW into Irion County where he began seeding in updrafts beneath cloud at 1631 CDT. Tom gradually worked his way NW into Sterling County, finding updrafts up to 800 ft/min along the way. Tom's clouds grew too, but again it was nothing obviously anomalous.

The flights has gone reasonably well in my judgement. My only regret is that I did not keep Seed 2 in Crockett County longer before bringing him back to the E to work with Seed 1. Some of the best and most organized showers formed later in south-central Crockett County. We should have been there when they were just getting organized. I should have followed my intuition on that one.

The rest of the evening was pretty benign in the local area. In the distance toward Abilene, however, there were larger cumuli growing up into what appeared to be anvil cloud. I was not surprised to learn, therefore, that Abilene was having a thunderstorm at the time.

<u>September 5, 1996</u>

San Angelo had several scattered to broken cloud layers this morning, beginning with low thin scud and followed by a scattering of soft towering cumuli above, especially to the E. Scattered to broken altocumulus clouds were higher still. The cumuli were moving from the SE but the altocumulus clouds were moving from the WSW. This wind shear was readily manifested in the clouds whose tops leaned to the E and NE. The winds were light and the temperature and dew point were in the mid to upper 60's. A few small echoes were noted to the distant E and SE of the radar.

Hurricane Fran is bearing down on NE South Carolina with maximum winds of 115 mph. Its minimum central pressure has settled down to between 955 and 950 mb. I am frankly surprised that this storm is not stronger than it is. Regardless, it will do its share of damage on the Carolina coastlines.

Yaron and I stopped by the National Weather Service Office here at Mathis Field so that I might obtain the official climatological record for San Angelo for August 1996. I inquired further about the dedication of their new building and NEXRAD radar at 0930 CDT tomorrow. George Bomar, Yaron Segal and I will attend, but, if it were not for the tent that has been put up to shade the ceremonies, I would have forgotten about it completely.

San Angelo had an average monthly temperature of 81.3°F, which is 0.6°F below normal. The highest temperature was 104°F on August 3rd and the lowest was 65°F on August 13th. The precipitation total for the month was 7.66 in, which is 5.73 in. above the monthly average. The were 11 days with at least 0.01 in. of rain. The largest 24h total was 4.66 in. spanning August 28th and 29th. Thunder was heard on 9 days during the month. The peak wind was 36 mph on August 6th.

By 1200 CDT San Angelo had a field of towering cumuli. They did not look too good in that their bases were low and irregular and their tops were sheared. In many cases they seemed to be too tall for their bodies. Most of them were capped at the level of the altocumulus. There were a few echoes nearing the target. One group was near the E and SE border of Sutton County and the other group was just to the E of central Sterling County. All echoes were drifting to the W.

By 1330 CDT I had scrambled Seed 2 for a operational seeding flight into Sutton County where there were a few echoes growing. I was getting ready for a flight by 1415 CDT. The airport had already had a light shower and the strongest echoes were N-E-SE of Mathis Field.

I took off in the Duke at 1430 CDT, finding cloud base at about 4,700 ft at a temperature between 17°C and 18°C. There was an area of heavy showers N-E-SE of the airport at the time. I then made a climb to 17,000 ft at 1,000 ft intervals through fresh (in most cases) growing cumuli. The analysis of this data should produce some nice cloud-drop distributions. In looking at the 2D-C images in real time, I was surprised to find very little in the way of 2D-C particles.

During the climb I noted that the base of the stable layer was about 15,000 ft, which should have produced a resting point for the towers. Looking at the cloud field that indeed appeared to be the case, so somewhere in that cloud mass there had to be clouds with rain drops. I did not "waste" time looking for them. I was more concerned at the time with organizing our planned experiment, scrambling Seed 3 with Yaron and Tom on board for a rendezvous 25 n.mi. to the W of San Angelo. The cloud conditions looked ideal at the time and 25 n.mi. appeared to be the demarcation between the old showering clouds to the E and the fresh new towers to the W.

While Seed 3 was preparing for takeoff, the clouds in my chosen area and from W-N-NE of my chosen area began to subside and I started to look elsewhere for clouds. My only option was to the S and SE where Mark Rivard in Seed 2 was already seeding clouds from on top. His cloud field was magnificent, so I urged him to keep seeding while Seed 3 was enroute but to focus his activity on the eastern portions of the cloud field. I wanted to leave the new growing area to the W for us and our planned hygroscopic seeding experiment. Mark did as he was instructed and a line of Cbs resulted to the immediate NE of Eldorado in Schleicher County and stretching to the WNW.

By this time Mark was picking up a lot of ice and his flare total was approaching 60, so I began to encroach on his area. This upset the air controllers who said that I was to stay where I was until Seed 2 left the area. Because Seed 2 was now reporting great difficulty in staying aloft due to his ice load, I asked that Seed 2 descend to cloud base for AgI seeding and at the same time asked Kelly Bosch at the radar to "protect" our clouds from AgI seeding by Seed 2.

By this time Seed 3 was directly below us, the coordination having been made easy by our GPS navigation systems. The only problem for me was the loud chatter of the air controllers which frequently overrode the communications on our company frequency since Mike insisted on putting both sets of communications on our headsets. The problem faced by Yaron and Tom on Seed 3 were more troublesome. Cloud bases were no more than 2,000 ft above the terrain and this was making Tom nervous. Further, there was an abundance of showers of varying intensities throughout the area, making a hygroscopic seeding experiment of questionable value. Still we persisted because none of the clouds penetrated by either Mark in Seed 2 or me in Seed 1 had shown any rain drops.

We tried to find suitable clouds in the time left to Seed 1 before it ran out of fuel --- it can stay aloft no than about 2.5 hours. The clouds that I selected for study were in the right area but they had begun to subside here as well. In most cases the cloud field that we had encountered would produce many towers in succession for our study. These did not.

I am convinced, however, that our experimental design is a winner. We were directly over Seed 3 most of the time ready to pounce on anything that came up from below. Given suitable clouds, we will detect seeding-induced rain drops, <u>assuming that is indeed the effect of seeding</u>. Considering what I saw on the 2D-C images behind the burning flares, I would bet a large sum of money that these flares do indeed produce large rain drops. Whether we will be able to demonstrate that in the time left this year remains to be seen. The forecast is for a continuation of rather tropical conditions. A front may enter our area by late on Sunday, resulting in heavy precipitation and low ceilings and no research flights.

We then returned to the airport, landing at 1653 CDT for a flight duration of only 2 hours 23 minutes. With such a short flight duration no wonder we are having problems completing our mission. We were followed to the airport by Seed 3 and Seed 2.

In assessing my flight performance, I would give a grade of B-. I had obtained the desired droplet distributions but I waited about 30 minutes too long to scramble Seed 3. I don't regret that Seed 2 proved to have the best of the clouds, because no one could have imagined that suitable clouds would be so limited in our target area. The only potential instrument problem of which I am aware at this point was the failure of the video tape recorder. We did not obtain any video tape today for reasons that are not clear to any of us at this writing. I activated the VCR in the record mode and verified that the tape was moving after Mike hit the activation button on the camera before I climbed into the co-pilot's seat. Once in the seat, I verified that all of the required lights seen through the view-finder were lit, indicating proper camera operation. Despite all of this we obtained no video tape and the power to the VCR was off when I examined it at the end of the flight. We will look into this tomorrow.

After assessing the weather upon landing, I canceled all flight operations for the rest of the day. The sky was covered by cloud debris and we had a cool moist easterly breeze. The radar did not show any promising areas of growing convection anywhere in the target. The National Weather Service was still carrying a Flash Flood Watch in their forecast and continued to do so into the night for reasons that are unclear to me. Perhaps that were "freaked out" by the strong line of thunderstorms that had developed in Schleicher County earlier in the afternoon. This was the line worked by Mark in Seed 2.

After showering and changing clothes, I made an evening presentation to the local chapter of the Sierra Club about our cloud seeding activities, both research and operational. Despite my weariness, I enjoyed it and I think that the same can be said of them as well. George Bomar was also in attendance. I introduced him and he answered a number of questions. Overall the group was friendly and receptive, not at all the reception that I thought possible based on the reputation of the more radical segments of the Sierra Club.

Both Yaron and I are tired but it has not affected our performance to this point. If the Texas program is ever funded properly, we need another two full time people for our research activities. Besides two flight scientists/researchers, we need two people to handle data processing and analysis tasks. These tasks should be done over night such that Rosenfeld and Woodley work from 0800 CDT to perhaps 2000 CDT and the two others work from 1600 CDT until at least midnight. The overlap time can be used to discuss the results to date and to make assignments for the data obtained on the current flight day. The schedules might be adjusted somewhat when there are no flights so that all four people on the scientific team can meet in a more leisurely way --- when is anything ever leisurely with us? --- to assess where we are with the research.

The current schedule is a grind, but we are still almost current in our production of post-flight materials. If anyone gets sick even for a day, however, we will fall hopelessly behind. I will never, however, agree to simply filing away to data for examination on another day.

In the post-flight assessment we did manage to find one pass at 18,500 ft with some drizzle drops < 100 microns and a drop or two of about 500 microns. During the descent, however, we did encounter ice and rain in the cloud debris. This suggests that the clouds may have produced their rain in the stable region over time with very little of the rain being transported to our flight altitude above. Regardless of the process, today was not a good day for hygroscopic seeding.

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> " Some electron microscopic work, plus a bit of optical particle counter data, strongly suggests the flares actually produce nearly 10^{13} condensation nuclei per gram of composition. These nuclei have mean diameters of around two microns, with the largest being near five microns. Of the total particles per gram of composition, there seems to be more than 10^{10} particles with diameters greater than two microns....."

This passage raises two issues. First, the reason that we are not seeing anything on the FSSP instrument when flying in the smoke of the AI hygroscopic flares may be due to the small size of the particles. The first channel of our FSSP has been calibrated to 2.8 to 4.8 microns and we have checked that channel with the calibration beads. We should have detected the smoke particles from the AI flares. If either his sizing is off by a micron or two and/or our calibration is off by a micron or two, I could imagine how the FSSP might miss sizing the particles.

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I intend to test the AI flares one more time on a day when no other flights are warranted to see whether I can detect the smoke particles. Having accomplished that, I will give Tom Henderson a call. At this point, it is obvious that the South African and AI flares are quite different, and these differences may be manifested by differing effects of seeding.

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San Angelo had light fog this morning with temperatures and dew points in the mid 60's. Broken to overcast thin altocumulus could be seen above. The winds were light and there were no echoes on the scope. When the fog cleared, it was still quite hazy. the first cumuli had formed in the local area by 1015 CDT as Yaron and I left to attend a ceremony to celebrate the dedication of the new National Weather Service office and radar. Meanwhile, the Duke was in the shop for the repair of an engine manifold problem that involved welding. The aircraft should be ready by early afternoon.

After the dedication ceremony and buffet lunch at the NWS we returned to the office to prepare for the day's mission. The sky was filled with medium sized cumuli and it was still hazy. There were no echoes on the scope as of 1230 CDT, but by 1330 CDT there were a few echoes to the distant NE-E of the radar.

By 1500 CDT the clouds were taller but still topped by a stable layer in much the same manner as yesterday only today the convection was weaker. There were a few echoes on the scope but they were from relatively shallow clouds. Mike Douglas said that the aircraft would be ready to fly after 1530 CDT.

The weather never did improve enough for a research flight today. The clouds stayed rather soft and shallow and there were few echoes. By 1800 CDT most of the cumuli had disappeared and only a broken layer of altocumulus clouds remained. The aircraft was not ready until after 1600 CDT, but it really did not make any difference. We would not have used it anyway.

A cold front is passing through Colorado today while hurricane Fran has been downgraded to a tropical storm as it tracks into western Pennsylvania after having the North Carolina coast near Cape Fear. The cold front will be entering northern Texas tomorrow and it may be in our area by late on Sunday. At some point our convection will be enhanced but whether this enhancement will suit our purposes remains to be seen.

September 7, 1996

It was clear but hazy at sunrise this morning with light winds. The temperature and dew point was in the mid-60s. The local radar showed a weak echo 100 km to the ESE of the radar. The national radar and satellite images showed a mostly clear Texas except for a NE-SW band of cloudiness from NE New Mexico through the Texas Panhandle near Amarillo, which was reporting heavy rain. This activity was associated with the cold front that moved through Colorado yesterday. Currents forecasts call for this front to become stationary and dissipate around or south of Lubbock.

The remnants of hurricane Fran are in SW Pennsylvania to the N of Pittsburgh this morning with the heaviest rain to the W and NW of the weakening center. Meanwhile an area of disturbed weather identified as tropical depression #8 is approaching the central Leeward Islands.

The first cumuli had formed in the local area by 1015 CDT, much as they did yesterday, but they had not achieved much vertical development as of 1300 CDT. There was a small area of echoes over 200 km to the NE of the radar. They were no longer present, however, as of 1400 CDT.

By 1600 CDT I had taken a good look at the weather, including the radar maps, satellite images, soundings and forecasts. All things considered I could do nothing else but cancel all flight operations for the day. The cumuli had decreased in number and depth. There was literally nothing to work. The cold front in the Panhandle has become stationary and is dissipating, making it doubtful that it will be of much use in stimulating the convection in our area tomorrow.

<u>September 8, 1996</u>

San Angelo had scattered stratocumulus clouds at sunrise this morning and some of these clouds had developed cumulus-like bumps within a hour or so after sunrise. By 0900 CDT most of these clouds had dissipated but they reappeared later, looking like altocumulus. The winds were light and the temperature was in the 70's. The dew point started in the mid-60's but had risen into the upper 60's by mid-morning. There were no echoes on the radar scope and the National Weather Service is not forecasting any shower activity in this area today.

The first cumuli formed in the local area around 1000 CDT and by 1100 CDT there was a clump of towering cumuli to the SE of San Angelo in an area that appears to be favored for early cloud development. By 1200 CDT we had a field of small to medium sized cumuli that were drifting from the ESE and leaning to the W. There were a few small echoes to the distant E.

By 1330 CDT there was enough echo activity to warrant preparation for a research flight. The mid-level stable layer was still inhibiting the cumuli at mid-levels and allowing them to develop precipitation. I did, however, see a few clouds in the distance that were going above this layer and becoming mushy Cbs. It has been several days since we have flown and I am afraid of being too conservative in deciding whether to fly. We are getting late in the project and no day is going to be perfect. On the other hand, we have about 4 hours left on our original allotment of 48 hours. Once that is exhausted, it will cost us about $100 for each additional hour, which is a real bargain. George Bomar indicated that he might be able to find the funds for up to 20 additional flight hours. With that in mind, we likely will fly today.

I took off in the Duke at 1515 CDT without great expectations considering the rather soft nature of the clouds and the stable layer with its base at 15,000 ft and its top near 17,000 ft. Cloud base was at 7,000 ft at a temperature of 14°C, at least that is what the Rosemount probe said it was. I am guessing that the actual temperature was warmer than that. We'll see after more investigation.

The first order of business was the usual step climb up to 17,000 ft, which was accomplished without any problems. At 15,000 ft I had Mike fly into the layer of cloud debris at about 1542 CDT in which we found many small 2D-C particles consisting of ice needles and small graupel particles. The temperature at the flight level ranged between -2°C and -3°C.

I then spent some time looking at our target for suitable clouds, but it was hard to be impressed. The clouds did not look particularly good and the layer cloudiness was not helping matters. I did not even entertain any thoughts of sending out Mark Rivard for operational seeding in Seed 2. The area farther to the E, however, looked much better. The clouds were harder in appearance and more clustered and there was not as much middle cloudiness in the region that turned out to be 18 to 25 n.mi. to the ESE of our radar.

After deciding on this area for a potential unit, I scrambled Seed 3 with Tom Promersberger and Yaron Segal aboard. Meanwhile I made a prolonged pass through a cloud at 16,000 ft at 1547 CDT that was emerging from the layer cloud and was well above the aircraft. It contained an assortment of 2D-C particles including rain drops of varying size up to 3 mm, frozen drops and graupel. The temperature during the pass ranged between -3°C and -4°C. Once the Rosemount probe got wet, however, the temperature dropped another 2°C. I don't find this temperature probe to be very reliable in cloud.

This cloud should be examined very carefully in the analysis phase because of its relevance to our hygroscopic seeding experiments. I was surprised to find so many 2D-C particles in the cloud and I suspect that it used the precipitation embryos resident in the cloud layer to grow these large particles.

A pass into another cloud was made at 1551 CDT at 17,000 ft at an initial temperature of -5°C. It was about 1,000 ft above the aircraft and contained only a few 2D-C particles, most of which were quite small. A pass was made into another cloud at 1616 CDT at an altitude of about 18,000 ft and temperature of -7°C. It also had some tiny 2D-C particles. It appears, therefore, that the cumulus clouds that grew without involvement with the cloud layer did not develop large 2D-C particles at temperatures between -4°C and -7°C.

Those that did were able to grow some very large particles and these likely accounted for most of the echoes within view of our radar.

Seed 3 was airborne by 1612 CDT and joined with us in Seed 1 about 20 minutes later. Of course, we were still at about 18,000 ft and Seed 3 was just below cloud base near 7,000 ft. After a few minutes of searching, Yaron and Tom had found a good area for hygroscopic seeding. It was on the W and NW side of a cumulus cluster. The cloud towers appeared to be hard and vigorous.

Speaking of appearances, we will not be able to reconstruct the appearance of the clouds today because of the second failure of the aircraft video system. Kelly had checked it out before we flew and I checked that it was running at flight outset and during the flight. Still we did not get a good video tape. It ran all the way to the end and the indicator within the camera said that it was recording, but there was nothing on the tape after we pulled out onto the runway to take off. There was a brief segment of good video tape when it was first turned on. The tape had not stopped moving; it had just stopped recording. Kelly has promised to bring in a new system for our next flight.

Seeding began in our unit at 1650 CDT with the ignition of 2 flares and the release of the SF_6 gas. A few minutes later I had them light 2 more flares, so there were 4 flares burning at once in the updraft region that ranged up to 1,000 ft/min. A total of 22 flares were burned over 32 minutes beneath the cloud mass as we made repeated penetrations of the cloud towers coming up from the region of base seeding. Plots of the flight tracks of both aircraft, derived from GPS navigation, show clearly that both aircraft were working the same clouds.

The Duke made its first pass through one of the cloud towers at 17,900 ft in the seeded area at 1651 CDT, only 1 minute after commencement of base seeding. It was too soon, of course, to expect to detect any effect of seeding since the seeding material was being released about 11,000 ft below the aircraft. At an average draft speed of 1,000 ft/min, it would take about 11 minutes to reach the flight level of the Duke. The cloud had almost 3 gm/m^3 of SLWC, FSSP drop concentrations of about 225/cc and FSSP equivalent drop diameters of 20 microns and no large 2D-C particles.

Another cloud pass was made at 1655 CDT. It was similar to its immediate predecessor, although broader and more vigorous. Again, there were no large 2D-C particles, although the cloud did contain some very tiny water drops up to 70/1. The flight altitude for the pass was 17,500 ft at a temperature of -6°C. The SF_6 trace remained quite steady and did not suggest that any SF_6 as was present in the air.

The next pass in a cloud tower above the seeded region was made at 165830 CDT at 17,200 ft. There were no large 2D-C particles. The FSSP equivalent diameters ranged up to about 20 microns. Cloud passes at 1700 and 1701 CDT still did not show any large particles nor did the pass beginning at 170540 CDT, which lasted 50 sec, although drops up to about 300 microns diameter were noted. It was now nearly 15 minutes after commencement of base seeding. If there was to be a microphysical effect of seeding, it would have to show up soon.

The cloud pass beginning at 1708 CDT was different from the earlier ones. It lasted nearly 3 minutes and in the initial half of the pass contained very large water drops up to 5 mm diameter, updraft and SLWC values around 3 gm/m^3 and very little ice at an altitude of 16,700 ft and a temperature of about -4°C. There were also a number of splash images. The SF_6 trace was still flat, giving no unequivocal indication that the aircraft was in the seeded plume. Toward the end of the pass was a huge expanse of inactive cloud that contained a great assortment of small ice particles. In many ways it resembled the structure of the cloud debris layer that had been documented earlier in the day. On the way back through the cloud at 1711 CDT on a reciprocal heading the aircraft re-entered the region of assorted ice forms but encountered a few rain drops having diameters of about 3 mm later in the pass.

Strangely enough the cloud pass at 1715 CDT did not contain any large water drops and had a structure that was similar to those clouds penetrated prior to commencement of seeding even though this tower was within the presumed region of potential seeding effect. The pass around 1718 CDT, however, did contain some very large rain drops between 5 and 6 mm diameter as estimated from the 2D-C images. There were also a number of splash images. This zone of large drops was followed by a region of frozen water drops, rimmed frozen drops, graupel and pockets of smaller liquid drops. Only about 10% of the pass length contained updraft. The trace of the SF_6 detector remained flat.

The next pass though the cloud beginning just after 1721 CDT was similar to its predecessor. The largest rain drops were in the region of highest SLWC and strongest updraft. The smaller water drops plus an assortment of ice particles were found in the more inactive portion of the pass. It should be noted, however, that the updrafts through all of the clouds were relatively brief and rarely exceeded 1,000 ft/min. This was the case at cloud base as well. Nevertheless, the seeded region was growing slowly to Cb stature with maximum reflectivities of about 52 dBz. Considering the sizes of some of the rain drops, I guess I should not be surprised by the reflectivity.

The next pass through the cloud mass came at 1723 CDT. It had maximum SLWC values of 2.0 gm/m^3, weak updraft and strong downdraft and an assortment of 2D-C particles, some of which were frozen. Embedded within the pass was a region of cloud having > 3.0 gm/m^3 of SLWC and an updraft of 1,000 ft/min. There were no large 2D-C particles in this limited region.

The last hygroscopic flare burned out at cloud base during this pass. The seeding duration had been 32 minutes. Any effect of treatment should persist, however, long after cessation of seeding.

I should mention that the cloud-pass durations were longer than I like; I could have shortened them greatly by concentrating on one tower. I was not certain, however, exactly where the seeding was taking place and exactly which towers were ingesting the hygroscopic material. I thought it best, therefore, to pass through as much of the cloud as possible <u>while flying at right angles to the shear</u>. The clouds were shearing to the ESE, so most of the passes were N-S or S-N. Even though the passes were made cross shear, the pass durations were still quite long.

The cloud pass at 1727 CDT was over three minutes duration. It contained an assortment of particles including large rain drops, and frozen drops and graupel particles. It contained virtually no updraft over most of the pass. The largest unfrozen rain drops were found in updraft up to 1,000 ft/min and in zones of high SLWC (> 3.0 gm/m^3.) A few of the drops approached 6 mm in size.

After this pass I made a special effort to find a good cloud tower that I believed was not affected by the seeding, so that it might serve as a control. I flew about 5 n.mi. to the NNE to a separate hard tower that appeared to have no connection to the clouds being seeded entering it at 1733 CDT. It had some small drops up to 400 microns diameter, an updraft of 700 ft/min, maximum SLWC values of 3.0 gm/m^3 during a pass duration of 45 sec.

Thinking that the cloud was too young to develop large particles, I decided to go back through the same cloud at 1736 CDT, about 3 minutes later. The pass duration was 50 sec during which a few rain drops up to 1 mm diameter were encountered. The SLWC remained high at 3.0 gm/m^3 and the updraft was nearly 900 ft/min. On both this pass and the previous pass I estimate that the cloud was up to 2,000 ft above the aircraft. Unfortunately, I do not have a good video tape from which I might recheck my height estimate.

At this point I should mention that it was determined later that the reason that we did not obtain any video today was due to a bad video cable. The video was going from the camera but it was not reaching the recorder due to this bad connection.

After the second pass through the "control" cloud, I returned to the seeded cloud mass for another pass, entering cloud debris containing ice particles on the N side of the mass just before 1738 CDT. Some of the frozen particles had diameters up to 2 mm and the

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San Angelo had scattered stratocumulus clouds at sunrise this morning and some of these clouds had developed cumulus-like bumps within a hour or so after sunrise. By 0900 CDT most of these clouds had dissipated but they reappeared later, looking like altocumulus. The winds were light and the temperature was in the 70's. The dew point started in the mid-60's but had risen into the upper 60's by mid-morning. There were no echoes on the radar scope and the National Weather Service is not forecasting any shower activity in this area today.

The first cumuli formed in the local area around 1000 CDT and by 1100 CDT there was a clump of towering cumuli to the SE of San Angelo in an area that appears to be favored for early cloud development. By 1200 CDT we had a field of small to medium sized cumuli that were drifting from the ESE and leaning to the W. There were a few small echoes to the distant E.

By 1330 CDT there was enough echo activity to warrant preparation for a research flight. The mid-level stable layer was still inhibiting the cumuli at mid-levels and allowing them to develop precipitation. I did, however, see a few clouds in the distance that were going above this layer and becoming mushy Cbs. It has been several days since we have flown and I am afraid of being too conservative in deciding whether to fly. We are getting late in the project and no day is going to be perfect. On the other hand, we have about 4 hours left on our original allotment of 48 hours. Once that is exhausted, it will cost us about $100 for each additional hour, which is a real bargain. George Bomar indicated that he might be able to find the funds for up to 20 additional flight hours. With that in mind, we likely will fly today.

I took off in the Duke at 1515 CDT without great expectations considering the rather soft nature of the clouds and the stable layer with its base at 15,000 ft and its top near 17,000 ft. Cloud base was at 7,000 ft at a temperature of 14°C, at least that is what the Rosemount probe said it was. I am guessing that the actual temperature was warmer than that. We'll see after more investigation.

The first order of business was the usual step climb up to 17,000 ft, which was accomplished without any problems. At 15,000 ft I had Mike fly into the layer of cloud debris at about 1542 CDT in which we found many small 2D-C particles consisting of ice needles and small graupel particles. The temperature at the flight level ranged between -2°C and -3°C.

I then spent some time looking at our target for suitable clouds, but it was hard to be impressed. The clouds did not look particularly good and the layer cloudiness was not helping matters. I did not even entertain any thoughts of sending out Mark Rivard for operational seeding in Seed 2. The area farther to the E, however, looked much better. The clouds were harder in appearance and more clustered and there was not as much middle cloudiness in the region that turned out to be 18 to 25 n.mi. to the ESE of our radar.

After deciding on this area for a potential unit, I scrambled Seed 3 with Tom Promersberger and Yaron Segal aboard. Meanwhile I made a prolonged pass through a cloud at 16,000 ft at 1547 CDT that was emerging from the layer cloud and was well above the aircraft. It contained an assortment of 2D-C particles including rain drops of varying size up to 3 mm, frozen drops and graupel. The temperature during the pass ranged between -3°C and -4°C. Once the Rosemount probe got wet, however, the temperature dropped another 2°C. I don't find this temperature probe to be very reliable in cloud.

This cloud should be examined very carefully in the analysis phase because of its relevance to our hygroscopic seeding experiments. I was surprised to find so many 2D-C particles in the cloud and I suspect that it used the precipitation embryos resident in the cloud layer to grow these large particles.

A pass into another cloud was made at 1551 CDT at 17,000 ft at an initial temperature of -5°C. It was about 1,000 ft above the aircraft and contained only a few 2D-C particles, most of which were quite small. A pass was made into another cloud at 1616 CDT at an altitude of about 18,000 ft and temperature of -7°C. It also had some tiny 2D-C particles. It appears, therefore, that the cumulus clouds that grew without involvement with the cloud layer did not develop large 2D-C particles at temperatures between -4°C and -7°C.

Those that did were able to grow some very large particles and these likely accounted for most of the echoes within view of our radar.

Seed 3 was airborne by 1612 CDT and joined with us in Seed 1 about 20 minutes later. Of course, we were still at about 18,000 ft and Seed 3 was just below cloud base near 7,000 ft. After a few minutes of searching, Yaron and Tom had found a good area for hygroscopic seeding. It was on the W and NW side of a cumulus cluster. The cloud towers appeared to be hard and vigorous.

Speaking of appearances, we will not be able to reconstruct the appearance of the clouds today because of the second failure of the aircraft video system. Kelly had checked it out before we flew and I checked that it was running at flight outset and during the flight. Still we did not get a good video tape. It ran all the way to the end and the indicator within the camera said that it was recording, but there was nothing on the tape after we pulled out onto the runway to take off. There was a brief segment of good video tape when it was first turned on. The tape had not stopped moving; it had just stopped recording. Kelly has promised to bring in a new system for our next flight.

Seeding began in our unit at 1650 CDT with the ignition of 2 flares and the release of the SF_6 gas. A few minutes later I had them light 2 more flares, so there were 4 flares burning at once in the updraft region that ranged up to 1,000 ft/min. A total of 22 flares were burned over 32 minutes beneath the cloud mass as we made repeated penetrations of the cloud towers coming up from the region of base seeding. Plots of the flight tracks of both aircraft, derived from GPS navigation, show clearly that both aircraft were working the same clouds.

The Duke made its first pass through one of the cloud towers at 17,900 ft in the seeded area at 1651 CDT, only 1 minute after commencement of base seeding. It was too soon, of course, to expect to detect any effect of seeding since the seeding material was being released about 11,000 ft below the aircraft. At an average draft speed of 1,000 ft/min, it would take about 11 minutes to reach the flight level of the Duke. The cloud had almost 3 gm/m^3 of SLWC, FSSP drop concentrations of about 225/cc and FSSP equivalent drop diameters of 20 microns and no large 2D-C particles.

Another cloud pass was made at 1655 CDT. It was similar to its immediate predecessor, although broader and more vigorous. Again, there were no large 2D-C particles, although the cloud did contain some very tiny water drops up to 70/l. The flight altitude for the pass was 17,500 ft at a temperature of -6°C. The SF_6 trace remained quite steady and did not suggest that any SF_6 as was present in the air.

The next pass in a cloud tower above the seeded region was made at 165830 CDT at 17,200 ft. There were no large 2D-C particles. The FSSP equivalent diameters ranged up to about 20 microns. Cloud passes at 1700 and 1701 CDT still did not show any large particles nor did the pass beginning at 170540 CDT, which lasted 50 sec, although drops up to about 300 microns diameter were noted. It was now nearly 15 minutes after commencement of base seeding. If there was to be a microphysical effect of seeding, it would have to show up soon.

The cloud pass beginning at 1708 CDT was different from the earlier ones. It lasted nearly 3 minutes and in the initial half of the pass contained very large water drops up to 5 mm diameter, updraft and SLWC values around 3 gm/m^3 and very little ice at an altitude of 16,700 ft and a temperature of about -4°C. There were also a number of splash images. The SF_6 trace was still flat, giving no unequivocal indication that the aircraft was in the seeded plume. Toward the end of the pass was a huge expanse of inactive cloud that contained a great assortment of small ice particles. In many ways it resembled the structure of the cloud debris layer that had been documented earlier in the day. On the way back through the cloud at 1711 CDT on a reciprocal heading the aircraft re-entered the region of assorted ice forms but encountered a few rain drops having diameters of about 3 mm later in the pass.

Strangely enough the cloud pass at 1715 CDT did not contain any large water drops and had a structure that was similar to those clouds penetrated prior to commencement of seeding even though this tower was within the presumed region of potential seeding effect. The pass around 1718 CDT, however, did contain some very large rain drops between 5 and 6 mm diameter as estimated from the 2D-C images. There were also a number of splash images. This zone of large drops was followed by a region of frozen water drops, rimmed frozen drops, graupel and pockets of smaller liquid drops. Only about 10% of the pass length contained updraft. The trace of the SF_6 detector remained flat.

The next pass though the cloud beginning just after 1721 CDT was similar to its predecessor. The largest rain drops were in the region of highest SLWC and strongest updraft. The smaller water drops plus an assortment of ice particles were found in the more inactive portion of the pass. It should be noted, however, that the updrafts through all of the clouds were relatively brief and rarely exceeded 1,000 ft/min. This was the case at cloud base as well. Nevertheless, the seeded region was growing slowly to Cb stature with maximum reflectivities of about 52 dBz. Considering the sizes of some of the rain drops, I guess I should not be surprised by the reflectivity.

The next pass through the cloud mass came at 1723 CDT. It had maximum SLWC values of 2.0 gm/m^3, weak updraft and strong downdraft and an assortment of 2D-C particles, some of which were frozen. Embedded within the pass was a region of cloud having > 3.0 gm/m^3 of SLWC and an updraft of 1,000 ft/min. There were no large 2D-C particles in this limited region.

The last hygroscopic flare burned out at cloud base during this pass. The seeding duration had been 32 minutes. Any effect of treatment should persist, however, long after cessation of seeding.

I should mention that the cloud-pass durations were longer than I like; I could have shortened them greatly by concentrating on one tower. I was not certain, however, exactly where the seeding was taking place and exactly which towers were ingesting the hygroscopic material. I thought it best, therefore, to pass through as much of the cloud as possible <u>while flying at right angles to the shear</u>. The clouds were shearing to the ESE, so most of the passes were N-S or S-N. Even though the passes were made cross shear, the pass durations were still quite long.

The cloud pass at 1727 CDT was over three minutes duration. It contained an assortment of particles including large rain drops, and frozen drops and graupel particles. It contained virtually no updraft over most of the pass. The largest unfrozen rain drops were found in updraft up to 1,000 ft/min and in zones of high SLWC (> 3.0 gm/m^3.) A few of the drops approached 6 mm in size.

After this pass I made a special effort to find a good cloud tower that I believed was not affected by the seeding, so that it might serve as a control. I flew about 5 n.mi. to the NNE to a separate hard tower that appeared to have no connection to the clouds being seeded entering it at 1733 CDT. It had some small drops up to 400 microns diameter, an updraft of 700 ft/min, maximum SLWC values of 3.0 gm/m^3 during a pass duration of 45 sec.

Thinking that the cloud was too young to develop large particles, I decided to go back through the same cloud at 1736 CDT, about 3 minutes later. The pass duration was 50 sec during which a few rain drops up to 1 mm diameter were encountered. The SLWC remained high at 3.0 gm/m^3 and the updraft was nearly 900 ft/min. On both this pass and the previous pass I estimate that the cloud was up to 2,000 ft above the aircraft. Unfortunately, I do not have a good video tape from which I might recheck my height estimate.

At this point I should mention that it was determined later that the reason that we did not obtain any video today was due to a bad video cable. The video was going from the camera but it was not reaching the recorder due to this bad connection.

After the second pass through the "control" cloud, I returned to the seeded cloud mass for another pass, entering cloud debris containing ice particles on the N side of the mass just before 1738 CDT. Some of the frozen particles had diameters up to 2 mm and the

SLWC was < 0.5 gm/m^3. Later in the pass the water and updraft increased somewhat and fewer of the drops were frozen. I would not, however, call it a vigorous cloud.

The return pass to the N came at 1742 CDT into what appeared to be fresh cloud. the maximum SLWC at an altitude of 16,500 ft and a temperature of -5°C was > 4.0 gm/m^3 and the updraft was about 1,200 ft/min and a few drops were > 6 mm. None of the drops in this region were frozen. Again, there was no change in the flat SF_6 trace.

The next pass into the seeded area, heading S, began at 174730 CDT. It contained maximum SLWC values of 4.0 gm/m^3, updrafts of 1,000 ft/min and water drops, including some giants. The return pass to the N was at 1752 CDT through the older portion of the cloud mass. As with the previous passes, it was a prolonged run that initially contained small particles and low SLWC values. Larger particles were observed in the higher SLWC areas, but in general this portion of the cloud mass was decaying. Most of the particles were frozen and some of the graupel particles were around 3 mm diameter.

We began our return to Mathis Field in San Angelo at 1757 CDT. The seeded cloud was still active with maximum reflectivities > 50 dBz. We landed at 1802 CDT, returning in near record time.

After landing I had time to reflect on the day's events. The day had worked out better than I had reason to expect at the time that I took off. Although there was an annoying stable layer that served as the germinator of precipitation embryos, the clouds were still better than I had expected. I was particularly pleased with the area of forced clustered convection with good cloud-base updrafts within the radar scan.

Although there were a few tense moments prior to unit qualification, we did a good job in conducting the experiments. I am certain that we worked the same clouds, even though the SF_6 gas was not detected. The PMS particle data look good. Whether we played a role in the generation of the rain drops with diameters > 5 mm remains to be seen. Were it not for the role that the cloud debris obviously played in providing rain drop embryos to some of the natural convection, I would be ready to offer my opinion that the intensive hygroscopic seeding had been responsible for the large rain drops. Now I am not so sure.

I had two major disappointments today, both of which will compromise our analyses to some extent. First, the failure of the video camera will make it extremely difficult to evaluate the clouds based on their visual appearance. One never realizes the importance of the flight videos until he doesn't have them. Second, not detecting the SF_6 gas calls into question whether we were ever in the seeded plume. That I believe that we were does not count for much. An SF_6 hit would have removed all doubt. I really can't say that I am surprised, however, considering the small size of the SF_6 hits that we have noted at cloud base. If they were barely detectable at cloud base, for whatever the reason, it would be unreasonable to expect to detect the gas 3 km above cloud base.

At this point I see no point in buying more SF_6 gas. We have enough remaining for another flight and Yaron leaves on Wednesday. Although I hope to keep the research effort going through at least Thursday and perhaps Friday, there is no guarantee that I will be able to do so. Even if I can, I view the purchase and release of more gas without further checking of the SF_6 detector as a waste of money. That the release and detection of a tracer gas is crucial to our efforts is without question. We have done the best that we can for this year. We should make the best of what we have now and move on from there.

<u>September 9, 1996</u>

San Angelo was clear but hazy with some high cirrus clouds at sunrise this morning. The temperature and dew point started out in the mid 60's but had increased to the upper 60's by mid-morning. There were no echoes on the scope. For that matter most of Texas was free of cloud and echo. Meanwhile Hurricane Hortense at 986 mb was moving WNW to the SE of Puerto Rico.

By 1300 CDT San Angelo had a field of towering cumuli with a few small Cbs to the distant E. I called Mark Rivard in to get ready for an operational flight and then Mike Douglas to get ready for our hygroscopic research mission. I learned then that around 1100 CDT Mike had painted some material on the radome of the Duke to repair some small holes that were caused by the graupel of yesterday. Unfortunately, this material takes several hours to cure, so the earliest we can fly today is 1530 CDT. It is unfortunate that this material was not applied to the aircraft last evening or earlier this morning at the latest. Had that been done, we could have flown at any time this afternoon.

The echoes had developed well enough for me to scramble Seed 2 as of 1433 CDT. By the time he took off at 1505 CDT I was having second thoughts. The Cb echo on the E border of Schleicher was decreasing in intensity as were the few echoes in Schleicher County itself. Mark found cloud base at 6,800 ft at an uncorrected temperature of 19°C.

By 1535 CDT the cumuli were more shallow than before and all echoes in our target were < 19,000 ft. Suppression was obviously moving into the area. Because continued flight of Seed 2 was futile, I asked that he return to the airport. He did so, landing at 1552 CDT. The rest of the afternoon saw a further decrease in the convection in the local area as the dew point dropped to the low 60°F. A few TCU and a Cb did develop in southern Sutton County by late afternoon and I scrambled Seed 1 to have a look at them. These clouds were apparently growing in the old frontal boundary that was in our area yesterday.

Once Seed 1 was in SW Sutton County he took a good look at the clouds and began on-top seeding at 1939 CDT at 188° at 65 miles from the radar. His last seeding was at 1954 CDT for a seeding duration of 15 minutes during which he expended 9 flares. After his last seeding the cloud began to decay, so I recommended that he return to the airport. Mike concurred, landing at 2022 CDT. Had I been smart enough to get Mike out there earlier, he likely would have done much more seeding.

September 10, 1996

San Angelo had high broken cirrus and altocumulus clouds this morning with light winds. The sunrise visibility was better today than yesterday. The temperature and dew point were in the mid-60's. The dew point should rise into late morning as evaporation moistens the air, but it should decrease into the afternoon as atmospheric mixing takes place.

Hurricane Hortense is moving through the Mona Passage between Puerto Rico and Hispaniola this morning. It passed over the extreme SW tip of Puerto Rico during the night. Its pressure is still about 990 mb, but that should drop when it emerges over open water later today. I do not think that there is any chance of this storm getting into the Gulf of Mexico to threaten Texas. For that matter, a trough, forecast to dig into the eastern U.S., should keep it away from there too.

Today is the last day before Yaron Segal leaves to return to Israel. I will keep the research hygroscopic program operating through Friday after which it will be shutdown. I will then concentrate exclusively on the operational seeding program through the end of September when it is scheduled to end for this season.

The first cumuli formed in the local area by 1030 CDT with most of the activity ESE-WSW. In looking at the clouds there appeared to be a strong moisture gradient from N-S such that only the S half of our area might develop large clouds. By 1130 CDT the clouds to the distant S were reaching towering stature with a few small echoes. I called Mark at this time to get him ready for flight into Sutton County. I also had Mark alert Mike and Tom for a possible research mission as of 1400 CDT.

In looking at a visible satellite image for Texas, it was easier to understand what was going on. The image showed a broad swath of clouds covering the southwest third of Texas in a NW-SE orientation. In central Texas it was unusually clear. The cloud patterning and the lack thereof seemed suggest organization on the synoptic scale.

By 1230 CDT there were echoes on the scope, primarily in Sutton and Crockett Counties. There were just a few small echoes in Schleicher and nothing elsewhere. Seed 2 was airborne at 1330 CDT and flew into Crockett county and began seeding to the E of Sheffield in Crockett County. When I left the radar to get ready to fly in Seed 1, Seed 2 had already expended 27 flares.

Seed 2 was continuing to work in SW Crockett at the time I took off in Seed 1 1506 CDT. It was totally clear in the local area, so I decided to climb right to altitude of 18,000 to 20,000 ft toward the Cb line that now stretched NW-SE from SE-WSW of San Angelo. I decided to obtain stepwise measurements in the clouds on my descent back to San Angelo. My initial intention was to do on-top operational seeding in the line while looking for a separate cloud mass for hygroscopic seeding in conjunction with the Seneca.

About one-half hour into the flight I scrambled Seed 3, sending them about 40 n.mi to the S of the radar where a separate cloud mass was growing. Such an area might prove to be suitable for a research hygroscopic seeding mission. Meanwhile we began on-top seeding about 35 n.mi SSW of San Angelo. We were at 18,500 ft at a temperature of -7°C. At the same time Mark Rivard in Seed 2 was working his way to the N of the line of echoes, hoping to find feeder clouds on its N side in Upton County. Because nothing was suitable in the portion of the line in Upton County, I suggested that he come ESE in the line towards where we were working. This made air traffic control rather nervous. Further, Mark could not find suitable feeder towers even though the line was still quite active. Apparently they were so tightly tucked into the Cb masses that he could not get to them. The presence of extensive anvil cover did not help matters. I then suggested that he descend to cloud base for seeding in the inflow areas to the line. He agreed and began seeding with the AgI burners.

I thought that I had everything figured out, but as usual Nature had the last laugh. The line was producing an enormous anvil that was moving over and down the line rather at an appreciable angle to it. This meant that the Cb mass was cutting off the solar insolation needed for continued cumulus generation and the ice particles falling from the cirrus were shrouding the new towers and naturally seeding them.

Seed 1 and Seed 3 flew in the same area for awhile, with Seed 3 about 12,000 ft beneath Seed 1. Mike Douglas continued his over-the-top seeding while Tom and Yaron in Seed 3 looked for good inflow at cloud base. I was no longer thinking of doing a microphysical experiment because of the very messy conditions at our altitude. I had hoped, however, that Seed 3 would find a good inflow area for a hygroscopic radar experiment. As best I could tell, no echo was > 50 dBz today, so if our selected cloud produced reflectivities > 50 dBz, it might be indicative of a seeding effect. It was a long shot and under normal circumstances I would have scrapped the mission right then, but I was anxious to do another intensive hygroscopic seeding.

Although we tried, the conditions never warranted hygroscopic seeding for either research or operations. There were no suitable clouds and those that looked suitable were covered by anvil precipitation. Further, there were no strong inflow regions where Seed 3 was flying. At this point I suggested that Seed 3 return to the airport. Tom readily agreed and left for San Angelo. Now we in Seed 1 was the only ones left attempting to do operational seeding. We worked our way through miles of anvil to the N of the now dying line and then turned WNW on its N side, flying ultimately into Glasscock County where we ejected 3 flares into a fairly hard sunlit cumulus tower just beneath the aircraft.

While this was going on, I was apprised that the dew point had fallen dramatically in both San Angelo and Abilene during the afternoon. The dew point was already 50°F in San Angelo and still dropping. I found this hard to believe. It seems as though we have had something of a "back-door" frontal passage carried on the strong surface E winds. The early afternoon visible satellite image showing no clouds over a large area to our N and E then made sense. Because this air mass had acted like a front, I would guess that the cloud line had formed at the leading edge of this moisture discontinuity.

By this time the only suitable clouds were in Midland County outside of our target area, so we began our return to San Angelo, landing at 1753 CDT. I am happy to report that the video camera worked just fine today. Although we could not obtain a hygroscopic seeding unit, we had done our job with the operational seeding. The visibility at sunset was spectacular.

In view of the strong drying, I think it unlikely that we will have operational seeding tomorrow, but one never knows. I did not feel confident enough about it to cancel tomorrow's flight operations. Because the project is low on ejectable AgI flares, Mark and Tom left for Oklahoma in the Cessna 340 to pick up more flares. I expect them to return later this evening.

Meanwhile, Yaron Segal was completing his work before he takes his 0550 CDT flight from San Angelo to Dallas and then on to New York and Israel. I have appreciated his help, over the past 3 weeks, especially so since he was paid only for his expenses and not any salary. With Danny gone, I could not have carried out any research missions without Yaron. I wish him a safe trip!

The evening was clear and cool except for the anvil cloud that still remained over the area. With the dry air and breeze it felt as though fall was in the air.

September 11, 1996

Yaron Segal began his return trip to Israel well before sunrise this morning. By dawn San Angelo had broken cirrus and altocumulus clouds with no wind. The temperature and dew point were in the upper 50's, which is likely the coolest it has been here since last spring. The morning radar and satellite depictions showed cloudiness and some echoes in extreme SW Texas. This activity was associated with a strong monsoonal flow through New Mexico and Arizona that should result in heavy rains in these areas. A cold front will be passing through Colorado and Kansas today and it should reach our area tomorrow. It will be most active well to the E, but its presence may still enhance the convection. I don't see much chance of activity in this area today.

Hurricane Hortense is now N of the Dominican Republic, tracking WNW to NW, and intensifying. Its central pressure is now 973 mb but the southern half of its circulation is being disrupted by Hispaniola. As it moves farther away, I expect it to intensify further. The troughing over the eastern U.S. is forecast to eventually turn this storm to the N and NE; it likely will miss the U.S. mainland.

After looking at the morning weather data I had to revise my forecast somewhat. Although I still do not look for any activity in the San Angelo area today, portions of Crockett, Upton and Glasscock could have clouds that are suitable for seeding late in the day. I will have to keep a close watch on these areas.

By 1300 CDT it was still crystal clear except for a few cirrus clouds, some natural and some from jet condensation trails. Altocumulus could be seen SE-W and a few Cbs could be seen on the S-SW horizon. These were well out of our area at this time. Some of the cirrus in our area appeared to be decayed anvil from these distant storms.

The first small cumuli formed in our area at 1330 CDT but they showed no development well into the afternoon. The dew point dropped into the upper 50's as the temperature rose into the mid and upper 80's.

I spent most of the late morning and afternoon working on a presentation that Dale Bates needs to brief individuals within the target area on the results of the program. It will involve video taping of two video monitors simultaneously. One will have a replay of the flight tracks of the seeder aircraft and the other will have the contoured echo presentation that is synchronized with the time on the flight tracks. I will do the voice-over to explain what is going on. Christopher Woodley likely will do the video taping no later than the week of September 23rd. It should not take more than a day or two.

While I was doing this, I asked Tom Promersberger to assist with the estimation of the sizes of drops that were imaged by the 2D-C on September 8th. In some cases it involved cutting up copies of the drop images and piecing together the parts. Once this was done, the drop radius was reconstructed using standard geometric techniques. If our procedures are correct, the largest drops imaged in clouds seeded with hygroscopic flares ranged between 4.5 mm and 10.1 mm for the ten drop measurements. Although drops of this size certainly occur naturally, they must be rare in west Texas. With the exception of one cloud that ingested precipitation embryos from a supercooled layer of cloud debris, all the other non-seeded clouds on September 8th had drops < 1 mm in diameter. The largest drops in this one natural cloud ranged between 2 and 4.6 mm. Virtually all of them appeared to be frozen and rimming could have added slightly to their measured radii. Although smaller than the drops in the seeded cloud, this non-seeded cloud suggests that caution must be exercised in attributing the gigantic drops in the seeded cloud unequivocally to hygroscopic seeding.

Looking at this uncertainty from a more optimistic perspective, the seeded cloud did not appear to have the benefit of ingesting natural precipitation embryos and still grew gigantic drops, presumably due to the seeding. On the other hand, the non-seeded cloud was seen to emerge from a layer of cloud debris, likely ingesting precipitation embryos in the process and still it was not able to grow gigantic drops. I am not taking sides at this point; we need more measurements.

The weather the rest of the day consisted of mostly clear skies with light east winds. Altocumulus and cirrus clouds persisted all SW-NW of San Angelo and there was a lot of precipitation W of the Pecos River that borders Crockett County and this shower activity extended NW into New Mexico.

<u>September 12, 1996</u>

Most of SW Texas had overcast clouds this morning with showers and rain SW-NW of our operational area. In the local area the clouds were primarily thick overcast cirrus anvil from old thunderstorms. The wind was calm and the temperature and dew point were in the mid to upper 60's and low 60's, respectively.

The cloudiness in SW Texas has been moving into the area from northern Mexico for the last couple of days in association with a weak upper level disturbance in New Mexico. The moisture may be increased further in a couple of days after Hurricane Fausto (Category 3) moves N to the tip of the Baja Peninsula. Meanwhile, Hurricane Hortense (Category 3) in the Atlantic to the N of the eastern Bahamas is now tracking NNW and should turn N away from the U.S. mainland as a strong trough digs in the eastern U.S. Its central pressure is now 959 mb and the maximum sustained winds are 115 mph.

We should have a lot of cloudiness today, but I doubt that we will have much convection because of the relatively low dew points and the lack of solar heating. Still, I will have to be vigilant for suitable convection along the SW-NW boundaries of our area. Even here I expect any convection to be embedded in the thick middle and upper cloud.

By late morning the middle and upper cloudiness was beginning to thin in the local area and a few small cumuli were forming underneath. There was still an area of rain in western Crockett and Upton counties that was tracking toward us. This area was decreasing as well. Everything looked embedded, so I did not send an aircraft out to investigate.

By 1225 CDT I was back in the radar for a second look. The area of light to moderate rain was persisting to the SW as it advanced toward San Angelo. There were a few cores up to 35 dBz in the mass and cumuli were forming SE-S-E of San Angelo under the broken upper cloud. At this point I scrambled Mark Rivard in Seed 2 for a cloud recon flight. Then I called Mike Douglas to be ready for a possible research flight at 1400 CDT. Our only chance would be the cumuli forming S-SE of the airport in a region with minimal upper cloudiness. If the upper clouds to the W stay away long enough we might have a chance for a hygroscopic seeding mission.

Seed 1 had its engines running as of 1300 CDT and took off shortly thereafter. Mark climbed through Irion and Reagan Counties on his way to Crockett County, encountering multiple cloud layers and no obvious cumuli on the climb. He then flew through central Crockett and then SE into Sutton and N into Schleicher. By the time he was entering Sutton County he was already descending for possible seeding at cloud base.

Once Seed 2 was at cloud base, he flew back to the W and SW into Crockett County, but encountered only light to moderate rain, poor visibilities and no obvious inflow areas. Hearing this, I suggested that he return to the airport. He did so, shutting down his engines at 1453 CDT for a total flight duration of 116 minutes. It had been an unproductive but necessary flight to see what the conditions were firsthand.

With the above as background, it will come as no surprise to learn that the afternoon conditions were totally unsuitable for a research mission. I canceled all operations as of 1600 CDT. It was a good decision since the cloudiness increased and thickened toward sunset. Light rain showers were in the area as of 1700 CDT and continued well into the evening. The surface dew point stayed in the low 60's despite the rain. The light showers continued through the night.

September 13, 1996

San Angelo had a thick overcast with light rain showers at dawn this morning. The radar presentation indicated that most of the shower activity was NE of a NW-SE line running through the radar. This is in agreement with the morning satellite images which show the cloudiness thinning to the W. The temperature and dew point were in the mid-60's and the wind was 10 kts from the NE. What happens here today will depend on how much clearing we get. If it clears, we may get enough heating to generate suitable clouds. If not, we will not have anything to work.

Hurricane Hortense is now tracking harmlessly to the N in the western Atlantic. It became a category 4 storm late yesterday with a minimum central pressure of 935 mb and sustained winds of 140 mph. It is weakening slowly now. Meanwhile, Hurricane Fausto is taking aim on the southern tip of the Baja Peninsula. It too appears to be weakening. The big uncertainty for us is how much of its moisture ultimately finds its way into Texas.

The low ceilings persisted in the San Angelo area through 1400 CDT. The lighter spots in the overcast suggested that there was not much cloud above. A few patches of light rain persisted in the SE half of the radar scan. The temperature was only 67°F.

After looking at the satellite images and radar depictions, I concluded that the chances of our obtaining suitable convection in the area today are nil. The images showed overcast low clouds except for extreme SW Texas and even in the clear areas the new convection was underdeveloped. I then canceled the research mission for the day and, in effect, brought an end to TEXARC 1996. Kelly and Mark then worked on the Duke to remove the PMS probes for shipment to their owners. Meanwhile, Tom Promersberger prepared for his return flight to Fargo.

My cancellation of the research flight did not put us down for an operational mission late this afternoon and evening, but the chances for that were slim as well. Hurricane Fausto was nearing the SW tip of Baja California and its moisture will soon be caught up in the digging trough that is passing through California. The effects of this moisture should be felt in the SW U.S., including Texas, beginning tomorrow.

By 1500 CDT there was a E-W broken short line of rather weak echoes in NE Schleicher County and westward into Crockett County. It had not changed much as of 1600 CDT and I was not thinking seriously at that time of scrambling Seed 1. The PMS probes are off the aircraft, so its performance should be much better on its next flight. Seed 2 is down until tomorrow because of the discovery of some large holes in its exhaust manifold. The replacement part should arrive tomorrow.

APPENDIX B

TENTATIVE DESIGN OF A RANDOMIZED HYGROSCOPIC SEEDING EXPERIMENT
(Developed by Woodley and Rosenfeld at the outset of TEXARC 1996)

1.0 PURPOSE

The purpose of the hygroscopic seeding experiment is to determine whether the seeding at the bases of vigorous convective clouds results in the formation of rain drops in clouds that would not otherwise develop many such drops. By implication, therefore, the biggest effect should be noted in cloud with relative cool high bases. The "L" coalescence discriminator of Graeme Mather should be helpful in identifying which days should have clouds that might be responsive to hygroscopic seeding, where

$$L = 8.6 - T_{CCL} + 1.72pb_{500}$$

and T_{CCL} is the temperature at the convective condensation level and pb_{500} is the potential buoyancy at 500 mb.

2.0 EXPERIMENTAL PROCEDURES

On days identified as suitable for cloud-base hygroscopic flare seeding the cloud base (Seneca) and cloud physics aircraft (Beech Duke) will takeoff in a search for suitable clouds. The Duke may fly first to identify an area of suitable clouds. The Seneca will be scrambled to join with the Duke and the meteorologist on the Duke will identify a specific cloud target, noting the GPS position of the prospective base seeding. If the cloud base is hard and if a maximum updraft of at least 500 ft/min is noted, the meteorologist on the Duke in concert with the meteorologist on the Seneca <u>may</u> jointly declare an experimental unit. The treatment decision will be drawn from a set of randomized instructions on the Seneca. Commencement of seeding or simulated seeding cannot begin until the meteorologist on the Duke notes and reads back the center point of the projected seeding that has been provided by the meteorologist on the Seneca.

When a Seed decision has been drawn, two hygroscopic flares, one on each wing, will be ignited as the aircraft flies in a tight orbit in the updraft. Simultaneous with the seeding will be the release of SF_6 gas to be used as a tracer for the hygroscopic material. As long as the updraft at cloud base persists, the treatment will continue up to a maximum of one hour (24 total flares burned). If the updraft at the initial center point wanes, the seeding will continue at the base of a new tower on the upshear side of the first tower. The new treatment position must be provided to the meteorologist on the cloud physics aircraft.

The Duke cloud physics aircraft will monitor the tower being seeding using traverses at the level of the 0°C isotherm. The focus will be on the detection of the SF_6 gas. When a SF_6 spike is noted, its position will be entered into the GPS and the aircraft will then be flown relative to that position. It is expected that the treated volume will contain more rain drops than the cloud volume that does not contain the hygroscopic material.

When the treatment decision is No Seed, the same procedures will be followed, although it may not be possible to release SF_6 gas because of the added expense in doing so. In this case, it will be necessary to navigate the Duke through the cloud towers using the position provided by the base seeder at the outset of the experiment and then allowing for the drift with the wind.

No hygroscopic seeding will be conducted under severe weather conditions as identified by the National Weather Service with a severe storm warning. When such a warning exists, no seeding will be done within 25 n.mi. of the storm position.

After completion of the experiments the cases will be partitioned into several categories: 1) the subject cloud is associated with a Cb system, where a Cb in west Texas is defined as an echo having a top $\geq$ 10 km <u>and</u> a maximum reflectivity > 40 dBZ. To be associated with a Cb the subject cloud must be within 10 km of the boundary of the Cb at a 12 dBZ threshold. If the subject cloud is farther away, it is not associated with a Cb, 2) the subject cloud is isolated and not associated with a Cb, and 3) the subject cloud is capped such that its top does not reach the level of -10°C.

Within categories 2 and 3, it will be noted whether there is an echo at a threshold of 30 dBZ within 10 km of the subject cloud. This will give two potential bins for categories 2 and 3 but only one for category 1 since the no echo Cb class is not defined for category 1.

Note: This preliminary design was not used in TEXARC 1996 because of unsuitable weather and problems with the aircraft that allowed for only a few non-randomized cloud physics cases. It will be revised and set down in writing prior to TEXARC 1997. The results of the planned TEXARC 1996 analyses (See Section 10.0) will strongly influence that final design.

APPENDIX C

CALIBRATING THE FLOW METER FOR SF_6 GAS

Early this afternoon Danny and I calibrated the flow meter to be used in the release of the SF_6 gas. The calculation involved the assumption that 1 part per billion (ppb) of gas can be detected by the instrument and that 1 km^3 in which the mean updraft was 3 m/sec, would be affected during the gas release. It is assumed further, of course, that the gas would be distributed uniformly in this volume. To accomplish this we figured that the release rate of the gas would have to be about 1/3 liter/sec.

The flow meter used on SF_6 tanks were intended for use with argon gas, which has about 1/3 the molecular weight of SF_6 gas. It was necessary, therefore, to calibrate the meter for SF_6 gas. We did this by varying the flow rate until we filled a balloon to a volume of 2 liters in about 6 sec, which gives a release rate of 1/3 liter/sec. A setting of 60 ft^3/hr gave the desired balloon volume in 6 sec. When accounting for the decreased pressure at an expected average cloud-base height of 9,000 ft, a flow rate of 50 ft^3/hr seemed appropriate. At this rate we estimated that the gas bottles would be exhausted by about 100 minutes after commencement of gas release at the rate of 1/3 liter/sec. At best, therefore, each gas bottle should last us for roughly two actual seeding cases. We purchased five bottles of SF_6 gas, giving us nearly 10 cases before all of the gas would be gone.

If we are not able to detect the SF_6 gas using a release rate of 1/3 liter/sec, we will have to increase the rate. How much may prove to be a matter of trial and error. It is crucial that we detect the gas, so we will increase its rate of release until we find it. We would rather have fewer cases and detect the gas than many cases without gas detection.