AN OKLAHOMA WEATHER MODIFICATION PROGRAM STATUS REPORT AND PROJECT REVIEW

"NON-REVIEWED"

Timothy E. Sedlock*, Nathan R. Kuhnert♠, Rebecca L. Resler*,
Michael E. Mathis♠, Bruce A. Boe*, and Brian Vance♠

*Weather Modification, Inc.
Fargo, North Dakota

♠Oklahoma Water Resources Board
Oklahoma City, Oklahoma

Abstract. The recent history of the Oklahoma Weather Modification Program (OWMP) is presented, the 2001 field program summarized, and the current status of the statewide rainfall stimulation and hail suppression program reported. Some suggestions for program improvement are also enumerated.

1. BACKGROUND

The State of Oklahoma has histories of both prosperity and hardship due to either an abundance or shortage of water. During periods of long-term drought the state's agriculture suffers tremendously. The infamous statewide drought of the 1930s became known as the "Dust Bowl" and was devastating to the farming and ranching industries. Since the 1930s droughts reoccurred during three periods: 1951-57, 1961-72, and 1975-82, as determined from streamflow records. A significant but more localized drought occurred during 1984-86 (Tortorelli, 1991). More recent drought episodes impacted the state in 1995-96, 1998, 1999 and 2000.

Oklahoma's average precipitation distribution shows a large contrast between 18 inches (457 mm) received in the western Panhandle to more than 54 inches (1372 mm) that typically fall in southeast Oklahoma (Figure 1).

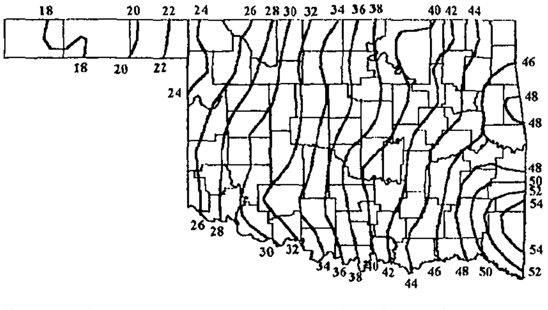
NORMAL ANNUAL PRECIPITATION
OKLAHOMA: 1971-2000

Figure 1. The thirty-year (1971-2000) average annual precipitation for Oklahoma. (courtesy of the Oklahoma Climatological Survey). The 1990s were considerably wetter than the 1960s, and as a result, the thirty-year mean is on average several inches wetter, statewide.

The Oklahoma Weather Modification Program (OWMP) sponsor is the Oklahoma Weather Modification Advisory Board (OWMAB), in cooperation with the Oklahoma Water Resources Board (OWRB). The cloud seeding program has been funded by the State, supplemented by voluntary donations from the insurance industry. The OWMP has the dual intent of hail damage mitigation and precipitation increase.

Cloud seeding was re-introduced to Oklahoma during the fall of 1996 in cooperation with the OWRB, and patterned after similar successful programs in Kansas, North Dakota, Texas, and Alberta, Canada. This statewide demonstration program was established to mitigate the effects of the 1995-96 Oklahoma drought. The results were promising:

- Qualitative analysis of specific rainfall enhancement operations suggested that they were consistent with the seeding hypothesis.
- An analysis of the liquid water content and droplet concentration based on randomized seeding during research flights supported the static seeding hypothesis.

- An analysis of the hail reports showed that the operator was capable of identifying the systems most likely to produce significant hail damage (Greene et al. 1997).

Since that time, the program has evolved into an operational effort fueled by a cooperative state/private insurance funding mechanism. It has been implemented as a long-term water management in Oklahoma for both rain enhancement and hail loss reduction (Kuhnert et al. 2000).

Significant benefits result from increased precipitation. Agricultural benefits include increased crop yields, improved grazing conditions, and reduced irrigation costs. Social benefits include increased runoff into reservoirs used for drinking water supplies and recreational purposes, improved water quality, and reduced pumping from aquifers. In addition, hail suppression operations are conducted to reduce property and crop damage across the state.

The OWMP's target area is the entire State of Oklahoma. Since certain areas of Oklahoma (such as the Panhandle) are often drier than others, special consideration is given to the drier areas by the OWMAB/OWRB.

Perhaps the greatest impetus for the OWMP implementation was the Oklahoma drought of 1995-1996. That drought produced numerous and far-reaching impacts, and was strongly felt by the state's agricultural community. Growers of wheat, Oklahoma's second largest agricultural commodity with an average annual value of $500 million, had little or no harvest in many areas. With very low cattle prices, bankruptcies and foreclosures increased significantly. Economic impacts were exacerbated by wildfires and forest fires, which resulted in widespread loss of grazing pastures, rangeland, woodlands and forests. By May of 1996, the drought was estimated to have cost the state between $1.0 and $1.2 billion. Bolstered by favorable recommendations from the Agriculture Committee, the Oklahoma State Legislature appropriated $1 million for weather modification from the Constitutional Reserve ("Rainy Day") Fund (Vance and Mathis 1997).

The passage of Senate Bill No. 101 (Oklahoma Weather Modification Act) by the Oklahoma State Legislature in May 1999 provided an additional appropriation of $1 million, and created the Oklahoma Weather Modification Advisory Board. One of the Board's responsibilities was the coordination of a long-term program funding through voluntary participation by state property/casualty insurance companies and other interested person, firms or corporations (Kuhnert et al. 2000). The OWMAB received voluntary contributions from the insurance industry since that time. State funding ceased at the end of State Fiscal Year 2001, and as a result, operations were suspended in June 2001.

The OWMAB presently believes that renewed weather modification research, coupled with the subsequent verification of the OWMP will be necessary to gain the desired $3 million in voluntary support from the insurance industry. Voluntary support of this magnitude has been realized in a Calgary-based hail suppression program in Canada (Krauss and Renick 1997).

2. CONCEPTUAL MODELS

The seeding conceptual models for the OWMP has been adopted from similar weather modification projects conducted by Weather Modification, Inc. (WMI) in North Dakota, Texas, and Alberta, Canada. The methods and techniques have been developed, reviewed, and refined over a period of years (Boe et al. 1998). The hail suppression concept employed is based heavily upon the idea of "beneficial competition", as discussed by a World Meteorological Organization-sponsored "Meeting of Experts" in 1994 (WMO 1995).

The premise of the glaciogenic seeding, as employed in Oklahoma, is as follows: Natural ice nuclei at temperatures warmer than −15°C are often relatively scarce, so cloud droplets remain in the liquid phase within a significant region of the cloud, even when supercooled. Measurements in cloud chambers indicate that these natural freezing nuclei commonly number about 1 L^{-1} at -20°C, increasing by about one order of magnitude for every 4°C decrease in cloud temperature. This general relationship (Fig. 2) was first published by Fletcher (1962).

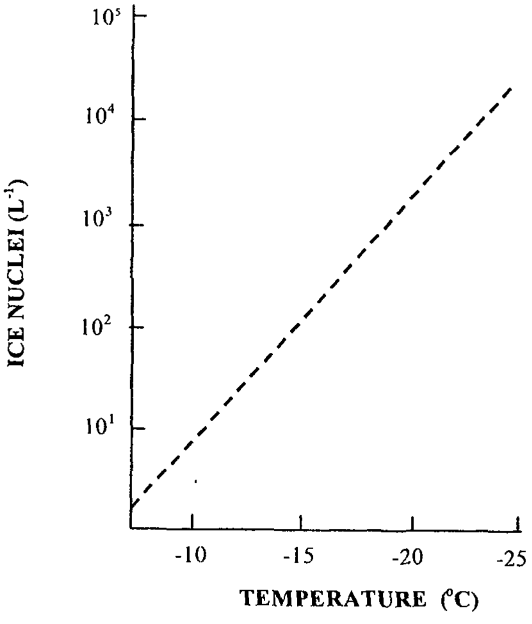

Figure 2. Natural ice nuclei concentration as function of temperature (from Fletcher 1962).

Cumuliform cloud turrets most often must grow taller and colder than −15°C before they produce much natural ice. The introduction of artificial ice-forming nuclei that function at much warmer temperatures (-6°C, DeMott 1999) serve to initiate the ice-phase precipitation formation process (Bergeron 1935) several minutes earlier in the turret lifetimes, providing a head start in precipitation development, when compared to untreated natural turrets. This is thought to accelerate precipitation development, and in cases when vertical cloud growth is limited, to result in precipitation development when none would otherwise occur. This "static" seeding would allow rainfall to form and fall from treated clouds for a greater fraction of the clouds' lifetimes, increasing total rainfall.

In more vigorous storms, glaciogenic treatment will result in the production of greatly increased numbers of ice particles, which then "compete" with each other for the hail-building supercooled liquid water in the cloud. The number of ice particles is increased, but their sizes decreased. The smaller ice particles have a much-improved chance of melting during transit of the warm sub-cloud layer. Particles which do not melt completely will at least be of smaller sizes, and thus possess reduced kinetic energy, reducing the potential for damage.

There are many interrelated cloud microphysical and dynamic factors that determine a cloud's response (or likely response) to treatment with ice-forming agents. Such discussions are beyond the scope of this paper. For more detailed consideration and discussion of these factors, the interested reader is referred the references previously listed in this section, as well as the as the OWMP Operations Manual (WMI 2001).

3. SEEDING AGENTS

The most effective (glaciogenic) seeding agents available, as demonstrated by testing at the Colorado State University (CSU) Cloud Simulation and Aerosol Laboratory (SimLab) have been used in the OWMP.

3.1 Silver Iodide-Complex Solution

The formulation of seeding solution used for base seeding on the OWMP was tested at CSU SimLab in February 1997 (DeMott 1997). A 1-mole solution of silver iodide-silver chloride-salt ($AgI_{0.8}$ $AgCl_{0.2}$ –NaCl) produced great numbers of nuclei (per gram AgI), active at relatively warm temperatures. The great number or ice nuclei, which function by the efficient condensation-freezing nucleation mechanism, make the solution a very effective mixture.

3.2 Pyrotechnics

Silver iodide-complex flares manufactured by Ice Crystal Engineering, LLC (ICE) have been used in the OWMP. The burn-in-place flares used for cloud-base treatment contained 70 g or 150 g of seeding material, and burned for either 2.2 to 4.6 minutes, respectively. The 20 g ejectable flares fired into actively growing cumulus congestus cloud tops fell approximately 4,000 feet during their 37-second burns. The ejectable and burn-in-place flares were of the same formulation.

The ice nucleating effectiveness of these flares has been determined by testing at the CSU SimLab (DeMott 1999). The SimLab has performed routine testing of the ice nucleating ability of aerosols produced from cloud seeding flares for many years (Garvey 1975). Testing was conducted in the isothermal cloud chamber from -4°C to -12°C, and at cloud liquid water contents (LWC) of 0.5 g m^{-3} and 1.5 g m^{-3}, which reflect values typically observed in growing Oklahoma cumulus congestus. The aerosol produced by the ICE pyrotechnics is highly-efficient, functions by condensation-freezing, and yields over 10^{11} nuclei per gram even at temperatures as warm as –4°C. The ICE pyrotechnics fire, ignite, and burn very consistently. The interested reader is again referred to the CSU SimLab reports for additional details.

Examination of data collected during research flights in southwest Oklahoma in 1986, and stratified by two different pass criteria, found mean LWC of 0.93 g m^{-3} and 1.05 g m^{-3} in penetrations warmer than –10°C, and a mean LWC of 0.90 g m^{-3} and 1.14 g m^{-3} in penetrations colder than –10°C (Mathis 1987, Poellot 1986).

4. SEEDING METHODS

Seeding agent was delivered to suitable cumulus congestus by aircraft, either by direct injection at cloud top, or by release of ice nuclei into the updraft region at cloud base.

4.1 Seeding Aircraft

Three Cessna 340 aircraft were deployed, two based near Oklahoma City, the third further west at Woodward. All three were rigged to seed with ejectable flares, burn-in-place flares, and wing-tip ice nuclei generators. The latter two seeding methods were used primarily at cloud base.

Aircraft were often pre-positioned prior to convective development, depending upon where convection suitable for seeding was forecast to develop. Though it was recognized that three aircraft would afford inadequate coverage of the state when convection was widespread, budgetary constraints forced this limitation. One of the three Cessna 340s deployed during the 2001 project is shown in Fig. 3.

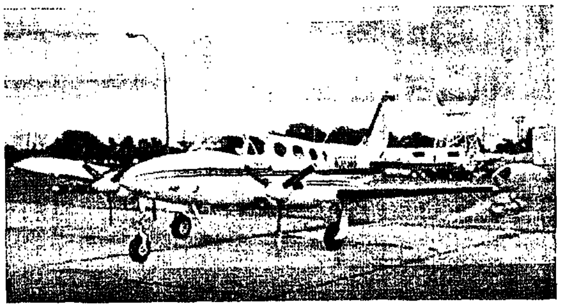

Figure 3. One of the WMI Cessna 340A aircraft, rigged for Oklahoma cloud seeding operations. The radar can be seen in the background.

4.2 Cloud Base Seeding

In cloud base seeding operations, silver iodide complexes were produced either by the combustion of acetone-based solutions in ice nuclei generators attached near the aircraft wing tips, or by the combustion of burn-in-place (BIP) silver-iodide flares attached to racks on the trailing edges of the wings. The nuclei thus produced were believed transported by the updraft of the growing cumulus congestus to the colder cloud regions containing supercooled liquid water. Near cloud top, turbulent mixing in the convective eddies dispersed the seeding agent through a significant portion of the cloud volume of the supercooled cloud, where nucleation occurred. If treatment was timely, the seeding agent reached the supercooled cloud top at about the time the cloud top was growing through the -10°C level. Nucleation in these seeded clouds was believed to occur on average about 5° to 10°C warmer than most natural nucleation (see again Sec. 2). Given typical cloud growth rates, this afforded a "head start" in precipitation development on the order of 3 to 5 min, which is perhaps ten to twenty percent of the expected natural cloud lifetime.

Cloud base treatment must have begun some minutes prior to the time the selected turret grows through the −10°C level. Exactly how long was determined by the cloud base height, the height of the −10°C level, and the average updraft speed, which is a function of atmospheric instability. The lead-time is typically on the order of 10 minutes.

4.3 Direct-injection Seeding

In direct-injection seeding, ejectable flares were used to target turrets growing through the -5° to -10°C level. The flares were ejected into the supercooled cloud top, where nucleation was desired, so the updrafts in these cases were relied upon only to provide a continuing source of condensate, not to transport the seeding agent upward from cloud base. This delivery technique required less anticipation on the part of those directing the seeding and had a more immediate effect.

In both methods, the intent was to glaciate portions of the cloud, initiating ice development minutes earlier than would naturally have been the case. For smaller or more isolated convective towers, glaciogenic seeding accelerated hydrometeor growth sufficiently to allow clouds to produce precipitation-sized hydrometeors during their short lifetimes (microphysical, or "static" effects), while adding buoyancy which stimulated updrafts and prolonged the cloud lifetime (dynamic effects). Both effects contributed to increased precipitation production.

For rain enhancement purposes, one 20 g ejectable flare was released into each turret. When seeding in a hail-suppression mode, seeding rates were significantly increased, with flares being ejected every few seconds as long at the aircraft remained within supercooled updraft.

5. METEOROLOGICAL SUPPORT

In addition to the cloud seeding aircraft and crews, the OWMAB/OWRB contracted with WMI to provide two field office facilities, two computer-controlled radars, the associated data acquisition and processing software, seeding aircraft tracking, and near real-time display of flight operations on the Internet.

5.1 Radar and Office Facilities

The field office facilities for the 2001 project were located at the Woodward Industrial Airpark in Woodward, Oklahoma, and the Sundance Airpark in Oklahoma City. All seeding operations were directed from these facilities (Fig. 4).

Each consisted of a customized trailer containing the on-site weather radar, aircraft tracking system, project computers, Internet access, and VHF communication equipment for communications with cloud-seeding aircraft. Both were air-conditioned to provide comfortable working conditions, and properly anchored to protect against high winds.

The two project weather radars were 5 cm wavelength WSR-74C sets manufactured by Enterprise Electronics Corporation of Enterprise, Alabama. These C-band radars were reconditioned, computer automated, and operated continuously in a volume scan mode.

The raw radar data were acquired and pre-processed by the Real-time Analysis and Prediction

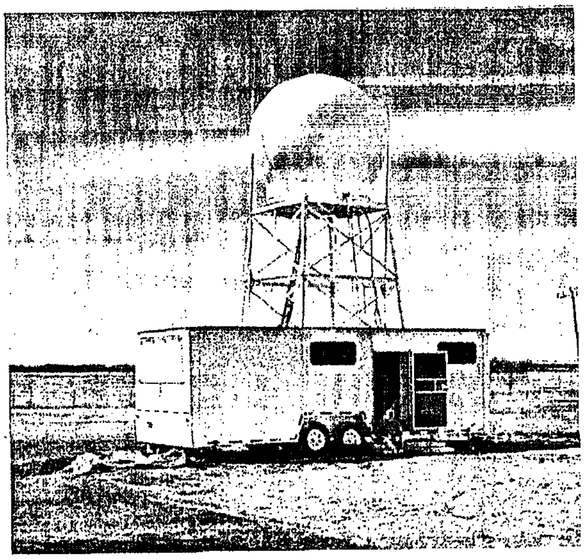

Figure 4. The WMI Oklahoma City 2001 field office facility and radar, sited at the Sundance Airpark, just west of Oklahoma City. A very similar facility was sited west of Woodward, Oklahoma, to provide radar coverage and improved aircraft support in the Panhandle and the western portion of the state.

System (RAPS), which consisted of a video processor and an angle interface that acquired raw radar video data.

The automated radar processing software did all of the following:

- Directly ingested the raw radar data.
- Pre-processed (applied calibration and stored) the data.
- Passed the processed data to another, Linux O/S computer.
- Applied a variety of weather algorithms to the processed data.
- Displayed data and the algorithm output.
- Provided post-analysis capabilities.

The data were then manipulated by TITAN (Thunderstorm Identification, Tracking, Analysis, and Now-casting, Dixon and Weiner 1993). TITAN is capable of many different post-analysis operations, including all of the following:

- CAPPI (Constant-Altitude Plan Position Indicator) display of reflectivity data.
- Creation of vertical cross-sections through the storms, from any user-defined endpoints.
- Real-time aircraft flight track display.
- Display of the history of storm motion and intensity.
- Projection of storm motion (interpolated from previous motions and trends).
- Mapping of radar-estimated precipitation.

The combination of RAPS and TITAN enabled the meteorologists to focus on the evolving convective situations, rather than having to expend much of their efforts engaged in record keeping activities. A sample TITAN image, captured by the Sundance radar, is shown in Fig. 3.

5.2 Aircraft Flight Tracking

Each field office facility was equipped to track OWMP aircraft during seeding operations. A Global Positioning System (GPS)-based data telemetry system developed by WMI received and recorded aircraft flight track data in real time. The system superimposed the position of aircraft on the radar display, enabling the meteorologists to accurately direct the seeding aircraft. Past and current positions were shown by flight tracks, each a unique color, allowing discrimination between all project aircraft.

The aircraft and operations center computers recorded GPS time, latitude, longitude, altitude, airspeed and seeding events. The recorded seeding events included wing-tip generator and BIP flares use, as well as a running total of the ejectable flare expended. At the end of each flight, the aircraft data were downloaded onto a 3.5" diskette. The flight tracks were then archived for use in training, analysis, and the public record.

Both the weather radar data and GPS flight track data were archived to CD-RW, for documentation purposes and possible future analysis.

The computer-generated radar reflectivity maps were automatically sent to an Internet web site every six minutes (Fig. 5), providing near real-time access to operational data. The publicly-accessible web site could be accessed using any PC with an Internet server. An example of the near real-time images, depicting storms and aircraft flight tracks, and obtainable from the project OWMP Internet web site is shown in Fig. 5.

5.3 Weather Forecasting / Nowcasting

The project meteorologists provided detailed weather forecasts each day, which were communicated via briefing to the project pilots. These forecasts were developed using real-time weather information obtained from the Internet. The daily weather forecasts were summarized by a single number, termed the Convective Day Category

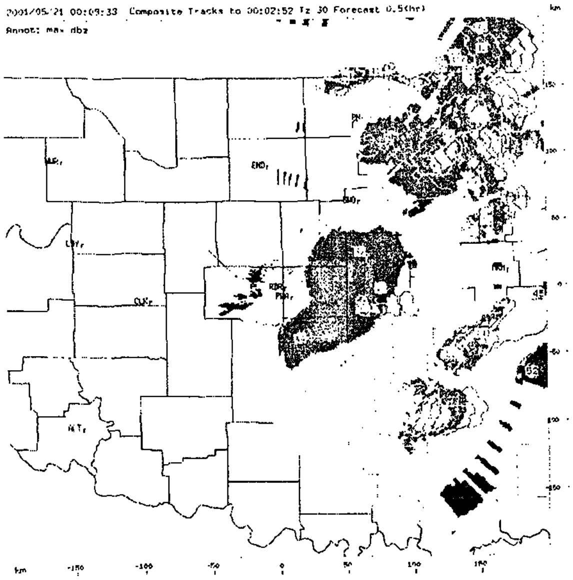

Figure 5. A sample TITAN image showing thunderstorm echoes, presently-defined storm cells (light blue outlines), projected future cell positions (red outlines), and maximum cell reflectivities (superimposed numbers, dBZ).

(CDC). This technique, developed for Alberta by Strong (1979), gives the cloud conditions and threat of hail or potential for rain enhancement for the day. A description of the weather conditions for each CDC is given in the Table 1, below.

Various meteorological parameters were also used in addition to the CDC, to develop a seeding strategy for the day. All project personnel were briefed at noon sharp by the meteorologists. The briefing included the CDC, a synopsis of the meteorological conditions, the time and location of expected first convection, and the seeding strategy for the day. Each flight crew was then placed on *weather watch*, *standby*, or *alert* status. *Weather Watch* meant that the development of convection was unlikely. Pilots were free to do as they wished, but were still required to carry their cellular phones. *Stand-By* status was given to the flight crews when convective cloud development was forecast or had begun, but clouds were not yet close to seedable. Aircraft were to have been able to launch and reach a target cloud within 30 miles of the airport *45* minutes after the (expected) request to launch was made by the meteorologist. *Alert* status was employed whenever seedable clouds were imminent. Aircraft were to have been able to launch and reach target clouds within 30 miles of the airport in *25* minutes after the (imminent) request to launch was made by the meteorologist. The meteorologists frequently updated the flight crews as each day progressed. The pilots carried cellular phones or pagers when they were not at home or at the airport.

Table 1. The Convective Day Category (CDC) Index.

CDC	Strategy	Description
-3	No Seed	Clear skies, cumulus humilis, or stratus (with no rain). No deep convection.
-2	No Seed	Overcast stratus-producing rain for prolonged periods, or broken to overcast low and middle cloud (cumulus clouds with tops warmer than -5°C) producing some weak rain showers.
-1	No Seed	Towering cumulus (tops warmer/lower than -10°C) with short-lived showers but no threat of hail or seedable targets. No reports of lightning.
0	Patrol flights, potential seeding.	Towering cumulus clouds to cumulonimbus (tops colder/higher than -10°C). Thunderstorms (at least one) but no hail. At least one report of lightning. Good rain enhancement candidates!
+1	Seed	Thunderstorms with pea or shot size hail (0.1 to 1.2 cm diameter) long-lived and conducive to seeding.
+2	Seed	Thunderstorms with grape size hail (1.3 to 2.0 cm diameter) long-lived and conducive to seeding.
+3	Seed	Mesoscale convective complexes, well-organized multicell storms, or line storms with walnut size hail (2.1 to 3.2 cm diameter).
+4	Seed	Deep convection (supercells possible) with golf ball size hail (3.3 to 5.2 cm diameter).
+5	Seed	Deep convection (supercells likely) generally containing hail and/or forming into well organized squall lines with a threat of severe weather. Hail greater than golf ball size (>5.2 cm diameter).

When suitable clouds developed and seeding aircraft were launched, operations continued as long as clouds suitable for rain increase or hail suppression persisted within the statewide target area, and as long as aircraft could safely reach the necessary cloud regions. Operations were routinely conducted after dark, aided by radar (aircraft and ground-based), illumination by lightning, and occasionally, the moon.

Operations were terminated when all suitable clouds left the state, when the clouds could not be safely reached by aircraft, or if the clouds weakened. In addition, operations were suspended when any of the suspension criteria were reached.

5.4 Suspension of Seeding Operations

The OWMP suspension criteria were based on those used in the North Dakota Cloud Modification Project (Boe et al. 1998). The project meteorologists terminated seeding operations whenever the following occurred:

- Tornado. Tornadic cells were not seeded. If seeding was in progress, it was terminated upon confirmation of a tornado. All tornado sightings by project personnel were reported immediately to the appropriate NWS office. This policy reflected the uncertainty of the effects of seeding upon tornadic cells, not upon any knowledge that seeding would exacerbate the situation.
- Stationary storms. Slow-moving storms that produced radar-estimated rainfall in excess of 2 inches per hour (reflectivities greater than 54.5 dBZ) were not seeded.
- Flood potential. Seeding ceased whenever a field meteorologist determined a potential for flash flooding existed, independent of other criteria.
- Flash flood warning. Seeding ceased in any region under a NWS flash flood warning, until the warning was cancelled.
- Harvesting. Seeding for rain enhancement was not conducted in regions where harvesting was ongoing, as identified by the OWMAB/OWRB.
- Client discretion. Seeding ceased upon the request of the OWMAB/OWRB.

Safety is always very important during any project. Pilots terminated operations whenever flight conditions became unsafe, or when they were about to become unsafe. Seeding was conducted at night only when visibility was sufficient. Weather radar coverage alone is not sufficient, as the targeted, precipitation-free cloud turrets are not readily detectable by radar, yet within minutes they may grow too large to safely penetrate.

6. OPERATIONS SUMMARY

The OWMP began in 1996 as a short-term emergency relief effort, and began full-season operations in 1997. The 1997 season ran from March 20 through October 31, the 1998 season from March 20 through October 17, and the 1999 season from September 22 through December 31. The 2000 season began on March 1, and ended on October 31, and the 2001 season began March 1 and ended on June 14.

The 1997 season utilized four aircraft until June 1, and three aircraft for the remainder of the season. Three aircraft were deployed for the 1998 through 2001 seasons. During the 1997 season, the aircraft were not equipped with wing-tip generators, but they were added to one of the 1998 aircraft, and to all aircraft thereafter. Each aircraft utilized belly-mounted racks for ejectable flares. One rack per aircraft was used during the 1997 season; second racks were added in 1998, and third racks added for the 2001 season. In all of the seasons, all aircraft utilized two burn-in-place flare racks mounted to the trailing edges of the wings.

6.1 Flight Hours

The total flight hours flown in each of the five seasons is shown in Fig. 6 (following page), which shows not only the seasonal progression, but also the project start and end dates. The reader may find it helpful to refer back to Fig. 4 when considering Table 2. The number of hours flown each season reflects the number of aircraft deployed, as well as the season and duration of the deployment.

6.2 Seeding Agent

The total seeding agent used, by type, is shown in Table 2.

Table 2. Seasonal Project Summary

Season	*Flight Hours*	*Ejectable Flares*	*BIP Flares*	*Wing-tip Generators (hours)*	*Total Seeding Agent (Kg)*
1997	334	3,716	805	--	195
1998	611	4,068	1,016	56.0	226
1999	180	1,961	228	23.9	77
2000	701	10,855	582	105.2	320
2001	550	13,574	1,213	190.6	481

As is suggested in Table 2, the primary mode of seeding was on-top, by direct injection with the 20 g ejectable flares. However, much seeding was also done from cloud base, especially at night, when the requisite visibility for on-top seeding was often lacking. The wing-tip generators and BIP flares were used when operating at cloud base.

7. FUTURE RESEARCH

In November of 2001, the Weather Damage Mitigation Program (WDMP) under the Bureau of Reclamation was signed into law. This approximate $2 million Program for Federal Fiscal Year 2002 will consist of a concerted, well-focused cooperative effort to assess the hazards, develop viable mitigation strategies, and apply the resultant technologies in measuring, modeling and quantifying atmospheric processes. The potential sharing of aircraft, radars, airports, regional meteorological information and related resources should maximize coverage and improve the overall efficiency of all involved programs. The WDMP will complement intensive, groundbreaking weather-related research conducted at the Oklahoma Weather Center.

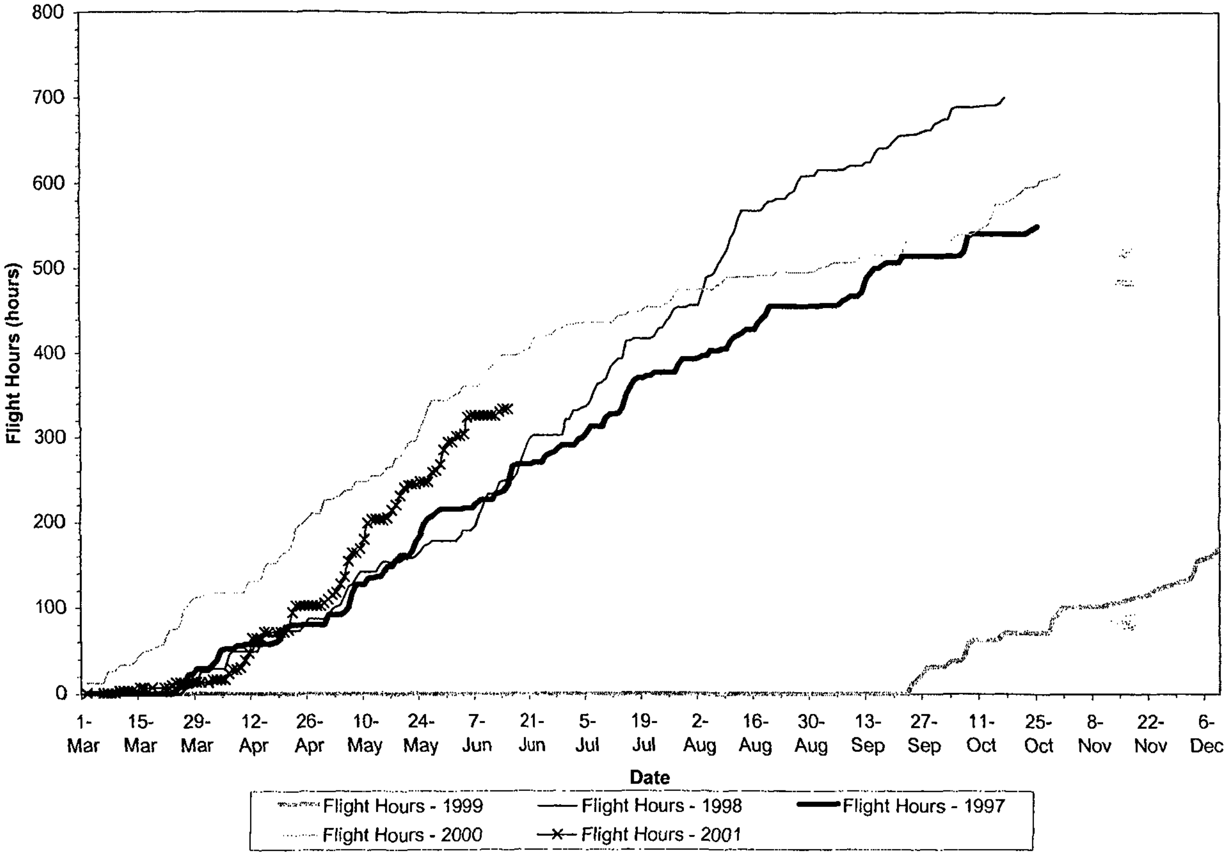

Figure 6. Cumulative OWMP flight hours for the1997 - 2001 seasons. The 1999 season did not begin until late September, and the 2001 project season was ended prematurely in June.

8. RECOMMENDATIONS

The following items have been identified as potential project improvements and/or enhancements, should program funding be made available for 2002:

1. Extension of the hail analysis to study treated and non-treated cells with respect to surface hail reports and longer-wavelength NWS radar signatures.
2. Expansion of economic impact studies to include analyses of top wheat producing counties in Oklahoma, and to include additional crops. This will provide a more detailed illustration of the overall potential economic benefit of a continued weather modification program.
3. Future examination of weather modification activities would benefit from continued and expanded efforts to collect cloud physics

information. Probes that can observe temperature, humidity, and cloud liquid water content, droplet spectra, and ice crystal sizes, shapes, and numbers can be affixed to the aircraft. Should the situation warrant (e.g., a surface or soil water surplus), certain periods might be designated for randomized cloud treatment, which would facilitate a faster statistical determination of the seeding effects.

4. Additional seeding aircraft are needed to better cover the state when outbreaks of severe weather occur. This is encouraged when funding allows. These aircraft would not necessarily have to be cloud-top seeders, but could be cloud-base seeders (Seneca II) instead.

5. Additional staff at the Woodward and Oklahoma City operations sites would be very helpful to assist the meteorologists during lengthy weather-watch periods and assist the flight crews in expediting their turn-around when they stop during ongoing weather episodes to get fuel and seeding agent. An intern program with the University of Oklahoma could be developed.

6. Fully investigate the advantages and disadvantages of moving operations from Sundance Airpark to Max Westheimer Airport of the University of Oklahoma Research Campus-North. One important advantage could be in increase in both collaboration and cooperation with the Oklahoma Weather Center including the potential development of an intern program and the leasing of office space at one of the Center's facilities.

7. *Investigate, with the assistance of the* National Severe Storms Laboratory and Weather Decisions Technology Inc. the potential for integration of high-resolution 10-cm radar data, in addition to other state-of-the science weather forecasting technologies.

8. Due to an increase in public awareness of the program, especially within the Oklahoma Weather Center community, the project needs to be better coordinated with representatives of the Norman National Weather Service and the Warning Decision Training Branch prior to the commencement of the next operational period.

9. All options for securing sustainable support for the operational program beginning in spring of 2002 should be investigated. Operational efforts must be coordinated with the Oklahoma Weather Center and other research organizations if/when state and federal sponsored research efforts become funded.

9. ACKNOWLEDGEMENTS

The OWRB and WMI acknowledge the support of the Oklahoma Weather Modification Advisory Board including Sen. Robert M. Kerr, President; Representative James Covey, Vice President; Senator Mark Snyder, Secretary; Representative Jack Bonny, Treasurer; OWRB Executive Director, Duane A. Smith, Chairman; Secretary of Agriculture Dennis Howard (and designee Duane Harrel); Secretary of Tourism and Recreation, Jane Jayroe; Insurance Commissioner Carroll Fisher; and Louis Fariss.

A number of agencies and people deserve recognition and thanks. The cooperation of Air Traffic Control facilities at Wichita and Fort Worth, is gratefully acknowledged. Special thanks are extended to Gary Varnell and Dave Brown, Managers of the Sundance Airpark and West Woodward Industrial Airpark, respectively. The cooperation of these persons helped make the 2001 project a success.

The constructive comments of the Editor are also appreciated. Howard Johnson of the Oklahoma Climatological Survey kindly provided Figure 1.

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