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COVER: The beautiful Sierra wave clouds, courtesy of Steve Chai.

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THE WEATHER MODIFICATION ASSOCIATION

The Weather Modification Association was organized in 1950 to develop a better understanding of weather modification among program sponsors, the operators and members of the scientific community. In 1966, the first suggestion for a professional journal was proposed and Volume 1, No. 1, of the *Journal of Weather Modification* was published in March 1969. This historic publication now includes 36 volumes (38 issues).

Originally called the Weather Control Research Association, the name of the organization was changed to the Weather Modification Association in 1967. During its 48-year history, the Association has:

- Pressed for sound research programs at state and federal levels.
- Promoted a better understanding of weather modification for beneficial use.
- Acted as a disseminating agent for literature.
- Provided extensive testimony before many federal, state and local committees and agencies in regard to all aspects of weather modification research and operations.
- Assumed an active role in the promotion of policy statements concerning all aspects of weather modification.
- Developed active positions on ethics, minimum standards for operations, and a strong certification program for operators and managers.
- Published the *Journal of Weather Modification*, the only professional journal in the world totally dedicated to the operational, societal, economic, environ-mental, legal and scientific aspects of weather modification.

The *Journal* is published annually and papers are always welcome for consideration in either the reviewed or non-reviewed sections. A nominal charge of $50 per page is made for each page published in the final double-column format of the *Journal*. An additional fee of $120 per page is charged for color pages; this fee is charged for all papers, foreign and domestic.

The general membership is open to all individuals and organizations who have an interest in any aspect of weather modification. The classes of membership and the present annual dues are:

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Applications for membership on a calendar year basis, as well as additional information, can be obtained by writing to WMA at the permanent address of the Association:

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Editor's Message

In this issue we have a reviewed paper, a reviewed reply, and seven non-reviewed articles including the "In Memoriam" for Dr. John Fluek provided by Roger Reinking. I wish to thank all the authors and advertisers for their contributions to this volume of the Journal. I also wish to thank Hilda Duckering, my Editorial Board members, the paper reviewers and my assistant, Vicki Hall, for their hard work and effort, without which this publication wouldn't be possible. Thank you all!

Sincerely,

Steve Chai, Editor

THE VARIABILITY OF CLOUD CONDENSATION NUCLEI AND CLOUD DROPLET POPULATIONS IN CONVECTIVE CLOUDS OVER THE HIGH PLAINS: HOW OFTEN ARE CONTINENTAL CLOUDS CONTINENTAL?

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Abstract. Observations and cloud microphysical modelling suggest that hygroscopic cloud seeding can be used to enhance precipitation from continental convective clouds. Model simulations demonstrate that the effect of such treatment varies with cloud microphysical characteristics. Significant enhancement is predicted for clouds with continental cloud droplet spectra, i.e. droplet concentrations on the order of 1000 cm^{-3}. The effect on maritime clouds with droplet concentrations of the order of a few 100's cm^3 or less is predicted to be much smaller. A survey of past studies of aerosols is presented along with a newly-assembled collection of observations of convective cloud droplet concentrations over the High Plains of North America. It is shown that while a majority of clouds are indeed microphysically continental, a significant fraction of clouds in this region have microphysical characteristics that are maritime or intermediate between maritime and truly continental. Practitioners of hygroscopic seeding in this region need to monitor aerosol and cloud characteristics and target microphysically continental clouds if they want to optimize the effects of their seeding. Furthermore, indiscriminant hygroscopic seeding of clouds or an evaluation of results without regard to the maritime or continental character of the target and control clouds could lead to inconclusive and/or spurious results.

1. INTRODUCTION

One general concept for modifying the precipitation produced by convective clouds is to in some way modify the microphysical evolution of the cloud so that more precipitation falls to the ground during the lifetime of the cloud or cloud complex. This may involve more efficient conversion of cloud water to precipitation as well as extending the size and/or lifetime of the cloud. The focus here is on the concept of seeding convective clouds with hygroscopic aerosols to increase precipitation. Several reviews over the past decade have covered this topic, including Czys and Bruintjes (1994), Bruintjes (1999), Silverman (2003) and National Research Council (2003). The specific focus here is the microphysical basis for precipitation enhancement by this method. The fundamental aim of hygroscopic seeding is to produce larger droplets more quickly that sweep out the naturally-nucleated smaller ones as they fall, thus to accelerate the growth of precipitation-size hydrometeors by collision and coalescence. In addition, hygroscopic seeding may influence supercooled cloud evolution in at least two ways. Production of a broader spectrum of cloud droplet sizes in mixed-phase cloud regions will lead to accelerated ice multiplication by the Hallett-Mossop rime/splintering process (Hallett and Mossop, 1974). In addition, larger precipitation-size liquid drops formed lower in a cloud by accelerated collision and coalescence, when carried above the freezing level, will freeze at lower altitudes (higher temperatures) and alter the vertical distribution of latent heat release, riming growth, and precipitation-loading (Beard, 1992).

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2. BACKGROUND

Biswas and Dennis (1972), Klazura and Todd (1978), and Todd and Howell (1982), among others, developed simplified quasi-steady-state one-dimensional models for understanding the situations in which seeding a convective cloud updraft with relatively large (~ 10 μm diameter or larger) water or salt particles will result in increased precipitation. This form of seeding introduces a population of large "collector" particles that accelerate the growth of precipitation-size hydrometeors by collision and coalescence. Reisin *et al*. (1996) more recently simulated this same process with a much more sophisticated time-dependent axi-symmetric cloud model with detailed treatment of aerosol and cloud microphysics, and full coupling between microphysics and dynamics. Issues typical to most cloud seeding concepts were addressed with these models, including optimum seed aerosol particle size and composition, mass of seeding material required, and the optimum timing and location for delivery of this material to clouds in various environments and states of development in order to produce the greatest enhancement in precipitation. These models were used to identify combinations of these factors that would in general lead to cloud-scale precipitation enhancement.

Of particular interest to the discussion here is how the variation in the background cloud condensation nucleus (CCN) population affects the simulated precipitation enhancement by hygroscopic seeding. In the model of Reisin *et al*. (1996) the concentration of active CCN varied with supersaturation as

(1) $$N = C \cdot \left(\frac{S}{S_0} \right)^k$$

where N is cumulative concentration of CCN active at supersaturation S(%), in number per cm^3, S_0 is 1%, and C and k are constants. Clouds developed from a "continental" cloud condensation nuclei spectrum with C =1100 cm^{-3}, a "maritime" spectrum with C = 100 cm^{-3}, or an "intermediate" spectrum with C = 600 cm^{-3}, the number active at 1% supersaturation with respect to liquid water. They found that hygroscopic seeding with relatively large water or salt particles will enhance precipitation significantly in clouds with "continental" cloud droplet size concentration and size spectra, roughly doubling the precipitation produced without seeding. In the "intermediate" situation there was much more modest enhancement, and in maritime clouds there was negligible effect on precipitation.

In the 1990's Mather *et al*. (1997) in South Africa developed the concept of seeding convective cloud updrafts with low concentrations of much smaller hygroscopic particles (d ~ 1 μm) than had been used in previous hygroscopic seeding experiments. The concept is that these seed nuclei will nucleate droplets more readily than most of the natural aerosol particles, and these growing droplets will deplete the supersaturation in the updraft so that many of the natural aerosol particles never nucleate droplets. The result will be a lower concentration of cloud droplets with larger mean size and wider size dispersion than would have occurred naturally, leading to more rapid and efficient collision/coalescence growth of precipitation. This method involves dispersal of much smaller masses of hygroscopic material than does hygroscopic seeding with large nuclei or water droplets, and is logistically much less costly to implement.

Cooper *et al*. (1997) using a parcel model with detailed microphysics, and Yin *et al*. (2000) using the cloud model of Reisin *et al*. (1996), simulated the results of this method of hygroscopic seeding. With respect to the influence of the cloud droplet spectrum on seeding-produced precipitation enhancement, they found trends similar to those found earlier for hygroscopic seeding with relatively larger particles. Hygroscopic seeding with small particles produces significant enhancement of precipitation in "continental" clouds, and has little or no effect in "maritime" clouds.

While it is tempting to assume, based on these results, that hygroscopic seeding can be expected to produce significant precipitation enhancements in all clouds developing in very continental locations such as the High Plains of North America, observations of cloud condensation nuclei (CCN) spectra in this region in fact suggest otherwise. Hobbs *et al*. (1985a, 1985b) conducted several weeks of airborne observations of CCN activation spectra in the planetary boundary layer over regions from Great Falls, MT, to Big Spring, TX spanning the summers of 1975 and 1976. More intensive observations were conducted in the Miles City, Goodland, KS, and Big Spring areas. They fit their observed spectra to the form specified in Eq. (1), and divided their observed spectra into three composite classes with differing concentrations and rates of increase of concentration with increasing supersaturation. These classes were "maritime" with C=290 cm^{-3}, "transitional" with C=1500 cm^{-3}, and "aged continental" with C=2200 cm^{-3} (CCN active at 1% supersaturation). The slope k varied from 0.7 for "maritime" to 2.8 for "transitional" to 0.9 for "aged continental." Despite the geographically continental locations of the observations, "maritime" CCN spectra were observed 25% of the time. A terrain-follow-ing layer-averaged trajectory model was used to infer air mass origins. They found that "maritime" CCN spectra can be observed over the High Plains in maritime or modified maritime air masses, or in air masses that recently were involved in widespread cloud processes. In general, maritime air masses would become more continental in character within only a few days of travel over continental terrain in non-precipitating situations.

Vali *et al*. (1982) report an extensive series of surface CCN activation spectra acquired in June and July, 1976, in northeastern Colorado and southwestern Nebraska as part of the National Hail Research Experiment (NHRE). Among 60 observations at two sites over these two months, only 2 were characterized by a concentration active at 1% supersaturation as low as 300 cm^{-3}. These observations are characteristic of a predominantly "continental" CCN population, and suggest a much less frequent occurrence of "maritime" CCN populations at these sites during this time period compared to those observed by Hobbs *et al*. (1985b) over a longer time period and much larger geographic area.

Demott *et al*. (1996) in central North Dakota obtained CCN spectra on the ground and in the air, then compared CCN activation spectra to cloud droplet spectra observed within quasi-adiabatic updraft regions in convective clouds in the same region. Data were acquired over an 18-day period near Bismarck in July, 1993. For the period the average CCN concentration active at 1% supersaturation was 300 cm^{-3}. In addition, the cumulative frequency distribution of cloud droplet concentrations showed that droplet concentrations less than 300 cm^{-3} occurred in 25% of the samples obtained during this period. These observations show that "maritime" aerosol and cloud conditions can occur a significant fraction of the time in this region.

According to Eq. (1), the activated CCN concentration increases with supersaturation. When relating CCN population characteristics to cloud droplet concentration in clouds, one must have an idea of what typical supersaturations are reached in the clouds. In the simulations of Reisin *et al*. (1996), Cooper *et al*. (1997) and Yin *et al*. (2000), typically peak droplet concentrations were less than the specified concentration of CCN active at 1% supersaturation. Politovich and Cooper (1988) used updraft speed and cloud droplet spectra to infer that peak supersaturations were always less than 1%, and most of the time were less than 0.5%, in the lower regions of convective clouds in the Miles City area during the Cooperative Convective Precipitation Experiment (CCOPE) in 1982. In contrast, the cumulative frequency distribution of droplet concentrations in nearly adiabatic updrafts in clouds similar to those sampled by Politovich and Cooper (1988) compared to the cumulative frequency distribution of CCN active at various supersaturations in the work of DeMott *et al*. (1996) suggested that peak supersaturations reached in the updrafts in the Bismarck sample were as high as 2% much of the time.

Klazura (1971) observed precipitation particle size spectra (d > 250 um) using a foil impactor on an aircraft sampling in the upper regions of warm cumuli over southeast Texas during the summers of 1968 and 1969. Based on the number and size distribution of precipitation particles, he concluded that the population of clouds in the same region was much more "maritime" during one summer, and much more "continental" during the other.

In order to gain a better estimate of the fraction of the time that hygroscopic seeding of convective clouds can be expected to lead to significant precipitation enhancement, more observations and more refined modelling are needed. Based on the available modelling results, significant enhancement is expected when "continental" clouds are treated, and much smaller enhancement when "maritime" clouds are treated. While the definition of "maritime" is not precise, and varies from investigation to investigation, the trend of decreasing enhancements with more "maritime" microphysical conditions should be robust. The more microphysically "maritime" a cloud is, the smaller the enhancement of precipitation by hygroscopic seeding, other factors being equal.

Data on CCN concentrations and cloud droplet populations is difficult and expensive to obtain. It is clear from the work surveyed here that over the High Plains microphysically "maritime" CCN spectra and clouds occur with significant frequency, but that the characteristics of CCN and droplet populations can vary significantly between the same seasons in different years at one location, or in the same season and same year at different locations. Short periods of measurement at a few locations do not necessarily capture the complete range of variability. In order to make available more data with which to characterize the microphysics of High Plains convective clouds, presented here are observations of cloud droplet concentrations in clouds observed in some of the same regions discussed by Hobbs *et al*. (1985a), sampled during several subsequent field experiments using a different aircraft. While Hobbs *et al*. (1985a) used direct measurement of CCN to predict the character of clouds developing in the sampled air mass, this discussion will be based on in situ cloud microphysical observations.

3. DATA AND ANALYSIS METHODS

This study is based on cloud droplet data obtained with the Particle Measuring Systems, Inc. (PMS) Forward Scattering Spectrometer Probe (FSSP) carried by the South Dakota School of Mines and Technology (SDSMT) armored T-28 storm-penetrating research aircraft (Johnson and Smith, 1980; http://www.ias.sdsmt.edu/institute/t28/index.htm) during three field campaigns. These include the June, 1987, field season of the North Dakota Federal/State Cooperative Weather Modification Program (NDCWMP) at Dickinson, North Dakota (Detwiler and Smith, 1988); the Texas Experiment in Augmenting Rainfall through Cloud Seeding (TEXARC) at Big Spring in August, 1994; and the Severe Thunderstorm Electrification and Precipitation Study (STEPS) at Goodland in May and June, 2000 (http://www.mmm.ucar.edu/community/steps.html). Dickinson is ~260 km east of Miles City where Hobbs *et al*. (1985b) made extensive CCN observations in 1975 and 1976, and Goodland and Big Spring are the two other sites where they made extensive observations in 1975. All three locations are along the western edge of the High Plains region and are characterized by semi-arid summer climates.

The FSSP used in this study was serial number 1 of the commercial production run of this PMS instrument, first used in the field on the T-28 in 1975 during NHRE. It is a single particle counter. Particle size is inferred from intensity of light scattered into a photodetector with an annular mask admitting light scattered 8^o to 12^o from the forward direction. Probe circuitry is designed to reject data from particles which are not completely immersed in the sample volume. Data are accumulated for 1 sec (~100 m of aircraft travel) then dumped to the data acquisition system.

The probe was routinely calibrated with latex and glass spheres to verify the relationship between particle size and scattered intensity, taking into account the difference in index of refraction between the test particles and liquid water. This procedure was not applied until several months after the Dickinson field season (with the data being corrected after the fact), but was performed multiple times in the field during the Big Spring and Goodland field seasons. The integrated liquid water concentration also was compared to cloud water observations from a Johnson-Williams (JW) cloud water meter (Dickinson and Big Spring) and a Droplet Measurement Technologies (DMT) liquid water content probe (STEPS). Allowing for known response characteristics of the two probes, further adjustments were made in the FSSP size vs. intensity relationship to arrive at an optimum calibration such that the integrated FSSP cloud water concentration matched the observations from the direct total water measuring probes. (See Feind *et al*., 2000.) The Big Spring data were also reprocessed using a numerical simulation of the FSSP (Baumgardner and Spowart, 1990) in order to better refine size and concentration estimates. The reprocessed and standard data were very similar in character for that year, and in this study data from all three years are processed in the standard manner.

Of importance to the discussion below is the correction of observed concentrations for instrument dead time. The probe circuitry requires a small amount of time (several microseconds) to record data from each droplet passing through its sample volume. In regions of higher droplet concentration (exceeding several 100's cm^{-3}) a dead-time correction must be applied to account for droplets passing through the sample volume while the probe is recording data from the previous droplet and unable to respond. For the data discussed here, the dead time correction is one derived by PMS based on the fraction of time the probe circuitry is busy recording data. The raw concentration is divided by the factor

$$1-(0.55\cdot \text{activity})$$

where activity is the fraction of the time during the current second that the probe is busy processing signals from droplets. As this factor is always less than 1 when droplets are present, it always results in an increase over the concentration based on the raw number of validly-sized droplets. Concentrations derived in this manner are in close agreement with the more rigorous model-based data reduction procedure discussed by Baumgardner and Spowart (1990) and applied to the Big Spring data, with the modeled concentration on the average 9% less than bulk correction concentration, with a root mean square difference of 35 cm^{-3}. While the absolute accuracy of FSSP droplet concentrations cannot be independently evaluated, similar concentrations obtained using two different processing schemes lends confidence to the relative concentration variations between updrafts.

Of possible significance in interpretation of the data presented below is an instrument refurbishment accomplished between the TEXARC project in 1994 and STEPS in 2000. Newer circuitry of the same design was installed, some of the optics was replaced, and the laser was upgraded. However, the same calibration procedures were successfully applied to data from all seasons and overall the data from different seasons appear to be consistent.

During all three projects, the mission of the T-28 was to sample growing to mature convective clouds or storms. Generally, isolated towering cumulus and cumulus congestus clouds were sampled at Dickinson and Big Spring, while larger more vigorous multicellular thunderstorms were sampled at Goodland. Typical sampling altitudes were 5 – 7 km MSL, with temperatures ranging from -5 C to -15 C, although occasional penetrations were made near cloud base. The sample size included here is fairly small. Presented below is a survey of two days including penetrations of three clouds with appropriate data from Dickinson, three days with a total of eight clouds from Big Spring, and seven days with seven thunderstorms from Goodland.

From the data collected on these days, passes through relatively precipitation-free updrafts were isolated using updraft speed estimated from aircraft motion, and PMS 2D-C cloud and precipitation particle imaging probe data. Peak cloud droplet concentration was extracted for each pass or pass segment corresponding to a region with a maximum in droplet concentration associated with a peak in the updraft and no precipitation or a minimum in precipitation particle concentration.

For these days reasonably representative proximity soundings based on radiosonde launches and the aircraft ascent and descent soundings are available. The observed cloud liquid water concentration is used to estimate how close to adiabatic the updraft conditions were by comparing to an estimate of adiabatic liquid water concentration derived from these soundings. The accuracy of these adiabatic cloud liquid water concentration estimates is difficult to assess. There are significant variations in boundary layer humidity on length scales of 100 km and time scales of hours, the typical separation in space and time between radiosonde sounding and sampled cloud. The representativeness of the sounding can be improved by modifying it using the aircraft ascent and descent temperature soundings. Humidity cannot be modified based on aircraft data as the T-28 carried no humidity sensor. Pilot observations of cloud base height are available in many cases, which further refines estimates of cloud base temperature. Finally, observed in-cloud temperatures are compared to those predicted by adiabatic ascent from the sounding convective condensation level. After arriving at a best estimate of cloud base conditions and penetration level temperature, an adiabatic liquid water concentration is found. Based on the maximum excess of any measured cloud liquid water concentration over the predicted adiabatic concentration (the theoretical maximum), estimates of adiabatic liquid water concentration were accurate to within 20%.

4. RESULTS

Figure 1 shows peak droplet concentrations in updrafts encountered in three cumulus congestus clouds during two days of operations during the NDCWMP near Dickinson as a function of fraction of adiabatic cloud liquid water concentration. For passes encountering more nearly adiabatic conditions, it is expected that the droplet concentration will more nearly represent the concentration of active CCN in the cloud base inflow air. The droplet concentration values exceeding 600 cm^{-3} are from one day, the lower values are from the other. Figure 2 shows the same relationship based on observations from eight cumulus congestus clouds observed on three days during TEXARC near Big Spring. The many nearly adiabatic observations are from two days, while the observations further from adiabatic conditions are from the third day. Finally, Figure 3 shows the same relationship for multiple penetrations of seven thunderstorms observed during STEPS near Goodland. Multiple updrafts were sampled within each storm.

There are several notable aspects of this relatively small sample, from 12 days during three different years at three different locations. Of the two days from Dickinson, one had a much more maritime character than the other. In Big Spring, most of the updrafts were more maritime than continental in nature. In Figure 2, the initial pass through the updraft with a peak concentration of nearly 600 cm^{-3} was followed by subsequent passes through the same updraft showing the same fraction of adiabatic water but peak concentrations of 340 and 430 cm^{-3}. Two other clouds sampled in the same region on the same day had peak concentrations less than 370 cm^{-3}. In Goodland, the droplet concentrations suggest a microphysically more continental cloud population in all storms sampled.

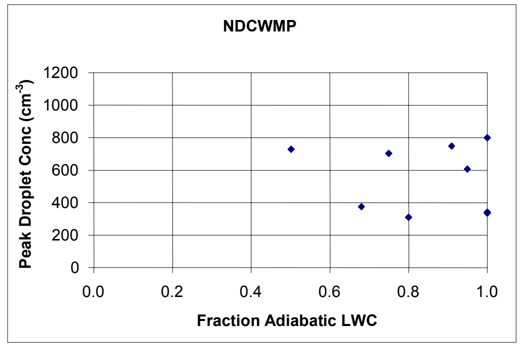

Figure 1: Peak cloud droplet concentration in updrafts from two flights during the NDCWMP as a function of the peak ratio of measured cloud water concentration to adiabatic water concentration within the updraft. The data were obtained in three clouds on two different days. The three lowest values come from the only cloud sampled on one of the days.

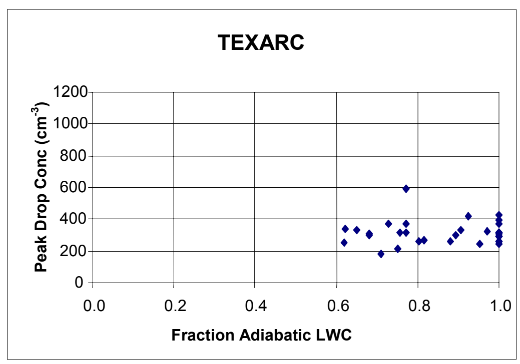

Figure 2: As in Figure 1, but based on observations from 8 clouds on 3 different days during TEXARC.

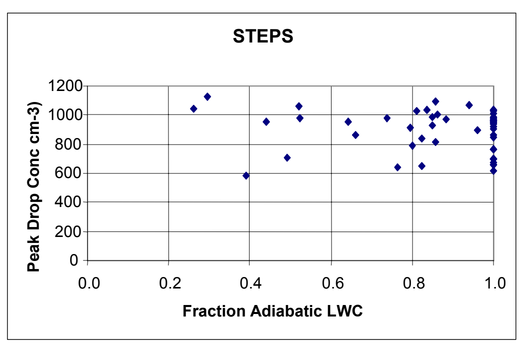

Figure 3: As in Figure 1, but based on observations from seven thunderstorms on seven different days during STEPS.

In all three locations the range of droplet concentrations does not vary significantly with the fraction of adiabatic liquid water. This suggests that in relatively precipitation-free updrafts, entrainment did not reduce peak droplet concentrations, within the accuracy of the methods used here for computing adiabatic liquid water concentration and measuring droplet concentration. On the scale of the droplet sampling, ~100 m, this is consistent with homogeneous mixing, where entrained dry air results in some evaporation of all droplets but disappearance of few.

In larger more vigorous storms, it is possible that more CCN are activated in stronger updrafts. Figure 4, based on TEXARC data, illustrates that peak droplet concentration was not a strong function of peak updraft speed. A similar pattern is seen in the STEPS data shown in Figure 5.

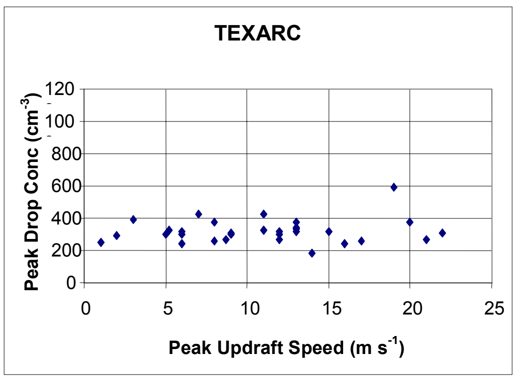

Figure 4: Peak cloud droplet concentration in updrafts sampled in 8 different clouds on 3 different days during TEXARC as a function of peak updraft speed in the updraft.

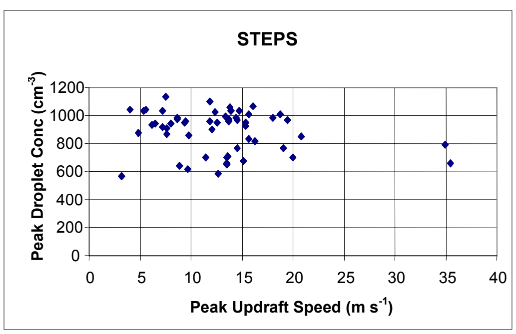

Figure 5: As in Figure 4, but for multiple updrafts in 7 storms during STEPS.

It would be desirable to characterize cloud microphysics using more than just the peak cloud droplet concentration. Maritime clouds also differ from continental ones in mean droplet size, and width of the droplet size distribution. Results of hygroscopic seeding will depend on these parameters, too. Peak concentration is used here because it is readily available from the three project data summaries, and because it is a relatively uncomplicated measurement. Cloud droplet size spectra must be computed from FSSP data with considerable care. In particular, even a well-calibrated FSSP yields noisy spectra when even small numbers of precipitation-size particles are present due to random sizing of irregularly-shaped (ice) particles or spherical particles larger than ~100 μm diameter (See Baumgardner and Spowart, 1990). Efforts will be continued to understand the microphysical character of High Plains convective clouds by extending this type of analysis to more seasons and locations, and by more carefully studying FSSP data from the projects discussed here as well as additional ones. In addition, air mass trajectory analysis like that performed by Hobbs *et al*. (1985a) will be a valuable tool for relating microphysical character to weather regime. Such a relationship will be a valuable guide for operational hygroscopic seeding.

5. CONCLUSIONS

If one looks at the set of peak cloud droplet concentrations from the NDCWMP, TEXARC, and STEPS, as a whole, on 8 out of 12 days the peak droplet concentrations clearly suggest microphysically "continental clouds". On 3 other days the peak concentrations are on the order of 300 cm^{-3} or less, approaching "maritime" in character. On one day during TEXARC, one cloud had much higher concentrations than two other clouds observed nearby.

Hobbs *et al*. (1985b) noted that the frequency of "maritime" CCN spectra, based on several weeks of sampling in two summers at several locations in the High Plains region, varied distinctly between the two summers. Atmospheric flow regimes can set up and persist for extended periods of time, subjecting a given region to a predominance of one air mass and/or weather type for weeks. In field projects of the type from which these data are drawn, several weeks of sampling will not characterize the complete range of variability observed over many years. Still, by using data accumulated over several weeks at three different locations in three different summers, it is shown that clouds that are microphysically maritime are observed a significant fraction of the time over various portions of the High Plains.

Modeling results of Reisin *et al*. (1996), Cooper *et al*. (1997), and Yin *et al*. (2000) suggest that enhancement of precipitation from convective clouds seeded with hygroscopic aerosols or droplets is much diminished the closer to maritime are the CCN supersaturation, and cloud droplet size, spectra. The data presented here support the conclusion of Hobbs *et al*. (1985b) that "maritime" CCN spectra, leading to microphysically “maritime” clouds, occur a significant fraction of the time over the High Plains. Operational seeding using hygroscopic aerosols should be targeted at clouds that are more continental in nature in order to optimize precipitation enhancement.

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REPLY TO A PAPER ENTITLED "REEXAMINATION OF HISTORICAL REGRESSION ANALYSIS APPLIED TO A RECENT IDAHO CLOUD SEEDING PROJECT"

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1. BACKGROUND

North American Weather Consultants (NAWC) conducted a winter cloud seeding project for the Boise Project Board of Control in the mid-1990's. The project was discontinued when some wetter winters impacted Idaho in the latter 1990's. In discussions with their Board of Directors in 2000 a question arose as to whether increases in streamflow that might be produced by a winter cloud seeding project would be lost to hydro generation at Lucky Peak Dam in the high runoff periods resulting from spring and early summer snow melt. Some board members indicated that the turbine capacities at Lucky Peak could be exceeded in some situations. This would obviously affect the value of the additional water from cloud seeding. We conducted an in-house study to determine if this might in fact be the case. We (NAWC) subsequently published a paper entitled "Economic Feasibility Assessment of Winter Cloud Seeding in the Boise River Drainage, Idaho" in the 2002 in the reviewed section of the edition of the WMA *Journal of Weather Modification.* That paper by Griffith and Solak will herein be referred to as GS. The intent GS was to explore the concerns of these board members and to produce some estimates of the potential economic benefits of the cloud seeding project, based upon estimates of increases in snowpack water content values on April 1st. Although the method used to produce the estimates of seeding effects was described briefly in GS as background material, the intent of that paper was not to present a definitive explanation of the historical target/control analyses that were used to establish the estimates of increases in April 1st water content. More comprehensive discussions on the target/control evaluations were provided in our annual reports to our client, but have not been formally published. The title of GS indicated that it was an economic feasibility assessment. We used the term estimate (or estimates) in discussions of the potential increases in April 1st snow water content. These numbers were never cited as exact, nor could they have been, based upon the type of analyses that were performed in the absence of a randomized data set.

2. CONCERNS

Subsequently, a paper was published by Super and Heimbach entitled "Reexamination of Historical Regression Analysis Applied to a Recent Idaho Cloud Seeding Project" in the reviewed section of the 2003 edition of WMA *Journal of Weather Modification* (Super and Heimbach, 2003). This paper will herein be referred to as SH. In this publication, the GS paper which had been reviewed and published in the 2002 Journal is criticized and characterized by inference as being gravely flawed. The criticisms presented in SH ignore the stated purpose of the original GS paper, which was by title and content a practical analysis of economic and operational project-specific issues. Instead, SH uses the data to disparage not only the GS paper, but in our view essentially any attempts to evaluate non-randomized operational cloud seeding projects.

We were not made aware of the SH paper prior to its publication, nor given the opportunity to respond to it when it appeared in the 2003 Journal. It has been our experience that the opportunity to reply to criticisms is often granted in situations such as these, e.g., in the Bulletin of the American Meteorological Society. The WMA Journal itself has used this approach recently (see the 2002 comment by Bigg on a paper written by Long, and also the subsequent reply by Long). A comment by Super and Heimbach on our original paper, followed by a reply from us in the same volume, from our perspective would have been fairer, providing the reader with all the relevant information and differing perspectives at once.

In the absence of the comment and reply scenario described above, another acceptable approach would have been for Super or Heimbach, or the Editor of the Journal to contact us directly to ensure complete understanding of GS before publishing SH. Some criticisms offered by SH are not entirely without merit, but misrepresent the intentions of GS, which as previously stated, were to provide some sense of the economic feasibility of the program.

To be sure, SH offers some valid advice as to how operational projects might be conducted and evaluated from the authors' viewpoints. From our perspective, it would have made more sense for SH to simply write and publish an original paper stating their positions on how operational projects should be designed, operated and evaluated.

3. AN IMPORTANT CONSIDERATION FOR THE WMA

The WMA Statement on Standards and Ethics was originally adopted in 1978 and recently updated (2003). Under the section *Standards of Conduct for Specific Projects* it states that "Evaluations of projects are strongly encouraged. Any limitations to evaluation will be reported to the client. Procedures to be used in evaluations will be specified in advance." Regarding this issue, NAWC has consistently attempted to perform annual evaluations of our operational projects. We indicate the difficulty in performing these evaluations and limitations in interpreting the results to our clients due to the non-randomized nature of these projects.

It has been NAWC's practice to develop a historical target/control evaluation (usually consisting of the development of a linear regression equation) following the first season of seeding activities. The target and control sites are then normally maintained in future seeded seasons unless any of the following happens: 1) stations are discontinued, 2) some of the control sites are subsequently included in the target area of another cloud seeding project, 3) data quality deteriorates. Should one or more of these situations arise, a revised regression equation is developed, retaining as many of the previous target and control sites as possible while maintaining a high correlation coefficient. The WMA statement says nothing about the importance of third parties performing these evaluations (as advocated in SH). Rather, we believe the implication is that the cloud seeding contractor is expected to perform these evaluations. We feel that it is ironic that we have attempted to comply with the WMA Statement on Standards and Ethics, and then have been criticized for doing so with the tacit approval of the Editor and Editorial Board of the Journal. We direct the reader's attention to the statement in SH regarding evaluations of non-randomized operational projects, in the context of statistical estimations. "The more valid alternative is to present ***no*** (our emphasis added) estimations of seeding effectiveness because such estimates without P-values must call into question ***any*** (again, our emphasis) interpretations of results. It is understood that sponsors expect some evaluation of whether seeding was successful. But they should be made to understand that evaluation of operational projects may provide suggestions but never scientific proof." These are strong statements. It appears to us that Super and Heimbach do not follow their own advice in some of their ensuing statements in their 2003 paper.

This type of critical paper and especially the manner in which it was published without any opportunity for comment by those criticized may well discourage others from publishing in the *Journal of Weather Modification.* This is especially true of papers containing any results derived to estimate the effectiveness of operational projects. In a sense, this is a very important precedent-setting situation since, to our knowledge, no previous papers of this (SH 2003) type have been published in the Journal. This negative outcome could be counter-productive to one of the stated purposes of the Association that the WMA, via its meetings and Journal, will serve as a clearing-house and dissemination agent for weather modification oriented literature and information.

4. ADDITIONAL CONCERNS AND OBSERVATIONS

It is our opinion that some of the conclusions stated in the SH paper cannot be accepted as proof. We submit that, just as it has been suggested by SH that *a posteriori* analyses do not provide an acceptable basis for conclusive statements regarding the effectiveness of cloud seeding, SH does not contain or cite any scientifically conclusive evidence "proving" that cloud seeding is ineffective. Thus, we believe that many of the negative points stated by SH as though conclusive are merely **opinion and conjecture**. Some examples of these negative opinions are as follows:

- Page 31, "When frequent and significant melt occurs prior to the sampling date, the historical regression relationship is no longer valid for evaluation of seeding effectiveness. Melt will be a particular problem when it affects the snow water content differently over target and control areas". This statement assumes that melt "problems" only occur during the seeded seasons. Is it not more reasonable to assume that melt also occurred during the 32 year historical not seeded period and that the regression equation(s) will compensate for this "problem"?

- Page 33, "April 1st SWE observations are generally unsuitable for historical regression analyses of winter orographic cloud seeding effectiveness in the climate of southern Idaho". Certainly this statement needs a qualifier. This is the authors' opinion, not a proven fact.

- Page 35, "Clearly the results of Table 4 and associated P-values provide no basis for considering the Boise Basin cloud seeding project to have been effective in snowfall augmentation up to March 1st. These results are totally at odds with the findings of GS who used April 1st observations". How about the "results" of Tables 5 and 6 in the SH paper which do show positive values? We are unconvinced that SH has proven anything by their "data mining" (16,383 re-randomizations!), based upon their own definition of scientific proof. Their initial position was that it was not possible to scientifically evaluate operational projects due to the lack of randomization. Our understanding of the idea behind re-randomization is to take an indicated result (preferably one obtained in an *a priori* fashion) and then test it through re-randomization to determine its significance. Re-randomization is not intended to find the "best" predictor after the fact.

  We believe that a double standard has been allowed here. Any positive claims about the efficacy of operational cloud seeding can be challenged and subjected to some high standard of statistical proof. It appears to us that any negative comments can be made without adhering to the same high standards of proof expected of the positive statements.

- Page 35, "….an apparently impressive but false suggestion of seeding effectiveness". Again, just an opinion, not a proven fact. (See again our comment above about page 31.)

- Page 36, "Including poorly associated control stations which marginally improve the mean control correlation is a suspect approach". Another opinion, not necessarily fact. What evidence was supplied that supports this claimed "poor association"?

- Page 39, "….*provides no reason to conclude that seeding was effective in snowpack augmentation."* Italicized for emphasis by SH, this is probably the most troublesome statement in the entire paper. We are surprised that the Editor and reviewers accepted such a strong statement as if it were a proven fact and not just an opinion. In the same section under recommendations SH states "Choose and publish all measurement stations and statistical approaches to be used before data becomes available from the first seeded winter". This is another example of a double standard. Again quoting from the SH document (page 38) "…post project analysis results should be viewed with considerable skepticism.". Given this statement in SH, that paper <u>*should be viewed with considerable skepticism since its analyses were conducted after the fact.*</u>

Again, somewhat ironically, we did specify the target and control sites following the first season of seeding. The ensuing three seasons did provide positive indications (+10.7%). SH argue for this approach, but then proceed to conduct detailed analyses after the fact (*a posteriori*) while discounting the indications from our paper because of a purported "snow melt problem." First of all, the reason our evaluation utilized April 1st water content information was because it is standard practice in the prediction of streamflow runoff in the western United States to utilize April 1st water content values (the National Weather Service uses this approach). Since the goal of our 2002 paper was to investigate the potential impact of the cloud seeding project upon streamflow (at the request of our client), we utilized April 1st snowpack information. This same approach was utilized by Dr. Norman Stauffer of the Utah Division of Water Resources in performing a similar analysis (Stauffer, 2001) to estimate the potential increases in streamflow from winter cloud seeding projects being conducted in Utah (Stauffer, 2001). If we had been asked, Super and Heimbach may have been interested to know that we had performed a concurrent target and control evaluation based upon NRCS SNOTEL December through March <u>precipitation</u> data. The same control sites were maintained once they were selected after the first season of seeding (1992-93). Many of the target sites were at the same locations as the ones used in the snow water content analysis. The precipitation analysis indicated an average 8.5% increase for the four seeded seasons. Since precipitation measurements would be unaffected by any "snow melt" problems, these data support the positive indications (if not the absolute values) obtained with the snow pack evaluation. A break in seeding operations during water years 1998-2001 (water year 1997 was excluded since seeding was conducted over the Payette River drainage by Idaho Power) provided an opportunity to gain some additional insight Using the target and control stations that were established *a priori* and the identical analysis method used to evaluate the seeded seasons, the evaluation trials indicated an average ratio of actual to predicted April 1st snow water content of near unity (1.02) for the four non-seeded winter seasons that immediately followed the seeded seasons. If there really was a snow melt problem with April 1st data, why did the regression analysis of the non-seeded seasons not indicate such an effect? This argues against the concern that global warming or some other unidentified phenomena impact only the seeded seasons of the early to mid 1990's, but not thereafter. Further, seasonal analyses since the operational seeding project was resumed in the 2001-2002 winter season have shown a return to more positive indications (these analyses are discussed in a later section). This result is contrary to the statement in SH that "The important point is that this evidence of increased melt frequency in the last decade strongly suggests that the historical regression relationships were not constant with time" (page 32). Although we have argued that the snow melt issue does not seem to have produced a significant problem in multi-season analyses of the Boise project, we acknowledge that the potential of snow melt influences is an issue worthy of consideration in the evaluations of winter orographic projects, especially if performed on a single season basis.

Another concern with the SH re-examination is the *carte blanche* elimination of the month of March from any assessment of potential seeding effects, again justified only on the basis of a purported snow melt "problem". NAWC in-house analyses of monthly target/control evaluations of a long-term winter project being conducted in the State of Utah have indicated that, statistically speaking, the month of March has the highest indicated effects of seeding of the four months (December through March) that have been consistently seeded. One hypothesis that might explain such an outcome is the likely increase in embedded convection in springtime storms. The presence of embedded convection could increase the amount of supercooled liquid water that is available, plus assist the vertical transport of ground released seeding materials.

5. CLARIFICATION ON CRITIQUES OF OUR WORK

We certainly welcome unbiased and positive criticism of our work, such as one might expect from peer reviewers of technical papers (incidentally, there were two reviewers of our original paper, one with a large number of comments). We gave serious consideration to these constructive comments, made a number of changes to the draft paper and submitted the final version which we felt had benefited substantially from the reviewer's comments. The negative tone taken by SH can only serve to polarize the parties involved, and to heighten the debate about operations versus research level-of-proof issues.

6. DIFFERENT LEVELS OF ACCEPTANCE

In SH, Super and Heimbach are essentially asking for levels of scientific proof expected of research projects, yet GS reported on a non-randomized operational project. This is obviously a no-win situation, since without any randomization the application of statistical tests is always subject to a question of bias. A considerable number of operational projects have been conducted in the past and continue to be conducted without the requirement of the level of scientific proof sought by SH. Sponsors of operational projects are not naive. They are practical decision makers. As our original paper attempted to demonstrate, the potential benefit-to-cost ratios can be significant from properly designed and conducted seeding projects. Our original paper suggests a possible ratio of 10:1 when using the estimate of a 12% increase (considered a conservative estimate since only one half of the calculated increase in streamflow was used in this calculation to account for periods when turbine capacity could be exceeded). If one assumes that SH is closer to estimating the real effect of seeding with its estimate of an average 4% increase in the December through February period, the benefit-to-cost ratio would still be 3.6:1. We remind the reader that our December-March precipitation analyses indicated an average estimate of an 8.5% increase for the four seeded seasons, which would result in a ratio of 7.6:1. These numbers ***do not account*** for any increased hydroelectric power generation from the Anderson Ranch Dam, nor do they include the value of the additional streamflow to irrigated agriculture downstream of Lucky Peak Dam. In other words, the project could be justified from a benefit-to-cost standpoint based solely upon increases in hydropower production from Lucky Peak Dam, based upon what we consider to be conservative estimates of the increases from cloud seeding and power production. **This was the real intent of GS, our original paper, i.e., to demonstrate the potential economic impacts of an operational project** and why sponsors of projects like this one are willing to support such projects without the 5% or better significance levels demanded of research projects. It comes down to practical risk assessment and decision-making. For example, can the sponsors of a potential project accept the risk that there is perhaps a 20% possibility that there will be no effects from a cloud seeding project to potentially multiply their investment by a factor of 3 to 10? In the real world, decisions such as these are made routinely in the affirmative. We would all like a 95% or even better 99% confidence level that each decision we make in life would be correct. However, we almost never have this luxury. Silverman (1978) concluded "Users of weather modification are shrewd business people. They understand that they are, in many cases, taking a gamble when they use weather modification, but it is no greater risk than they take in other aspects of their business."

The opinions expressed above are not just our own. Dr. Roelof Bruintjes of NCAR in a cloud seeding review published in the AMS Bulletin (Bruintjes, 1999) makes the following observations:

"The fact that many operational projects have been going on and have increased in number in the past 10 years indicates the ever-increasing need for additional water resources in many parts of the world, including the United States. It also suggests that the level of proof needed by users, water managers, engineers, and operators for the application of this technology is generally lower than what is expected in the scientific community. The decision of whether to implement or continue an operational project becomes a matter of risk management and raises the question of what constitutes a successful precipitation enhancement project. This question may be answered differently by scientists, water managers, or economists depending on who answers the question. This difference is illustrated by the fact that although scientific cloud seeding experiments have shown mixed results based on the level of proof required by the scientific community; many operational cloud seeding projects are still ongoing. However, it also emphasizes that the potential technology of precipitation enhancement is closely linked to water resources management. It is thus important that the users of this potential technology are integrated into projects at a very early stage in order to establish the requirements and economic viability of any project (Ryan and King, 1997). In addition, the continued need for additional water and the fact that most projects currently ongoing in the United States and the rest of the world are operational projects emphasizes the need for continued and more intensive scientific studies to further develop the scientific basis for this technology".

The dichotomy we see is the desire of the "scientific community" to convert operational projects into research or quasi-research projects and, perhaps on the other side of the fence, for the operational groups to want to adopt new ideas being tested in research projects into operational projects too quickly. We, as a company, have in the past supported and continue to support additional research in this evolving technology. Our company has participated in the conduct of a number of prior research projects. We do not, however, accept the notion that the operational projects that we conduct for our clients have to fit into the research mode or be expected to individually produce unequivocal "scientific proof" of the effectiveness of cloud seeding.

7. A RE-START OF THE BOISE PROJECT

This Boise cloud seeding project was inactive for a five year period (water years 1997-2001) but was reactivated for the 2001-2002 winter season. It has continued for the 2002-03 and 2003-04 winter seasons. NAWC was awarded the contract to re-start this project through a competitive bid process. NAWC has used the same project design used in the conduct of the original four season (1992-96) project that served as the basis of the GS paper. The operational periods for the first two seasons of the re-activated project were November 15, 2001 - April 15, 2002 and November 1, 2002 – April 6, 2003.

Evaluations of the apparent effectiveness of the seeding were provided in our reports to the client for those two winter seasons. The same set of target and control sites used in the earlier snowpack evaluations discussed in GS (except Camas Creek Divide, a target site, which was dropped because the manual snow course observations were discontinued in 2000) were again used to determine if there appeared to be any effects from the seeding. The ratio of the observed to estimated natural April 1st snow water content for the 2001-2002 season was 0.91. This would indicate 9% less snow water content than expected from the regression equation prediction. The target and control sites used in a 1996 analysis of the December – March precipitation (with one station added to the target sites to achieve better representation of the mid-elevations of the target area and one dropped from the control sites due to poor data quality) were used to determine if any effects of cloud seeding were indicated. The resulting observed-to-predicted ratio was 1.07, suggesting a 7% increase in precipitation. This was an unusual winter season with a disproportionately large amount of precipitation occurring in the middle (approximately 3500 – 6500') elevations in central Idaho compared to the higher elevations (>6500'). In fact, we had concerns expressed by several of our seeding generator operators in the mid-elevation zone about the depth of the snowpack they were having to deal with and even questioning whether the cloud seeding should continue. It was theorized that the difference in average elevations between the snowpack control sites (6377') and target sites (7387') may have resulted in an overestimation of snow water contents in the target area for the 2001-2002 winter season. Nonetheless, the results from these two analyses (snow water content and December-March precipitation) were reported to our client.

The evaluation of the 2002-2003 seeding project provided some additional challenges. The Idaho Power company re-started a cloud seeding project on the Payette River drainage during this winter season. The Payette River drainage is the river basin immediately north of the Boise River drainage. Idaho Power had previously conducted a project in this area during the 1996-97 winter season. Unfortunately, four of the seven control sites used in the earlier snow water content evaluations for the Boise River project were located in the Payette River drainage. When the original regression equation was used (with one of the sites dropped from the target group since snow course measurements at this site were discontinued in 2000) the resulting actual over predicted ratio for the 2002-2003 winter season was 1.01, that is no indication of any effects of cloud seeding. This outcome would be expected if the Idaho Power project was successful in increasing snow water content in the Payette River drainage (i.e., more snow water produced through seeding at the four control sites in the drainage would artificially inflate the estimate of the natural amount of snow water in the Boise River drainage). We concluded that the project for the Payette drainage had been successful, so that some of our control sites had been contaminated and therefore we needed to establish a new set of control sites to be used in the 2002-2003 evaluation.

A set of nine sites was judged to be the best alternative set for a new control group, based upon 1) their correlation with the target area, 2) geographic bracketing of the target area, and 3) similarity to the target area in terms of elevation and meteorology. These nine sites were selected and a new linear regression equation developed **before** the equation was used to estimate the amount of April 1st snow water content in the target area. That is, the selections were made mathematically to achieve the best correlations prior to any estimation of the resultant evaluation indications. Adhering to this sequence removes any deliberate bias on our part (for example, this procedure precludes our deliberately selecting a set of control sites that yielded a positive result or tuning the group for a best result).

When the April 1 snow water content at the alternate grouping of sites was averaged for each historical year and compared to the average for the target area snow water content, the two groups were found to be strongly correlated with one another, a correlation coefficient (r) of .966 (compared to 0.978 for the original control group). This means that approximately 93% of the variance is accounted for in the regression equation developed from the historical (non-seeded) period. Somewhat lower correlation for the alternate control group than for the original group is not surprising, since the original group includes many sites in closer proximity to the target area. However, the correlation between the alternate control group and the target group is still very great. The average elevation of the alternate control sites is 6,898 feet MSL, somewhat higher than the 6,377 foot average for the original control group and closer to the target site average (7,387 feet) than the original. The lowest alternate control site is located at 6,240 feet, compared with 5,380 feet in the original control group.

When the new regression equation established through this procedure was used to calculate the natural snow water content for the 2002-2003 winter season, the observed-to-predicted ratio was 1.10 which would suggest a 10% increase in April 1st snow water content. If the indicated effects from the five seeded seasons (1993-1996 and 2001-2002) using the original control sites are combined with the indicated 10% increase for the 2002-2003 season using the alternate control sites, the average difference is +7.5%, with an average estimated increase in April 1st snow water content of 1.68 inches per season.

As was the case in the snow water content analysis, the observed-to-predicted ratio for the December-March precipitation was 0.87 for the 2002-2003 winter season. This again indicated a seeding effect on three of the control sites due to the Idaho Power seeding project in the Payette basin. A similar process was used to establish a new grouping of control sites for a December-March precipitation evaluation. A grouping of eight sites was judged to be the best alternative set for a new control group, based upon 1) their correlation with the target area, 2) geographic bracketing of the target area, and 3) similarity to the target area in terms of elevation and meteorology. These eight sites were selected and a new linear regression equation developed **before** the equation was used to estimate the average amount of December-March precipitation in the target area. Again, site selection prior to this analysis, as indicated in the snow water content analysis, removes any question of deliberate bias on our part. The historical years of 1982-1992, and 1998-2001, were used in the development of the linear regression equation. This period was selected in order to include only those years that data were available from SNOTEL observations (i.e. no estimated data), and excluded the water year of 1997, which was a seeded year in the Payette drainage. The resulting linear regression equation had a correlation coefficient of 0.94 (an r^2 value of .88). This equation was used to predict the amount of December-March precipitation in the target area for the 2002-2003 winter season and then compared to the observed precipitation. The resulting observed-to-predicted ratio was 1.13, which suggests a 13% increase in precipitation. When this information was combined with the prior five seasons of seeding using the original control sites, the average indicated increase was 6% with an average seasonal increase of 1.18".

We felt it was important to document that there were continued indicated increases in both snow water content and precipitation after the project was re-started. The average indicated increases are 7.5% April 1st snow water content and 6% for December-March precipitation. The 7.5% indicated increase in snow water content was used to estimate the average annual benefit from this project in terms of hydropower production only, as was done in the original GS paper. Working under the same assumptions and using the average runoff of the first four seeded years as representative of the six seeded seasons (official USGS data are not yet available for 2002 and 2003), the average annual value would be $584,598. Dividing this amount by the estimated cost of conducting this winter's project ($90,000) would result in an estimated benefit/cost ratio of 6.5:1. This analysis is considered conservative in nature since 1) only one-half of the estimated increases in annual streamflow were used, 2) it does not include any estimate of the value of additional electricity produced from the Bureau of Reclamation Anderson Ranch Dam facilities, and 3) the value of the additional irrigation water downstream of Lucky Peak Dam is not considered in this analysis.

8. SUMMARY

In summary we offer the following points for consideration:

- Ongoing evaluations of the Boise River project continue to indicate positive effects from cloud seeding that average from 6.0-7.5% for six seeded winter seasons.

- During a four winter non-seeded period between an earlier seeding project period of 1993 and 1996 and the restart of the seeding project during the 2001-2002 winter season, the regression equation developed after the first season of seeding (1992-1993) was used to estimate the target area snow water content. The average observed/predicted snow water content April 1st ratio was 1.02. This suggests no effect of seeding as would be expected, and also provides no indication of a "snowmelt" problem claimed in SH to have influenced the four seeded seasons.

- Any evaluations or reviews of non-randomized projects by "independent" parties need to provide the evaluation procedures, equations to be used, etc. **prior** to the beginning of the evaluations (preferably before any seeding is conducted). Otherwise, the intentional or unintentional biases of the "independent" reviewers are either likely to influence the conclusions reached through this "independent" evaluation or there may well be a suspicion of such biases coming into play. Repeated re-analyses using different procedures, control gauges, or time periods are subject to the same criticisms as would be multiple evaluations conducted *a posteriori* by a contractor. Thus, the "conclusive" statements in SH should be considered as opinions, not as unequivocal facts. The 2003 WMA Statement on Standards and Ethics states the following: "Evaluations of projects are strongly encouraged. Any limitations to evaluation should be reported. Procedures to be used in evaluations should be specified in advance."

- The evaluation of operational projects presents challenges first of all because they are not randomized. Less statistically rigorous evaluation techniques (e.g. target vs. control) are therefore necessary if we wish to attempt to evaluate operational projects at all. There always seems to be a segment of the weather modification community that says "your evaluation techniques are not good enough". Our question to this segment is as follows: What is your solution and is your solution an affordable and established technique? We seldom, if ever receive any alternative suggestions to the target vs. control evaluation approach other than randomization. Some of the other challenges of evaluating operational projects relate to the availability of both current and historical data that can be used in the evaluations. Ideally, we would like to find snowpack control sites at the same elevations as the target sites that are well correlated with the target sites. Oftentimes the unavailability of historical data precludes this desirable mix of control and target sites. Ideally, we would like to establish one set of target and control sites that would be used throughout the duration of the seeding project. However, in the real world, stations are retired, data quality declines, or a cloud seeding project may be initiated in an area that contains some of the "control" sites. Should we give up the evaluation attempts at that point, or do we develop new regression equations to address the new reality? We think the latter course of action is the obvious choice. Is it time for the WMA to attempt to develop a list of cost effective and acceptable techniques that may be used to evaluate operational seeding projects? Perhaps so.

- It is our opinion that the Editor and Editorial Board of the WMA need to develop standard procedures to be used in accepting or rejecting highly critical articles submitted for publication in the *Journal of Weather Modification.* For example, comment and reply procedures, and the grounds on which papers submitted to either the reviewed or non-reviewed sections can be rejected, should be established. How are papers that are critical of others' work to be handled in light of the phrase in the recently adopted WMA Statement on Standards and Ethics that says "The operator or manager will not unjustly criticize fellow workers in the profession?"

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IN MEMORIAM
DR. JOHN ALBERT FLUECK
1933- 2003

Roger .F. Reinking
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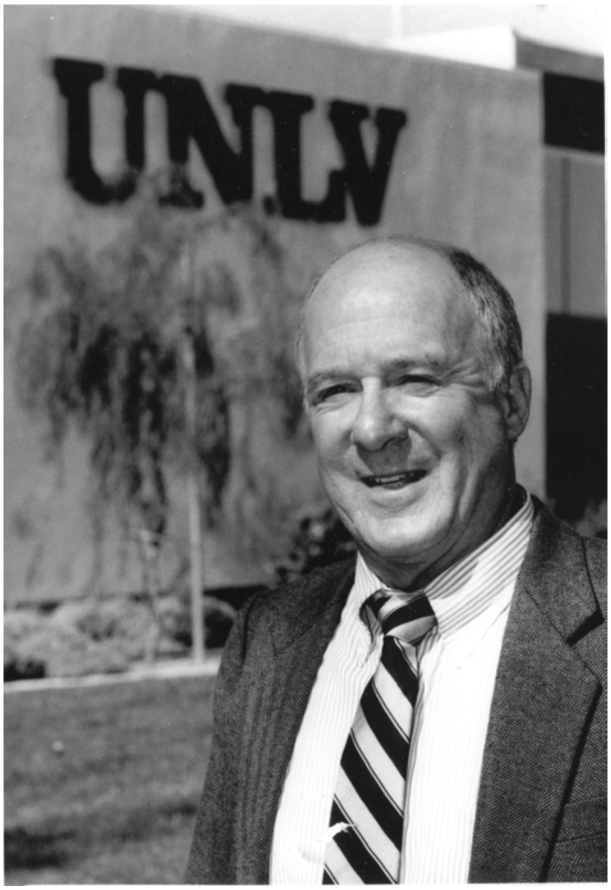

A Las Vegas colleague attended a lecture on quality in business. The lecture was unimpressive, but he wondered, "*Who is this fellow up front who thinks he is the keeper of the intellectual property of the world*?" An introduction led to a very productive relationship, and a deep appreciation for John Flueck. John, 70, died September 25, 2003 in Las Vegas. He was born in Cincinatti on April 13, 1933, and retired as a Visiting Professor, Department of Management, University of Nevada Las Vegas (1992-1998) where he previously served as Director of the Environment Statistics and Modeling Division, Harry Reid Environmental Research Center. He moved to Las Vegas from Boulder, Colorado, where he worked as a Senior Research Fellow at the National Atmospheric and Oceanic Administration and the National Center for Atmospheric Research.

In the late 1970's, Merlin Williams of NOAA's Weather Modification Program Office hired John Flueck to critique the Florida Area Cumulus Experiment, directed by a WMA past-President, Bill Woodley. Sparks flew as John took on his standard role as an abrasive "Grand Inquisitor". However, John knew his statistics and how to run a randomized cloud seeding project, and Bill and John eventually developed the mutual respect of a very beneficial friendship. Bill notes that he "even found John's irreverent behavior refreshing—as long as someone else was on the receiving end; he made life and science enjoyable and interesting with his keen, sarcastic wit and sharp mind." John may be forgiven for his lack of social graces, which he more than made up for with his parched but provocative humor that could invoke intense laughter and insight in the direst of situations.

In weather modification in the 1980's, John emphasized the steps in the physical chain of events in designing experiments as a means to remove just one or two levels of uncertainty, to move emerging experimental results beyond gridlock. He promoted high standards as he participated in evaluations and workshops on the Greek hail-suppression and Thailand rain-making experiments, among many others. The depth and breadth of John Flueck's knowledge and energy is evident from his accomplishments. He received his MBA and PhD from the Graduate School of Business, University of Chicago. He co-established the Dept. of Statistics, Temple University and the Statistics in Sports section of the American Statistical Association. The reason for the latter is clear: He was an intense competitor in skiing, tennis, sailing, soccer, football and track. He served as a consultant to the NCAA, EPA, NSF, DOE, and the FAO and WMO of the United Nations, and published some 100 papers in statistics, atmospheric science, climate, environmental sciences, data graphics, and business quality and productivity improvement. He served in the Office of Statistical Policy, OMB, Executive Office of the President and on the Malcolm Baldridge National Quality [in business] Award Board, and helped to found the Nevada Governor's Awards for Performance Excellence. John was a Fellow of the American Statistical Association and the American Association for the Advancement of Science. Even so, he was always modest.

John's second wife, Judit, herself an astute and strong personality, accuses me, affectionately, of instigating their marriage. Her escape from a communist block country prepared her well for managing John. Three sons, Alex, David, and Michael, and stepson Mark, all speaking at the memorial service, recalled how John carried his constant probing to the dinner table, offering them daily challenges as they were raised by the disciplinarian who described himself as the "Prussian Colonel." In the end, their mutual great fondness and highest regard for this unusual father and husband is very evident. Colleague Bill Hooke of NOAA, now at the AMS, notes appropriately that "life was always a little better after you talked with John". This brilliant man ironically and tragically succumbed to a dementia related to Alzheimer's and Parkinson's disease. With my own deep appreciation for John, I sorely miss the Grand Inquisitor and Drought-dry Humorist, a professional and personal dear friend.

Roger F. Reinking

THE SOUTHERN OGALLALA AQUIFER RAINFALL (SOAR) PROGRAM – A NEW PRECIPITATION ENHANCEMENT PROGRAM IN WEST TEXAS AND SOUTHEASTERN NEW MEXICO

Duncan Axisa
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Abstract. The Sandy Land Underground Water Conservation District, South Plains Underground Water Conservation District, and the Llano Estacado Underground Water Conservation District have participated with the High Plains Underground Water Conservation District #1 for a number of years in their precipitation enhancement program. Convinced from past assessments that precipitation enhancement is a potential water management tool, the three boards decided that a program beginning in 2002, apart from the High Plains would be beneficial. The Texas Department of Licensing and Regulation (TDLR) issued a permit on January 31, 2002 authorizing a weather modification program to conduct rainfall enhancement in Yoakum, Terry and Gaines County. Additionally, with the cooperation of the State of New Mexico, an area west of Gaines and Yoakum Counties is included in the target area. This precipitation enhancement program was named Southern Ogallala Aquifer Rainfall (SOAR) program. This document presents a brief summary of the SOAR 2003 annual report detailing an effort to systematically characterize the clouds, precipitation and the seeding effectiveness of the SOAR program. Independent evaluations show average rainfall increases of 68% and 52% in favor of a seeded cloud when compared to a matching control cloud. This results in an average estimated benefit/cost ratio of 235/1.

1. INTRODUCTION

A scientific evaluation of cloud seeding for rainfall enhancement requires several efforts designed to systematically characterize clouds and precipitation in order to determine their potential response to seeding. The two fundamental questions that SOAR has searched to answer during its first year of operation in 2002 were 1) whether the frequency of clouds in the area and the associated weather patterns warrant the need for a cloud seeding program, and 2) are the clouds that occur receptive to glaciogenic and/or hygroscopic seeding?

The SOAR program has defined specific long term objectives that would systematically characterize the clouds, precipitation and the seeding effectiveness of a rainfall enhancement program, including:

1. A climatology of thunderstorm tracks and cloud characteristics as recorded by weather radar over several years to determine the suitability of clouds and their frequency of occurrence.

2. A continued assessment of seeded versus non-seeded clouds by independent qualified evaluators using scientifically accepted methodologies and statistical methods.

3. Launching carefully designed field programs, using an instrumented cloud physics aircraft and weather radar during periods when a high frequency of convective clouds is observed or anticipated. The objective of the field studies should be to document: a) background concentrations, sizes and chemical composition of aerosols that participate in rainfall processes, b) size resolved nucleation processes at variable super saturations of hygroscopic aerosol particles and their effect on the cloud droplet spectra, and c) the degree of ice nucleation achieved by glaciogenic cloud base and cloud top seeding.

4. Assessment and improvements in the data collection of rainfall, with an emphasis on the integration of conventional methods (surface rain-gauges) with more frequently used methods that demonstrate better spatial coverage and temporal resolution (radar).

This report presents a summary of the efforts employed by SOAR to characterize the clouds, precipitation and the seeding effectiveness of the SOAR program and details the recommendations made that would improve on current achievements.

2. A CLIMATOLOGY OF THE SOAR TARGET AREA

The climate of the Llano Estacado Region is classified as a dry, steppe type. The region is characterized as semi-arid, with a wide range in temperatures. In an average year, about 80 percent of the annual rainfall occurs during the warm season (May through October). Monthly rainfall quantities ordinarily decline markedly in the colder months of the year, when frequent periods of cold, dry air from North American Polar Regions surge southward and cut off the supply of moisture from the Gulf of Mexico and the Mexican Monsoon. The long-term average (1945 through 1997) precipitation received in the region is 18.4 inches. The average ranges from a high of 22 inches per year in a small area in Crosby County, to a low of about 16 inches in Cochran County. Most of this precipitation is mainly convective during the warm season and thus it is more localized and its spatial and temporal distribution as well as the intensity of rainfall is highly variable.

It is widely accepted that the primary source of low-level moisture for the United States east of the continental divide is the Gulf of Mexico. However, Texas also receives moisture from the Eastern Pacific Ocean moisture carried into Texas from the southwest by tropical continental airmasses. It is necessary to examine the synoptic conditions that initiate convection in the target area and to analyze the sources of moisture that fuels thunderstorms.

Early in the growing season, convective initiation is caused by eastward moving cyclones. The topography of the region channels warm moist air from the Gulf of Mexico northward and cold dry arctic air from Canada southward. These two very different air masses, together with westerly downslope flow off the Rockies, have important influences on the convective mechanisms in the target area. The confluence of warm dry air off the southern Rockies and warm moist air from the Gulf of Mexico produces a strong west-east gradient in moisture called the dryline. The motion of the spring and summertime southern High Plains dryline in the absence of any large-scale weather systems usually exhibits a diurnal trend. In general, this trend is described as an easterly advance of the dryline during the daytime and a westerly retreat at night. It is known that convective development often is collocated with the dryline and such development may lead to thunderstorm initiation dependent upon various airmass properties in the vicinity of the dryline. Another important feature during this period is the cold front and how it combines with the dryline to act as a focus for convective development.

The middle of the growing season is characterized by a period of transition from the cold season circulation regime to the warm season regime. This is accompanied by a decrease in mid-latitude synoptic-scale transient activity over the continental United States as the extratropical storm track weakens and migrates poleward to a position near the Canadian border. The upper air becomes rather stagnant with a persistent pattern of a high-pressure ridge over the desert southwest. A prolonged east to west flow in the lower levels of the atmosphere increases the moisture from the eastern plains to the Continental Divide. Most of the convection remains confined to the mountainous areas of southwest Texas and southeastern New Mexico due to upslope low-level winds and upslope flow. Other areas rely on diurnal heating and humid conditions with some upper air feature support from disturbances rotating in the periphery of the high pressure for convection. When an upper level low pressure develops in the northern Pacific, the ridge breaks down and a trough pushes an occasional cool front, bringing some temporary relief from the heat in the Mid West and the Great Plains. However, these fronts usually stall to the north of the region due to a strong southerly flow.

The latter part of the growing season is characterized by the onset of the Mexican Monsoon in southern and southeastern New Mexico. The main synoptic feature is a persistent broad high-pressure ridge at the upper levels meandering over the southern plains and the desert southwest. This feature increases the convective inhibition due to synoptic scale subsidence over the region. The convective energy is weak and convection is hard to forecast due to the lack of a surface feature. The sea level pressure of the southwestern United States increases significantly and leads to the development of a thermally induced trough in the desert southwest. Surges of tropical continental air with convection along this trough are very common. Tropical maritime influences from the Gulf of Mexico may also be observed even though most of this moisture remains to the southeast. During this period the ridge over the western United States weakens as the monsoon high retreats southward and Mexican Monsoon precipitation diminishes.

3. CLOUD SEEDING IN THE SOAR TARGET

The objective of the SOAR program is to increase rainfall when rain-bearing clouds are known to have poor rainfall efficiency. The SOAR project currently uses glaciogenic seeding to improve the efficiency of the cold rain process. The target of such seeding operations is the supercooled water, which is found in the cold part of the cloud above the freezing level.

3.1 The methodology of glaciogenic seeding

The agent used is silver iodide, which is released in clouds to empower the formation of ice aggregates. The maximum efficiency for aggregation occurs around -5ºC. Seedable clouds must have top heights around this temperature but warmer than -15ºC.

Typically, clouds are seeded at -5ºC level and the silver iodide is released in the early stages of development and within the first half-lifetime. Dosages should reach the dynamic mode of seeding, around 100 ice-nuclei per liter of supercooled volume. Radar volume scans are used to measure the exact dosage required to reach the dynamic mode. Clouds that are seeded are very carefully chosen in that the in-cloud coalescence of the clouds is closely monitored using the Index of Coalescence Activity.
There are two methods of glaciogenic cloud seeding utilized by the SOAR program, 1) cloud base seeding and 2) cloud top seeding.

3.1.1 Glaciogenic seeding at cloud base

Glaciogenic seeding at base is accomplished by injection of 40 gram Silver Iodide pyrotechnic flares into cloud updrafts in excess of 200 feet per minute near the bases of clouds along predetermined tracks 10 to 30 miles upwind of the target area.

3.1.2 Glaciogenic seeding at cloud top

Glaciogenic seeding at cloud top is accomplished by an aircraft flying just above the freezing level that drops up to two ejectable Silver Iodide pyrotechnic flares, each flare releasing 20 grams of Silver Iodide smoke, into the top of the growing cumulus cloud 10 to 30 miles upwind of the target area.

3.2 Pyrotechnics used

The pyrotechnics used for seeding at cloud base and on top are manufactured by Concho Cartridge. Reports from cloud chambers show that the flares are producing about 10^^13 ice-nuclei per liter at 5 ºC, and about 2 x 10^^13 at -5 ºC.

3.3 Quantifying a seedable cloud

Clouds are considered to be seedable for increasing precipitation according to the static-mode seeding concept if 1) the collision-coalescence process is inefficient, 2) the rate of formation of supercooled condensate exceeds or is comparable to the rate of depletion of supercooled water, and 3) if there is sufficient time to grow seeding-induced precipitation particles that can reach the ground (Silverman, 2001). These seedable criteria specified by the static-mode definition are difficult to apply practically because of the lack of quantification.

3.3.1 Extensive use of TITAN to quantify a seedable cloud

The TITAN software processes volume scan data from the SOAR 5cm radar recording a full volume scan in 3 minutes. The data allows analysis of different variables such as storm identification, location, area, volume, mass of precipitation, Vertically Integrated Liquid (VIL) as well as rates of variation of these parameters.

TITAN provides a tool for an appropriately trained meteorologist to quantify a seedable cloud appropriately. The meteorologist usually undergoes a series of decisions that may be best characterized as: Nowcasting, decision time, qualification, treatment, maintenance and termination.

1. Nowcasting is when the meteorologist is monitoring the atmospheric conditions desirable for deep convection and seedable clouds to form. This decision is taken after studying the meteorological model output that forecast the prevailing thermodynamic conditions. This process is usually a routine analysis of upper air conditions and surface conditions. Nowcasting of the possibility of thunderstorms follows and weather modification pilots are briefed accordingly.

2. Decision time is when the meteorologist decides to launch a seeding operation based on his/her observations of the current and forecast atmospheric conditions. This decision is usually taken after observing cloud echoes on TITAN and the echo development trend. Sometimes an operation is launched after watching clouds grow visually or by observing the surface temperature reach a threshold when convection is expected to initiate or intensify. For an operation with good timing, decision time should be preceded by qualification.

3. Qualification is when a cloud becomes seedable. This decision can be made visually by the pilot observing a cloud before it is detected by radar. Most frequently, a cloud is observed on radar before seeding occurs. In the SOAR target area, a seedable cloud echo usually reaches a VIL of 10 kg/m^2 and continues rising. The volume of the cloud echo should be in the order of 200km^3 with cloud tops above 8 km. The development trend of other clouds outside the target area is usually observed to

determine the growth characteristics and the lifetime of the clouds. A short lifetime does not allow much opportunity for seeding. On TITAN, a seedable cloud usually shows a pocket of about 15% of the echo volume with a higher reflectivity at or slightly above 40 dBZ reflectivity at an altitude ranging from 6 to 10 km. This is characteristic of a cloud with weak coalescence and with a loading of supercooled liquid water above the freezing level early in its lifetime.

4. Treatment is the time after initial seeding. Occasionally, treatment may be preceded by qualification in isolated cases. In most cases, however, a cloud qualifies as seedable and the meteorologist instructs the pilot to start seeding. The seeding starts when the pilot encounters, locates or is directed to the updraft portion of the cloud where the agent is released. The updraft usually has to exceed 200 feet per minute.

5. Maintenance is when a constant rate of seeding is established with continued observations of growth in the echoing volume. During this period the cloud echo has not reached it's half-life time. Careful analysis of the dynamic variables of the cloud echo and their trend is necessary to define the half-life of the cloud. The pilot usually continues to experience updrafts and the meteorologist is able to locate areas of new growth within the cloud structure.

6. Termination is when seeding is stopped. A seeding operation is usually terminated either due to the absence of updrafts and/or due to the cloud echo exceeding its half-life time. When the National Weather Service issues a warning on the seeded cloud, the seeding is terminated.

3.3.2 Quantifying the collision-coalescence process

The Index of Coalescence Activity (ICA) has been developed as a predictor of in-cloud collision-coalescence activity using an atmospheric upper-air sounding. The ICA is best described as the summation of the collision and collection efficiency, which results in the coalescence efficiency. Since the inception of the SOAR program in 2002, the ICA has been used extensively as a measure of quantifying the seedability of a cloud.

3.3.2.1 The Index of Coalescence Activity (ICA)

Strautins et al. (1999) document the physics involved in the derivation of the Index of Coalescence Activity (ICA) and its relation to coalescence. The ICA is given by the equation:

$$ICA = 8.6 - T_{CCL} + 1.72(PB)$$

The temperature at the convective condensation level (T_{CCL}) is an approximation of the cloud base temperature and PB is defined as the temperature difference at 500 mb (18000 ft MSL) between the pseudoadiabat that runs through cloud base and the environmental temperature. This data is retrieved from an atmospheric upper-air sounding.

With this solution, negative ICA values are indicative of conditions when supercooled drizzle and raindrops are found in the clouds. If the ICA is strongly negative, the raindrop concentrations will be less because many of the drops will already have fallen from the clouds before reaching -10ºC. When the ICA is positive, little, if any, supercooled drizzle and raindrops are expected in the clouds (Strautins et al., 1999).

3.3.2.2 ICA for the SOAR target area

The number of positive vs. negative ICA ratio values (3:1) for the SOAR target area shows that there are good opportunities to investigate further the introduction of hygroscopic seeding in phase with glaciogenic seeding. This can also be justified after analyzing the differences in the moisture sources during the growing season as described in the SOAR climatology. Hygroscopic seeding is needed when ICA values are high and positive. This would make it possible to increase the level of success further if it were possible to use hygroscopic seeding to promote coalescence in continental clouds that have weak coalescence, increasing the efficiency of rain bearing clouds and eventually rainfall.

4. CONCLUSIONS

A careful examination of the meteorological conditions that are conducive to convective development has shown that seedable clouds navigate through the SOAR target area with a sufficient frequency to warrant a cloud seeding program. Independent evaluations by Woodley Weather Consultants (WWC) (Woodley, 2003) and Active Influence and Scientific Management (AISM) (Ruiz, 2003) have demonstrated that such clouds are receptive to glaciogenic seeding and respond positively producing additional rainfall. Advances in remote sensing technology has established radar as the tool of choice for evaluation of cloud seeding programs versus the use of more conventional methods such as rain gauges. The findings outlined in the 2003 SOAR Annual Report including the information provided by the independent evaluators has led to the following conclusions:

1. Precipitation meets about 60 percent of urban landscape water and irrigated crop demands. It provides all the water for surface reservoirs and all the water for rangeland and dryland crop production. By 2050 the region would be able to supply only 93 percent of the projected water demands unless supply development or other water management strategies are implemented (TWDB, 2002). The Llano Estacado Regional Water Planning Group identified precipitation enhancement as one of the seventeen potential strategies to conserve water. Rainfall enhancement could potentially relieve the deficit in the projected water demand.

2. Meteorological conditions, thunderstorm track climatology, Index of Coalescence climatology and the high occurrence of severe weather in the SOAR geographical region all indicate that the frequency of clouds in the area and the associated weather patterns warrant the need for a cloud seeding program. The prevailing drought conditions limits the frequency of clouds, but the number of observed cloud systems that develop in the SOAR region are big producers of rain and have responded positively to glaciogenic cloud seeding. The Woodley and Rosenfeld method of evaluation shows that projects located in the western half of Texas are much more positive than those results from projects located in the eastern half, suggesting that the seeding conditions are more favorable in the west than in the east. If true, it may be due to the more intense coalescence activity in the east that results in early cloud glaciation, leaving a smaller window of opportunity for seeding intervention (Woodley, 2003).

3. Clouds that do occur are receptive to glaciogenic seeding. Independent evaluations conducted by Active Influence and Scientific Management (AISM) (Ruiz, 2003) and Woodley Weather Consultants (WWC) (Woodley, 2003) show average rainfall increases of 68% and 52% in favor of a seeded cloud when compared to a matching control cloud respectively.

4. The scientific community seems to have reached a consensus that for continental convective storms that predominate the Texas high plains, radar should be the primary tool in detecting seeding signatures. Rain gauges should be used to quantitatively calibrate the radar data. Rain gauges used for such an application should have the capability of recording rainfall in real time. Obviously, this makes the SOAR rain gauge network immediately redundant due to its inability to record rainfall in real time.

5. Both the Active Influence and Scientific Management method and the Woodley and Rosenfeld method of evaluation of past SOAR cloud seeding events show significant increases in rainfall.

Active Influence and Scientific Management (AISM) conclude that seeding operations in 2003 appeared to improve the dynamics of seeded clouds. Seeding operations by cloud bases showed appreciable better performance and results than those made by the tops (Ruiz, 2003). Although this may indicate that seeding at cloud base may be a more effective methodology, SOAR has expressed its concerns to AISM in using the TITAN method to put forward such a suggestion. Seeding on top was conducted on 8 cases. On 4 of those cases, seeding on top took place before the cloud echo appeared on radar, which means that microphysical changes in the clouds and the reflectivity of the echo had already started to occur before TITAN had recorded or archived any data on the cloud system. This may produce significant errors in finding a match as a control, which makes it apparent that seeding on top was less effective. In addition, a sample size of 8 cases is too small to make any conclusions, especially when 4 of those cases where seeded before TITAN archived any data. Nonetheless, AISM concludes that SOAR has increased the rainfall by 86% in clouds that produce a precipitation mass less than 10000 kilotons, 76% in clouds that produce a precipitation mass more than 10000 kilotons and 42% in clouds that are seeded after a lifetime of 1 hour. This makes the average total increase in rainfall at 68% producing a total of 248491 acre-feet of water over the SOAR target area (Ruiz, 2003).

The Woodley and Rosenfeld method uses radar-defined floating targets to show increases in areas, duration, and rain volume of seeded clouds. The Woodley and Rosenfeld method provides clear proof of microphysical changes to simple cloud systems, with indications based on statistical results that precipitation has been increased in most cases. This analysis shows that the SOAR program has increased the average rainfall in seeded units by 52% in 2002. Each seeded unit shows an average increase of 5000 kilotons or about 0.1 inches over its unseeded counterpart. The apparent change in total unit rainfall due to seeding (the total change in unit rainfall is the product of the average rain increment per unit and the number of analysis units) was around 306739 acre-feet (Woodley, 2003). These results not only indicate an increase in rainfall due to seeding, but these results have achieved appreciable P-value support showing that the rainfall increases are very significant and that the probability that the results achieved where due to chance is very small (5% or less).

6. Using WWC's value for the total average increase in rainfall for the 2002 season and adding this to the AISM value for the total average increase in rainfall for the 2003 season would give the total average rainfall increase in 2002 and 2003 amounting to 555230 ac ft over an area of 5916000 acres. The cost per acre-foot of water produced by cloud seeding can be inferred by considering the cost of the SOAR program in 2002 and 2003. So far, the cost for cloud seeding in the participating counties of the SOAR program, based on average total values of rainfall increases of seeded clouds versus there matching non-seeded clouds can be assumed at an average value of 51 cents per acre foot of water produced by cloud seeding. One can go further and assume that a local farmer spends about $120 per acre-foot in pumping costs from underground water wells. This gives an average estimated benefit/cost ratio of 235/1. This means that for every dollar spent by participating counties of the SOAR program, the area benefits $235.

5. RECOMMENDATIONS

In view of the conclusions drawn above, the following recommendations are being made:

1. The results of the evaluations presented by AISM and WWC are a clear indication that the SOAR program is running a successful rainfall enhancement operation. The Woodley and Rosenfeld methodology includes statistical rerandomizations and corrections made for selection bias with the inclusion of very stringent selection criteria for suitable control clouds. However, scientists require that cloud seeding experiments be randomized, the physical hypothesis postulated be proved with sufficient P-value support and that the results be replicated. The results presented by WWC should not be viewed as substitutes for randomization and subsequent replication. It is therefore recommended that SOAR work closely with a scientific team to create an experimental randomized cloud seeding program within the SOAR target area. A large number of experimental units is required to detect a relatively small seeding effect that needs to be distinguished from chance variations and the natural variability in cloud systems. This may mean long and expensive experiments and may take several years.

2. Such a study should investigate the total seeding effect on all seeded storms' rainfall and how it compares quantitatively to an area seeding effect. So far evaluations have been relatively successful in showing a positive seeding effect of a seeded cloud when compared to an appropriately matched control, but no scientific study has been attempted to show how this seeding effect alters the area rainfall. The Woodley and Rosenfeld method has been the closest methodology in approaching such an endeavor in that all cloud systems are analyzed on a scale of roughly 2,000 km^2. The scientific community recommends that such an analysis be conducted using the latest radar technology available, with rain gauges used for ground validation.

3. It has been shown that TITAN is an indispensable tool in conducting cloud seeding operations. However, the SOAR project 5 cm radar was manufactured in 1978 and over the past few decades there have been considerable advances in the development of remote sensing technology and ground-based radar. It is recommended that SOAR upgrade its radar to match the current technology that would help the program to meet the challenges of weather modification. NEXRAD data will be available in the Spring 2004. The Midland and Lubbock NWS NEXRAD sites will cover the SOAR target area. The data will include a better-quality radar estimated rainfall product making radar estimated rainfall a much better tool in evaluating cloud seeding effectiveness.

4. The Woodley and Rosenfeld method has shown that the seeding effect is very strong after 75 to 450 minutes after the time of initial seeding. There is no question that seeding treatment early in the life cycle appears to show the greatest seeding effect. It is recommended that cloud seeding commence 15 to 30 miles upwind of the SOAR target area.

5. It has been shown that the climatology of the SOAR target area is suitable for cloud seeding. It is recommended that the SOAR meteorologist continue to define and quantify the seedable conditions within the SOAR target area and observe and document the mesoscale meteorological conditions and the microphysical changes in clouds that frequent the region.

6. So far, it has been demonstrated that the SOAR program has operated a rainfall enhancement program with a high level of success. It is being recommended that independent evaluations of cloud seeding operations continue to be funded. However, the results and hypothesis put forward by the

evaluators has failed to document the complex physical process of rainfall enhancement. Therefore, it is also recommended that SOAR investigate the possibility of working with a group of scientists capable of providing in-situ cloud physics aircraft measurements to supplement radar estimated rainfall and rain gauge data. Specifically, the data required is to:

Confirm that clouds seeded with silver iodide contain more ice than their unseeded counterparts.

Confirm that supercooled liquid water depletes faster in seeded clouds than in unseeded clouds.

Investigate the degree of liquid water depletion due to entrainment and whether on top seeding versus base seeding is a better method of exploiting the concentration of supercooled water to initiate precipitation.

Investigate the range of the size droplet spectra of convective clouds. A narrow spectrum may indicate the inefficiency of the collision-coalescence mechanism at the droplet sizes observed (ICA).

Investigate the effect of airborne pollutants below cloud base; their concentrations, sizes, chemical composition and how these alter the hygroscopic and glaciogenic seeding effect.

7. Analysis of the ICA climatology of the convective environment around the SOAR area shows signs of weak coalescence in the warm part of the cloud that leads to a very inefficient rain process. Supercooled water is retained in the cloud for long periods of time and rainfall in the cold part exhibits a delay in its initiation. When a strong forcing mechanism is present, especially in the spring, this supercooled water is pushed into the colder levels of the cloud where it freezes homogenously and usually is followed by the formation of hail. If these clouds are seeded and the supercooled water is nucleated before it moves upward in the cloud, the rain is enhanced and the hail is reduced. It has also been shown that recent experiments have renewed interest in the possibility of increasing rainfall from warm season convective clouds by cloud base release of hygroscopic particles. These particles have just the right characteristics to promote the formation of drizzle, which grows by coalescence into rain. This appears to be a fruitful area that requires further investigation. It is recommended that SOAR support or is involved in a project or experiment to investigate the opportunities of hygroscopic seeding within the SOAR target area.

To implement these recommendations, a link between the operational and research community needs to be established. The ambassadors of the Texas programs have been working hard to secure funding for such an endeavor with limited results.

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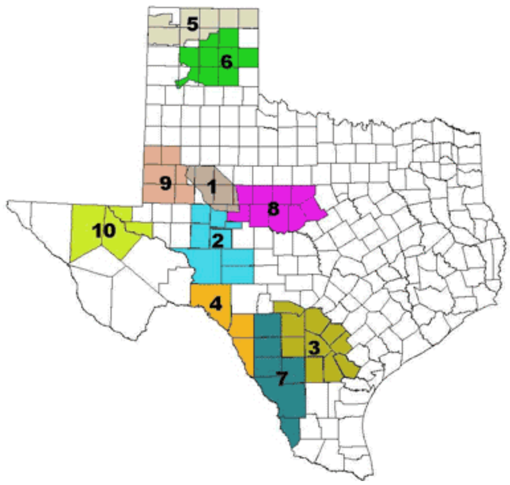

Figure 1: 2003 Cloud seeding programs in Texas (SOAR program on Texas side is number 9)

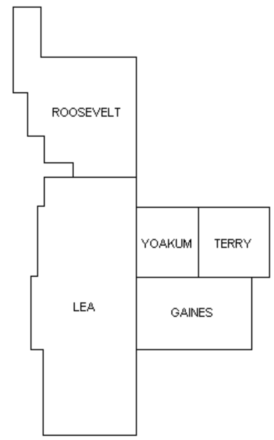

Figure 2: The SOAR 5.9 million acres target (Roosevelt and Lea Counties are in New Mexico)

CLOUD SEEDING EXPERIMENTS ON WARM CLOUDS IN PAKISTAN

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Abstract. Cloud seeding experiments were conducted on warm clouds in Pakistan during the year 2000. This was the first full-fledged experimental activity taken up in Pakistan to augment precipitation through the cloud modification programme. The activity emerged as a consequence of the history's worst drought in provinces in the southern half of the country in 1999-2000. Government of Pakistan immediately felt the need of combating this most crucial catastrophe and thought of taking up the project of artificial rainfall in the country particularly in the drought vulnerable areas. This paper will attempt to give a summary of the methodology adopted in the cloud modification experiments and the synoptic conditions under which the experiments were performed. What really was achieved out of these experiments, what were the limitations and problems and what should be the future strategies to improve the quality of such a work are the discussions contained in this study.

1. INTRODUCTION

Cloud seeding technology has developed over the last 45 years as a means for augmenting precipitation primarily in regions where additional precipitation is required as economic aspect (Elliot et al 1995). The adaptation of this technology gets justified when seen in the context that Pakistan, in each season, has at least some regions vulnerable to drought (Sheikh 2001). The technology is not without uncertainties but it still offers economic benefits (Reinking et all 1995). Although difficult to measure exactly, the perceived benefits far outweigh the cost of implementing programmes (Dennis 1980). Besides the above, cloud seeding is a highly potable and flexible technology. It does not require construction of large, permanent and costly structures such as dams or water conveyance systems. Comprehensive laboratory and field studies have indicated no significant environment impacts (Griffith et al 1999).

Hygroscopic seeding has revealed renewable interests in the past few years (Matheretal 1996, Cooper et al 1997). Matheretall (1997) & Bigg (1997) have studied the effects of seeding convective clouds in South Africa with hygroscopic flares and found strong indications of rainfall increases as much as 30 to 60 % increases from individual cloud complexes (Orville, et all, 1999).

Research on weather modification is going on in Australia, South Africa, Mexico, Canada, Israel and the United States. 38 weather modification activities were carried out in the United States in 1997. The technology was used in 1995 in the Northern Province of South Africa. The Government of South Africa approached the National Precipitation Research Program (NPRP) to employ cloud seeding as an emergency response to drought in the province (WMO Report No 35; 2002).

The history's worst drought in the country during 1999-2000 made the Government of Pakistan to go for the weather modification exercise to make a sound scientific judgment on the basis of short field experiments.

2. CLOUD SEEDING REQUIREMENTS

These required:

- In depth knowledge of the physical basis for cloud seeding.
- Tools for experimentation, their proper selection and use.

2.1. Physical Basis for Cloud Seeding

If cloud seeding is to trigger precipitation, certain atmospheric conditions must exist. Clouds must be present, for seeding cannot create clouds (Frederick et al 1998, Cloud Seeding page 129). Clouds are formed when atmospheric moisture condenses on small particles in the atmosphere called condensation nuclei. The number of cloud particles per cubic centimeter ranges from less than 100 to more that 1000 (Britannica Encyclopedia, vol. 3, 1996, "Cloud Seeding"). The cloud temperature is the important characteristic in the rain process. A warm cloud is a cloud above $0^{o}C$ and super cooled clouds are those below $0^{o}C$. Rain in warm clouds (above $0^{o}C$) is formed when large droplets collide and join together with smaller droplets. Opposite electrical charges may bind the cloud droplets together (Federick et al, 1998, page 421). The sizes, types and concentrations of nuclei play an important role in determining the efficiency with which a cloud system forms and ultimately produces rain or snow.

Man can assist nature by furnishing appropriate types and number of nuclei through seeding the clouds at the proper time and place (Atmospheric Incorporated, USA; www.atmos_inc.com/wedmod.html).

Seeding with very large condensation nuclei (hygroscopic particles such as salt crystals) can be done to accelerate the warm rain process (ibid). The consideration of cloud seedling to produce large and/or more vigorous clouds is, by its nature primarily limited to convective (cumulus) type clouds, although cloud modeling results in the 1980s have indicated the possibility of stimulating the formation of embedded connective clouds in stratiform clouds (Grant et al).

The cloud seeding experiments in Pakistan were conducted during the period July to Sep, 2000 when there were monsoonal rains in the country. The experiments, however, were conducted in the regions which mostly lay outside the monsoonal belt. The season was ideal in the sense that convective warm cloud formation was common in the season. Mostly Sc and Cu but Ac and As isolated cloud patches also were picked up for seedling. On the day of seedling, it was specifically kept in view that the target area was outside the influence of any natural rainfall generating weather system

2.2. Tools for Weather Modification

2.2.1. Radar Requirements

Radar data should be collected and analyzed in the cloud seedling experiments (Clouds Seedling Experiments in South Africa, WMO Report No35, 2000). Different weather radars are available in a variety of wavelength (K, X, C, S) each of which serves a slightly different function in cloud seeding projects (Don A. Griffith et al). By far the most commonly used radars are C-band (5 cm) radars. They provide sufficient sensitivity to both rain and snow. S-Band (10 cm) Doppler radars are superior but lack sensitivity in measuring snow (Griffith et al). A network of five 3 cm, six 5 cm and one 10 cm Doppler radar covering almost 80% of the country made it possible to study seeding responses in a way k not previously possible.

2.2.2 Satellite Remote Sensing – an Integral tool for Cloud Seeding Experiments

Satellite remote sensing can provide temporally and spatially uniform observational data useful in evaluating the opportunities and effects of hygroscopic seeding (WMO Report No. 35, WMO/TD No. 1006, 2000). The geostationary satellites (even polar orbiting satellites) allow routine observations over a wide area that can be targeted by aircraft for seeding and measurement activity (WMO Report 35, 2000). APT & HRPT system facilities are available at Karachi, Quetta, Lahore and Islamabad, and the satellite imageries / observations effectively supported the management of operational programmes of cloud seeding in Pakistan.

2.2.3 Aircrafts

The type of cloud seeding agent and the delivery system dictates the type of aircraft used (Don A. Griffthetal, 1995). However the commonly available aircrafts can be modified to carry an assortment of cloud seeding devices (ibid). Beaver and Fletcher aircraft of Plant Protection Department with liquid dispensers and Mashhaq aircraft of Army Aviation, mounted with solid dispenser joined the mission. Mashhaq aircraft was modified to the extent that a solid dispensing machine, indigenously manufactured in accordance with the requirements of Pakistan Meteorological Department (PMD) was fitted to the aircraft. The aircrafts were very old and had the limitations to go beyond a certain height. Some cases where conditions were conducive for cloud seeding could not consequently be tampered.

3. EXPERIMENTS CONDUCTED

Forty eight experiments in all were conducted, 14 in Sindh, 18 in Balochistan, 3 in NWFP and 13 in Punjab out of which 10 were undertaken in Southern Punjab. More than eighty percent experiments were conducted south of 30°N where intensity of aridity was much higher as compared to the aridity in northern half of the country. Experiments were made during the period 20th June to 15th September, 2000 which practically is the monsoon period in Pakistan where convective type of clouds makes their sufficient availability.

4. EVALUATION OF THE SEEDING RESULTS

Convective cloud systems have a strong special variability and the rain gauge measurements are not very accurate (WMO Report No. 35, WMO/TD No. 1006, 2000). In addition, it is almost never possible to gather the correct rainfall information from individual storms with surface data.

The best tool is radar. Though temporary rain gauges were installed in some of the experiments but the evaluation of the success or otherwise of the experiment were made using the radar pictures collected at nearby radar stations or through the general public. Mostly experiments were made in areas covered by weather radar or by a Met. Station, where the recorded rainfall data helped evaluating the experiments

5. OVERVIEW OF SOME SUCCESSFUL EXPERIMENTS

5.1. Experiments Conducted In Sindh

Thar desert is located in the Sindh Province. Eight experiments in this drought affected area were conducted from 1st July to 15th July, 2000; out of which six were successful. The experiments yielded that much rainfall, which at least eased out the drought conditions in the area. Chhor (25°31’ N; 69°47’E; Height 19 feet) was the field station established for the purposes of carrying out cloud seeding activity in the desert area. Chhor is more a monsoon dominated station as compared to winter rains. The month of July on the average receives 79.0 mm of rainfall and the average number of rainy days is 3.8 days (Climatic Normals of Pakistan, 1961-90, PMD; 1993).

The experiments conducted on 1st July, 2000; 3rd July, 2000; 13th and 14th July, 2000 make part of this paper:

5.1.1 1st July, 2000

The synoptic weather situation on 1st July was that a weak low lay over the Indian states of Orissa and eastern Madhya Pradesh and a westerly wave had been affecting northern parts of Kashmir. The station going to be experimented upon was not under the influence of any of the above systems and no chances of any natural rainfall existed at the station.

Six octa low clouds of the type cumulus (4) & Stratocumulus (2) were available at 3000 feet over the experimental site which was located in the southern quadrant of Chhor (as shown in Fig.1). Real time humidity at the time of operation was 34%. Westerly wind of 4 knots had been penetrating the target area. The operation for cloud seeding using the aqueous solution of 30 kg of NaCl and 200 litters of water was completed during the period from 1743 to 1830 hours PST (Pakistan Standard Time). The seeding generated sufficient rainfall, light at seven stations and 30 mm each at two stations.

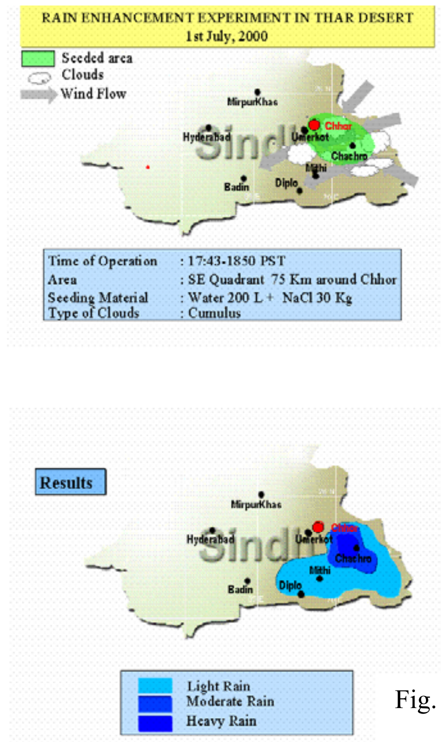

Fig. 1

5.1.2 3rd July, 2000

The synoptic situation on the day was that the monsoon low of 2nd July, 2000 over southwestern Uttar Pradesh had almost dissipated. The westerly wave, however, had still been affecting Kashmir and adjoining areas. Chhor had very little chances of getting any natural rainfall during that day. Over all six octa clouds, 5 Sc and 1 Cu were available at 3 to 5 thousand feet height. Relative humidity was 46% at the time of operation.

Beaver aircraft equipped with liquid dispenser used 60 kg of NaCl with 400 liters of water for seeding and completed its two operations during the period 1631 to 1730 and 1740 to 1840 PST. The area experimented upon encircled Chhor, Chachro & Mithi. Rain was reported from the following places:

Place	**Rainfall / Type of Rainfall**
Diplo	9 mm
Mithi	4 mm
Chachro	Light
Gudro	Light
Umar Kot	Light
Badin	Light

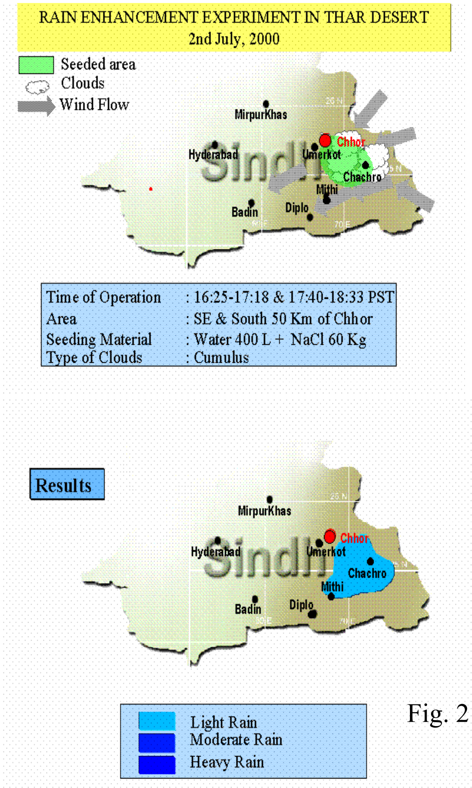

Fig. 2

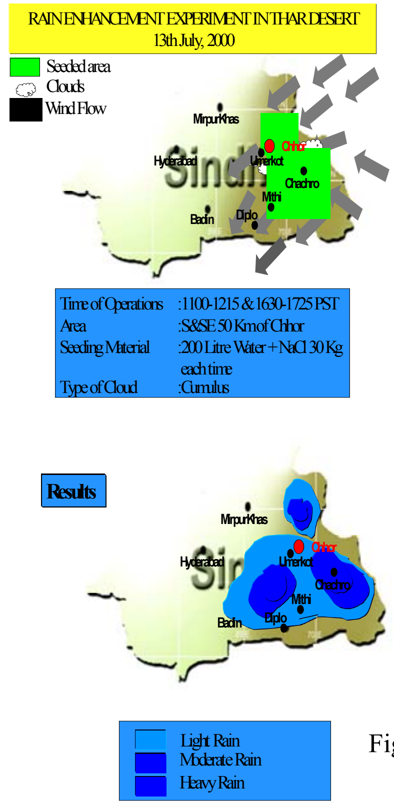

Fig. 3

The rain fell during 2330 to 2400 PST about 4 hours after the seeding. The nocturnal cooling along with abundantly available nucleating agents from seeding seems to have played a major role in causing this precipitation (Fig. 2).

5.1.3 13th July, 2000

The synoptic situation on the day was that a monsoon low which after having developed in Bay of Bengal, lay over northeastern Madhya Pradesh in India and was likely to move in the west northwesterly direction. It had been inducing monsoon currents in Kashmir, Punjab and Sindh. However there were no bright chances of rainfall at the station during the day time.

5 octa clouds, 3 Sc and 2 As clouds were available during the time 1100 to 1215 PST when the first operation was made and 3 Sc and 2 Ac were there during the second operation within 1630 to 1725 PST.

Beaver aircraft carrying 60 kg of NaCl and 400 liters of water was used for the seeding purposes. Area picked up was located southeast of Chhor within a triangle enclosed by Chachiro, Bavri and Jhakia as its vertices (Fig. 3).

Rainfall started three hours after the last seeding and continued till midnight. The nocturnal desert cooling and abundantly available nucleating agents from cloud seeding seemingly played their role. Rainfall ranging from 4 to 45 mm fell over six different stations. The dominant component of the rainfall seems to have occurred due to the incursion from the monsoon low over India yet the component from the seeding also seemed to have contributed as the rainfall over the seeded area was noticeably higher than the surrounding.
The most fascinating aspect associated to this experiment was that the reaction of the people living in the experimental areas was interesting and wonderful. Both Muslim and Hindu communities live in these areas. Muslims offered prayers whereas the Hindus put in their temples the idols of the Meteorological officer and worshiped him for being their “rain god”.

5.1.4 14th July, 2000

The synoptic situation was that the monsoonal low over northeastern Madhya Pradesh in India on 13th July, 2000, after having moved in a west northwesterly direction, lay on the day over central Rajisthan. It had slightly weakened but still it had been a source of moisture incursion in the Sindh Province. However there were no immediate chances of rainfall during the time of experiment. 4 octa Sc, As clouds were available. Relative humidity was 55%.

Beaver aircraft carrying 60 kg of NaCl with 400 liters of water was used for seeding. Rain recorded was as under:

Place	**Rainfall**
Diplo	62 mm
Nagarparkar	22 mm
Mithi	20 mm
Badin	23 mm

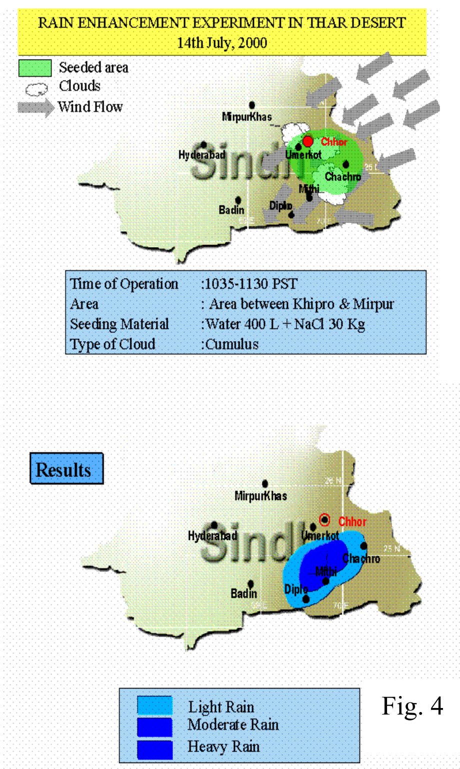

Fig. 4

The dominant contribution seemed to be due to the monsoon low over India, yet the pattern of rainfall over the seeded area supported the contribution of seeding activity too (Fig. 4).

5.2 Experiments at Zhob (31°21'N; 69°28'H; Height 4609 feet), Balochistan

Six experiments were conducted during the period 18th Aug, 2002 to 7th Sep, 2002 out of which four met the success. The station is dominated more by summer rains as compared to the winter rains (Climatic Normal of Pakistan, 1961-90; PMD, 1993). The mean normal rainfall and number of rainy days at the station during August are respectively 58.9 mm and 3.2 days (ibid).

Experiments conducted on 25th, 26th Aug, and 7th Sep, 2000 are made part of this study:

5.2.1 25th August, 2000 (Zhob)

The synoptic situation on the day was that a deep monsoon low lay over northwest Andhara Paradesh and adjoining Maharashtra state in India but the experimental station was not under the influence of this deep monsoon low. No westerly wave had been affecting Pakistan. The status around Zhob was either clear or partly cloudy. Over Zhob, in all, six octa clouds 5Sc and 1Ac at heights 5000 & 10000 feet were available. Relative humidity was 30%. Mashhaq aircraft carrying 22 kg of seeding material (Salt + Aerosil) was used. The operation was completed during the period 1712 to 1816 PST. Both low and medium clouds were seeded from a height of 11000 feet. The whole of the seeding material was consumed over an area of 20 square kilometers. The experiment yielded encouraging results and moderate to heavy rainfall fell over seven stations in the west, northwest & southwest directions (Fig. 5).

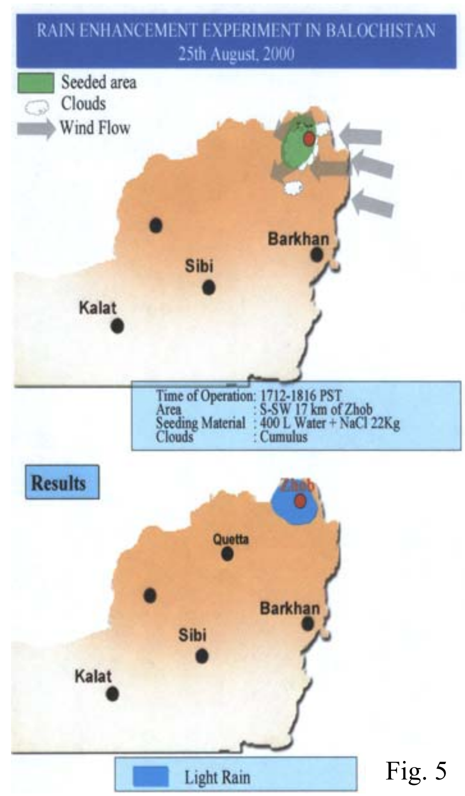

Fig. 5

5.2.2 26th August, 2000 (Zhob)

The synoptic situation on 26th August was that the monsoon low over India today existed over Gujarat and adjoining areas but it practically had no significant effect on the area of the experiment. 7 octa clouds, 5 SC & 2 AC were respectively available at heights 5000 & 12000 feet. Relative humidity was 25% and the conditions were conductive for the operation.

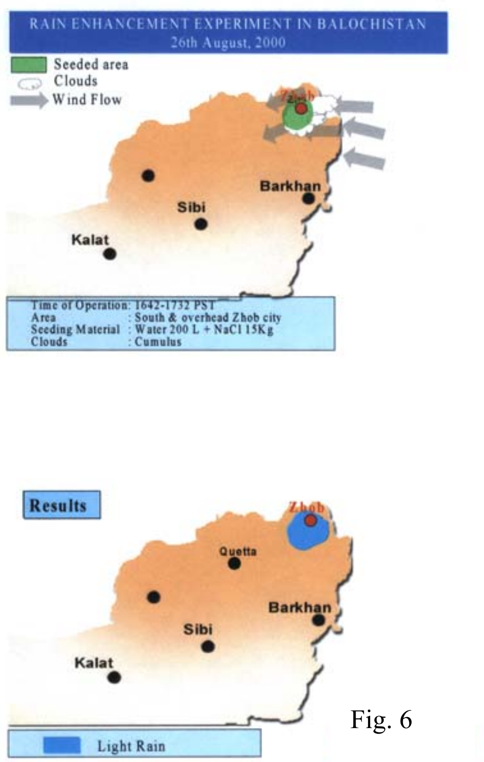

Fig. 6

Mashhaq aircraft carrying 15 kg of seeding material (NaCl + Aerosil) completed its operation during 1642 to 1732 PST. Seeding was done from a height of 11000 feet. This covered both the low & medium clouds over 4 square kilometer area south and over the station. After seeding, the clouds showed a rapid movement to the NNE direction.

Light to moderate rainfall fell in the North & Northeastern sides over the stations as given below (Fig. 6):-

Place	Location	
Moti Zai	16 km	N
Khajkzai	18 km	N
Narazai	21 km	N
Sohai	05 km	NE
Hassan Zai	06 km	NE
Manda Zai	06 km	NE

5.2.3 7th September, 2000 (Zhob)

According to the prevailing synoptic situation, a monsoon low was located stationary over Uttar Pradesh in India and a westerly wave persisted over Kashmir. A heat low also existed laying over northeastern Balochistan. The meteorological conditions, in aggregate, were favourable for convective cloud development, but there were still bleak chances of any natural rain to occur in a significant amount.

Two seeding operations were carried out during 1520 to 1614 and 1648 to 1741 PST, with Mashhaq aircraft mounted with solid dispenser. The seeding material contained 22 kg of NaCl mixed with an equivalent volume of aerosil. The clouds were seeded in an area of about 30 km radius in the west and northwest direction of Zhob. At the time of operation, half of the sky was covered with cumulus, stratocumulus and altocumulus clouds. The relative humidity was recorded as 44% while wind was blowing from east with an average speed of 10 knots.

About half an hour after seeding, rain started at Zhob and Meteorological observatory recorded 1.0mm rainfall. Moderate to heavy rainfall was reported from west and northwest up to 50 km of Zhob. It is note worthy here that the rain received as a result of cloud seeding was the first after a long dry spell of six months (Fig. 7).

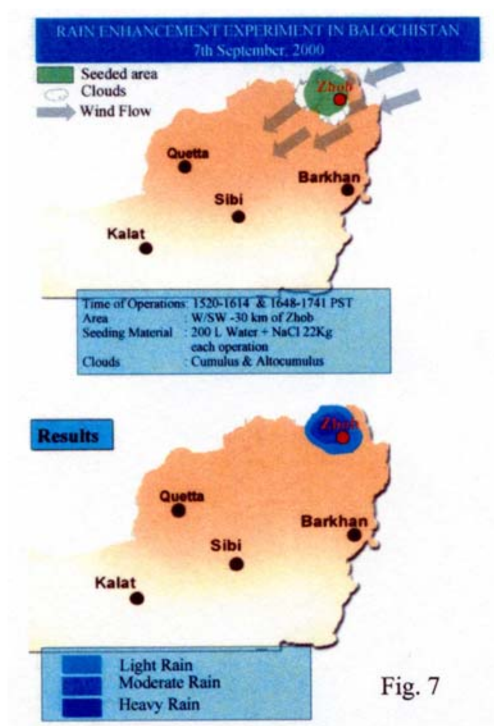

Fig. 7

5.2 Experiments on 25th And 27th August, 2000 at Quetta, Balochistan

Quetta (30°15'N, 66°33'E; Height 5253 feet) is the capital city of Balochistan. The city is dominated by winter rains (Dec to Mar) and lies mostly outside the influence of monsoon rains (June to September). The rainfall pattern (Climatic Normal of Pakistan, 1961-1990, PMD, 1993) reflects the position as given in Table:1.

Table: 1

Jan	Feb	Mar	Apr	May	Jun
56.7	49.0	55.0	28.3	6.0	1.1
July	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
12.7	12.1	0.3	3.9	5.3	30.5

The normal numbers of rainy days during the month are 0.9 days (Climatic Normal, PMD, 1993). This brief preamble would help assess the experiments conducted in the Quetta Valley.

5.2.1 25th August, 2000

The synoptic situation on the day of the experiment was that Quetta was not under the influence of any significant weather system. One to two Octa Cu clouds were available over the city.

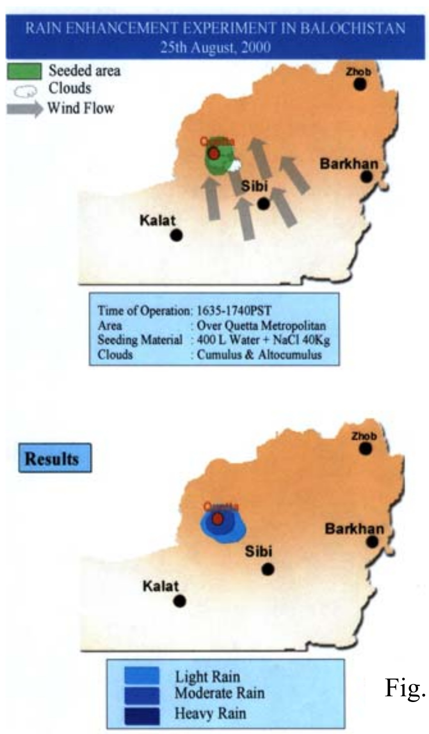

Fig. 8

Beaver aircraft carrying 40 kg of NaCl with 400 liters of water was used for seeding. The operation was completed within 1635 to 1740 PST. Light to moderate rainfall was reported to have fallen during the period 1815 to 1845 PST. It was something very interesting and amazing to note that this successful experiment terminated the long dry spell gripping the city for the last six months. Press media and masses expressed their feelings of happiness and lauded the efforts of Government and the cloud seeding team. The experiment is shown in Fig. 8.

5.2.2 27th August, 2000

The synoptic situation on 27th Aug, 2000 was that a monsoon low which had developed in the Bay of Bengal on 21st Aug, 2000 today lay over Northeastern Arabian Sea and adjoining coastal areas of Gujarat (India). Quetta was far out of the influence of this system. One to two octa Cu clouds were available over Mastung, a city some 40 km south of Quetta. Beaver aircraft carrying 30 kg of NaCl with 300 liters of water was used for seeding. The operation was completed during the period 1745 to 1838 which yielded light rainfall (Fig. 9).

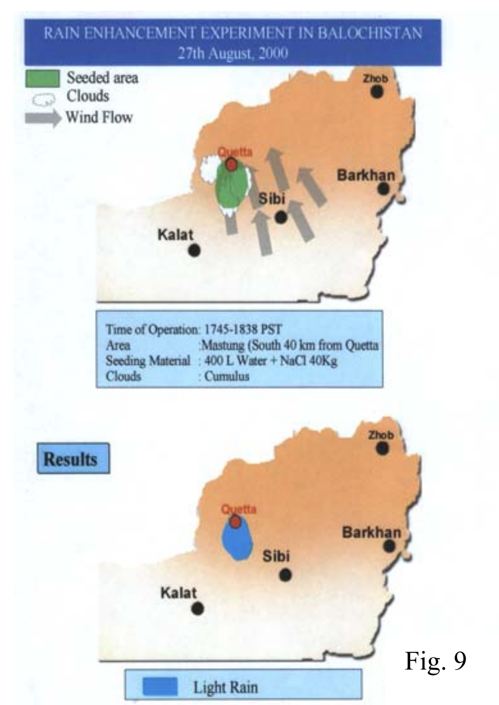

Fig. 9

6. CONCLUSION

Seeding the warm clouds was the first experimental exercise in Pakistan which apparently brought a reasonably high success. This, however, lacked many technical aspects to be followed. Even the technical evaluation of the experiments had no scientific and statistical assessment, yet the results reflected a promising potential in the technology to be applied in the country.

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ICE NUCLEATING BEHAVIOUR OF AQUEOUS AND ALCOHOLIC SOLUTION OF PHLOROGLUCINOL: A LABORATORY STUDY

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Abstract: The behaviour of ice nucleation at different temperatures has been studied in case of seeding with aqueous solution and alcoholic solution of Phloroglucinol. For aqueous solution, the nucleation has been studied starting from -17.9^0C and it was observed to terminate at -0.5^0C. In case of alcoholic solution, the study has been started from -22.3^0C and it was found to continue up to -3.5^0 C. The higher temperature is a cut-off temperature, but at the lower temperature end the nucleation becomes quite small, though not amounting to zero. However the peak in crystallization occurs at -13.0^0 C in the case of aqueous solution and the corresponding peak occurs at -17.8^0 C in the case of alcoholic solution. Apparently both these temperatures are close to the freezing temperature of the mixture.

Besides, dendrite structure is observed in both the cases in the temperature range of -20^0C to -17^0C. However, hexagonal crystals have only been observed in case of aqueous solution in the temperature range of $-15\ ^0$ C to $-10\ ^0$ C. Cubic crystals exist dominantly in case of alcoholic solution, but rod shape crystals dominate in case of aqueous solution.

1. INTRODUCTION

The study of ice nucleation by organic substances started from late fifties of the last century. Some of these which are reported in the literature may be mentioned here (Baskirova & Krasikov 1957, Komabayshi & Ikebe 1961, Head 1961,1962, Langer & Rosinki 1963, Fukuta 1963,1965,1966, Braham 1963, Parungo & Lodge 1965,1967, Fletcher 1972, Michelmore & Franks 1982, Gravish et. at. 1990, 1992, Hendrick & Ward 1992, Pattnaik et. al. 1997, Szyrmer & Zawadzki 1997).

In fact, Bashkirova and Krasikov (1957) were the first persons to identify Phloroglucinol as an efficient ice nucleant. During 1961-62, Langer & Rosinski were engaged in an Air Force sponsored study of basic characteristics of organic crystals as ice nucleant. Of more than 30 compounds studied by them in the laboratory (Langer & Rosinski, 1963), Phloroglucinol turned out to be most promising as ice nucleant. They conducted test in Armour Research Laboratory and found that Phloroglucinol dust can cause rapid nucleation in cold box cloud at the temperatures of -2^0 C to -3^0 C.

In 1963 Braham also identified Phloroglucinol as an ice nucleating substance. This group performed mainly field experiments. They released Phloroglucinol at different temperatures in the environment. They recorded a moderate snow shower (at -17.2^0C) at the ground and reported that the heaviest shower had occurred at -9.8^0C. Besides, they observed that dispersed Phloroglucinol had the ability to induce freezing of small droplets close to 0^0 C but on the negative side.

Some further experiments were carried out by Langer et. al. (1978) with the same substance. They used Phloroglucinol dust and observed that when the diameter size was in the range $0.04\text{x}10^{-6}$m to $0.06\text{x}10^{-6}$m, the dust particles acted as good cloud condensation nuclei. On the other hand, when the diameter size was reduced in the range of 0.02 $\text{x}10^{-6}$ m to 0.03 $\text{x}10^{-6}$ m, these served as ice nucleating agent.

In a more recent field experiment in Phillipines (Valeroso & Santos, 1999), alcoholic solution of Phloroglucinol was sprayed in a developing cumulus cloud in a region where temperature was close to 0^0C. Heavy rainfall was observed to occur almost 18 minutes after the seeding.

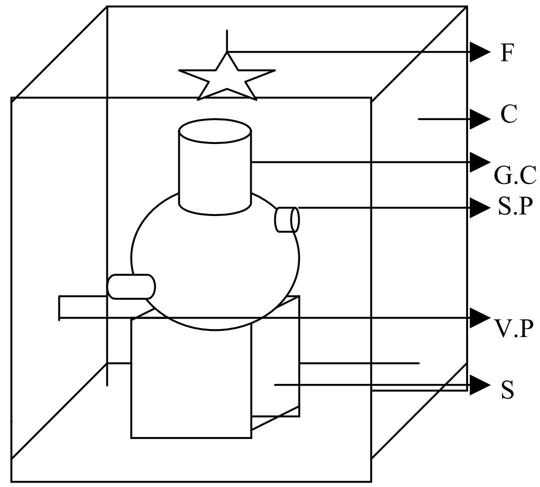
In fact, Phloroglucinol can be seeded in three forms i.e. as dust, as aqueous solution and as alcoholic solution. In case of dust, the nucleation depends on the size of dust particles, on the amount of dust seeded and lastly on temperature. Since the size of the dust particles can be varied over a wide range, it needs an exhaustive study. Here, only the alcoholic solution and the aqueous solution of Phloroglucinol have been used as seeding agent and the behaviour as ice nucleant over a wide range of temperature has been studied systematically. The entire experiment has been operated in a Cold Room. Firstly, the seeding temperature was systematically varied and the crystal count was made, keeping concentration of seeding material fixed. The same experiment was done for both the solutions. It can be concluded that some new results have come out from the present study.

2. EXPERIMENTAL APPARATUS & MEASUREMENT TECHNIQUE

The experimental work has been done inside a single door metallic room (Cold Room) with refrigerant lining and the dimensions of the room are as follows.

The length, breadth, and height are 1.52 m, 1.52 m, and 1.83 m respectively (Diagram 1). The room is made of galvanized iron sheet and is insulated by PUF. The temperature of the room can be reduced up to -35^{0}C. One thermistor is placed inside the Cold Room and this measures the temperature inside the room. A digital display shows the temperature. An air conditioner is operated outside the Cold Room to decrease the temperature difference between inside and outside of the Cold Room. Another thermistor measures the outside temperature and the temperature is displayed digitally. Inside the Cold Room a spherical glass vessel of 35.6 cm diameter and 20 liter volume is placed and it has several outlets on its body for different purposes. A cloud of supercooled droplets is produced by cooling the chamber and then passing steam through a hole near the floor of the chamber. To produce steam a closed container with water has been used, which is placed on a heater and steam is passed inside the vessel through a pipeline. The amount of water vapor content inside the vessel is controlled by adjusting the steam flow. There exists one seeding port on the body of the vessel through which the seeding material is injected. Two thermistors are used to measure the temperature inside the vessel where the seeding experiment is done. Of the two thermistors, one is kept just above the seeding port and the other is placed near the floor of the vessel. The seeding temperature being mentioned in the literature is actually the temperature observed from the sensor just above the seeding port as the nucleation mostly occurs around that region. The other sensor is used mainly to check if there is any temperature gradient inside the chamber. Both these sensors provide digital display. It should be mentioned that all the thermistors are calibrated at ice and steam points and the calibration error lies within 0.1^0 C. Also the temperature difference between the two sensors within the vessel never goes beyond 0.1 ^{0} C.

One circulator is fixed at the roof of the Cold Room to keep the temperature uniform inside the Cold Room as well as to circulate the water vapour. A light is also kept for working purposes inside the Cold Room.



(C= Cold Room, S.P.= Seeding Port, V.P.= Vapor Port, G.C.= Glass Chamber, S= Stand, F= Fan)

Diagram-1: Schematic Diagram of Cold Room

To collect the ice crystals, formvar coated slides are used. Formvar is a brand name of Polyvinyl Formal Resin. The slide acts here as a replicator. By taking 0.4 gm of formvar in 10 C.C. of chloroform a solution is made which is coated on the slides. Two formvar coated slides are placed on a tray near the floor of the spherical vessel to collect the crystal signature. When the slides are taken out, chloroform quickly evaporates leaving behind a plastic film of formvar. On the other hand, ice part of the crystal is also converted into water. Then the slides are kept inside a desiccator with sufficient silica gel so that water will evaporate and be quickly absorbed by silica gel. By this process a replica of the arrested crystals is retained and also the nucleating agent at the core in case of heterogeneous nucleation is left behind. The use of formvar for the purpose of replication is already documented (Saunders & Wahab 1973, Hallet 1976 a,b).

Though two types of seeding solution have been used, one is aqueous Phloroglucinol solution and the other is alcoholic Phloroglucinol solution, but in both the cases the concentration is kept at 0.25 gm of Phloroglucinol in 25 c.c. of either solvent. Only 0.5 c.c. of the solution is injected in one stroke with the help of an atomizer and the atomizer can produce droplets of size 0.4μm to 1.0μm with the maximum number at 0.7μm and the standard deviation being 0.21μm.

The replicators are removed from the vessel after 2 minutes of stoppage of the seeding operation. The slides are then kept inside a desiccator to dry. After the drying up of the slides, these are viewed with the help of a microscope. The microscope has 400 times magnification and the number of crystals in a field of view of the microscope is counted. The basic habit of crystals with change of temperature is also investigated. Photomicrography of those crystals has been done with the help of a camera attached to the microscope.

3. EXPERIMENTAL RESULTS

In the present work, the comparative ice nucleating property of aqueous solution and alcoholic solution of Phloroglucinol has been studied.

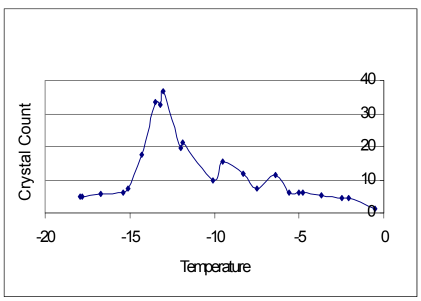


Fig-1: Crystal Count against Seeding Temperature in case of Aqueous Solution of Phloroglucinol

Phloroglucinol is moderately soluble in water, but its solubility largely increases in alcohol. In fact the dipole interaction between water and Phloroglucinol is much greater than that with Ethyl Alcohol, but it is evident that non-ionic weak interaction prevails in case of alcoholic solution.

One of the major aims of the present work is to examine how the crystal count changes with change of temperature at a definite Total Water Content (TWC). However, TWC could not be kept totally fixed but attempts were made to contain it within a range of 130 gm to 150 gm. In the present experiment two slides were kept at a time in the chamber. In each slide, ten fields of view were considered for counting. Then, at each temperature, four separate observations were taken. So, the average of 80 observations of crystal count is being presented here. In Fig.1, the variation of crystal count with seeding temperature in case of seeding of aqueous solution of Phloroglucinol is presented. Here, the most dominant peak in crystal count occurs at -13^0C. So, this temperature is most suitable for ice nucleation by aqueous solution of Phloroglucinol. It is also observed that the upper cut-off of ice nucleation occurs at -0.5^0C. In the lower temperature range, the observation has been continued up to -17.9^0C where nucleation becomes small, though it does not vanish. It should be noted that -12.0^0C is the eutectic temperature for Phloroglucinol and water mixture (this is observed experimentally). As reported in many other cases (Knollenberg, 1966; Hazra et. al., 2003) there is a common tendency for freezing at eutectic temperature as Gibb's free energy becomes minimum at that temperature (Azaroff, 1995). So the peak in number count observed at -13.0^0 C may be taken due to that usual tendency.

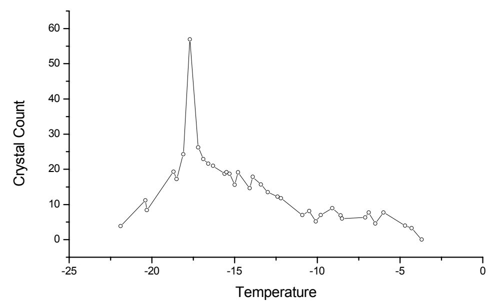


Fig-2: Crystal Count against Seeding Temperature in case of Alcoholic Solution of Pholoroglucinol.

In case of study of ice nucleation by alcoholic solution of Phloroglucinol, the amount of seeded material as well as its concentration are kept the same as previous case, as mentioned previously. The variation of number count of crystals with change of temperature is presented in figure-2. A sharp peak in number count is observed at -17.8^0C. There is a higher temperature cut-off at $-3.5\ ^0$C. The observation at lower temperature was continued up to $-22.3\ ^0$C and the nucleation did not totally cease there.

It should be noted that in case of alcoholic solution of Phlorogucinol in contact with supercooled droplets, three different interfaces are involved. One needs to consider the condensation of the three media together. However, in what ratio the three media will condense in the present environment that cannot be clearly judged. As the amount of alcoholic solution of Phloroglucinol is small in aqueous environment, a study has been conducted in the laboratory to find the freezing temperature of the mixture by varying the ratio of alcoholic solution of Phloroglucinol and liquid water (Fig.-3). It is observed that when 30 cc of alcoholic solution of Phloroglucinol is in combination with 100 cc of liquid water, the entire amount freezes exactly at temperature at –17.8^{0}C. So one can again conclude that the peak in crystal count occurs where the three body mixture can freeze together.

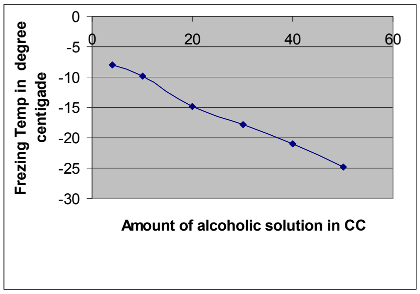


Fig-3: Freezing Temperature against Amount (CC) of Alcoholic Solution used with 100 CC of Water .

From Fig.- 1 and Fig.-2, it is clear that at the peak of nucleation, the alcoholic solution of Phloroglucinol is more efficient as ice nucleant than the aquatic solution of Phloroglucinol.

Some remarkable morphological features in ice crystal formation have been detected in both the cases. One of the distinctions between the two is the existence of hexagonal crystals in case of aqueous solution, in the temperature range of –15 ^{0}C to –10 ^{0}C; it should be mentioned that no hexagonal crystal has been observed in case of alcoholic solution. It should also be stressed that nice dendrites (ref. Photo 001,002) are observed in both the cases in the temperature range of –20^{0}C to –17^{0}C. Besides, dominantly cubic crystals are observed in case of alcoholic solution (ref. Photo 003,004) and in case of aqueous solution the rod shape crystals are more dominant(ref. Photo 005,006,007). Rod shape crystals observed in case of alcoholic solution are also being presented (ref. Photo 008).

4. CONCLUSION

Phloroglucinol may be considered as a seeding agent in three different forms at least. Already scientists have used Phloroglucinol as dust, as aqueous solution and then as alcoholic solution. It has already been reported in the literature that the nature of nucleation greatly depends on the size of the dust. As the detailed study of the character of the dust particles as condensation nuclei will involve exhaustive work, that attempt has not been made in the present study.

But the well known two solutions of Phloroglucinol as ice-nucleating agent have been utilized. In the present case, only a particular concentration of either solution has been seeded. One can also vary the concentration and examine whether the nucleation character has any variation.

One can conclude from the present study that the alcoholic solution of Phloroglucinol is more efficient for ice nucleation at the peak condition. Besides, the peak in ice nucleation in either case apparently occurs where the media have tendency to freeze together.

5. ACKNOWLEDGEMENT

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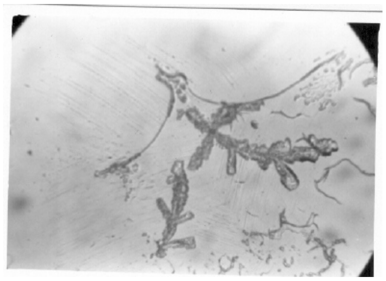
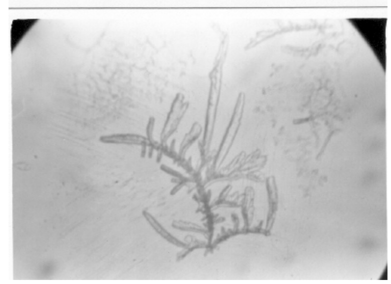
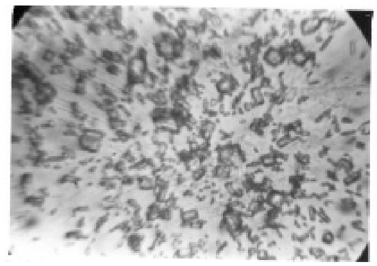


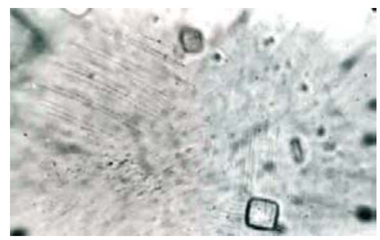
001:*Dendrite structure formed for aqueous Phloroglucinol at* -17.9^0



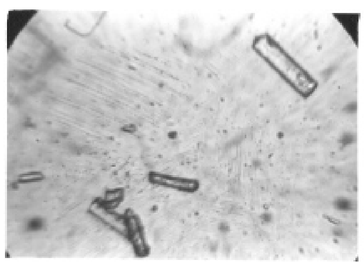
002*: Dendrite Structure formed in alcoholic Phloroglucinol at* $-20.4\,^0$ *C.*



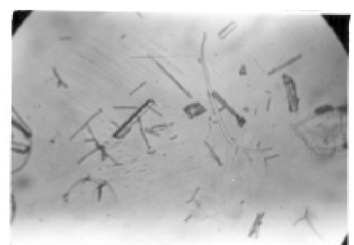
003*:Dense Crystal found for alcoholic Phloroglucinol at* -17.7^0*C.*



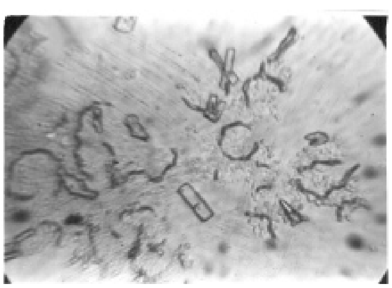
004*:Cubic crystal found in alcoholic Phloroglucinol* -8.6^0*C*



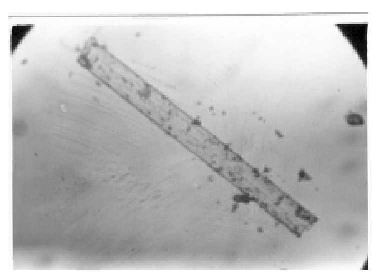
005*:Rod Shape Structure Found in Aqueous Phloroglucinol* -10.1^0*C*



006: *Rod shape structure formed for aqueous Phloroglucinol* -8.3^0*C.*



007*:Rod Shape and hexagonal crystal found in aqueous Phloroglucinol at* -13.5^0*C.*



008: *Nice rod shape found for alcoholic Phloroglucinol at* -14.1^0 *C.*

ON THE CONTRASTIVE NATURE OF WEATHER MODIFICATION KNOWLEDGE: COMMONSENSE REASONING AND COMMONSENSE KNOWLEDGE

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Abstract. Weather Modification specialists constantly face a difficult problem in their operation and research tasks. The explanation of events on the basis of data is neither completely deductive nor completely inductive. The reason is clear since it is very difficult to isolate the weather objects from their environment and their complex interactions; therefore any attempt of methodological isolation tends to destroy vital elements of their dynamics. Here I present a discussion about the role abductive inference plays in applied weather modification knowledge due to its contrastive nature, and how these general considerations are applied in Texas.

1. INTRODUCTION

Weather Modification activities should be conducted with some interests in research since they confront tasks that are almost always pallidly represented in the laboratory. Experiments at lab scale can lead to important discoveries about chamber clouds; however, these clouds are missing important features related to the meteorological and geographical dimensions of real weather. Early in time meteorologists, hydrologists, and climatologists made these same complaints against lab results that were then extremely celebrated by physicists and chemists.

The problem is really complex. Physicists look for general statements about the nature of observed phenomena and are very capable when they describe closed systems and reversible processes. However, weather objects and processes are neither closed nor reversible. For instance, storms need a strong interaction with the environment to import mass and energy, and to export entropy. Only in this way, storms can live in stages far from equilibrium. On the other hand, chemists approach their subjects with more concern for special features, are able to describe very well the particular processes called "chemical reactions", and have pinpointed the catalytic nature of weather modification actions. They have given a plethora of important results for Weather Modification (WM), though the most important features of weather are very difficult if not impossible to create in a laboratory. Once again, complexity asks for field realizations. Physics and chemistry form the basis around which we build powerful instruments to take measurements, constitute a precise language to describe objects and phenomena, and provide a beautiful set of mathematical equations that help this language to make models and predictions. Nevertheless, we don't know with enough detail the initial conditions for these equations, and the weather is easily influenced by variations in its early stage because it is chaotic and unstable.

Richard P. Feynman (1918-1988), Nobel Prize in Physics in 1965, once wrote:

> "Physicists always have a habit of taking the simplest example of any phenomenon and calling it 'physics', leaving the more complicated example to become the concern of other fields--say of applied mathematics, electrical engineering, chemistry or crystallography…"
> (Feynman et al, 1964; see also National Science Foundation, 1965)

Theses quotes probably point out why physics has become a paradigmatic science for epistemologists, but also indicate the clue for a methodology for the sciences that deal with open objects and irreversible processes: **Engineering.**

Weather Modification is applied science, but its applications are engineering. As an applied science **WM** enhances its connections with fundamental research in Meteorology, Cloud Physics, and Cloud Chemistry, whereas as engineering **WM** puts scientific knowledge into practice, applies its knowledge with judgment and attempts to develop ways to economically utilize that scientific knowledge.

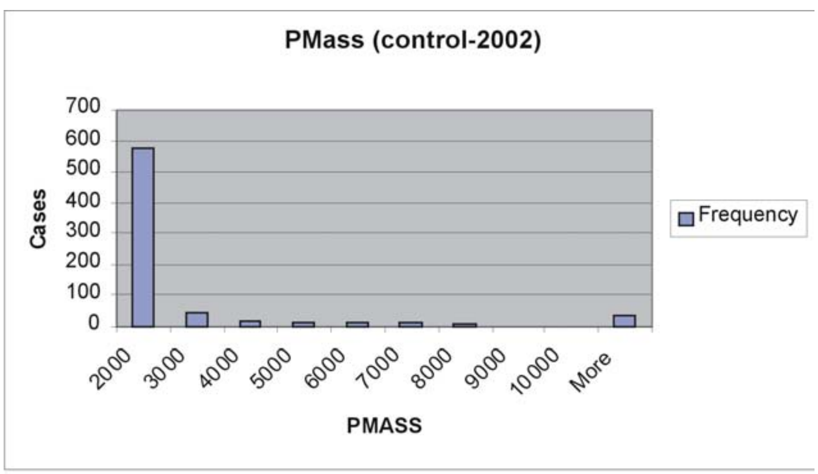
2. GALILEAN EPISTEMOLOGY

Galileo Galilei (1564-1642) founded a new epistemology with the statement that passive observation of ordinary events is not enough because these events are usually too complicated to reveal the underlying physical laws; therefore, **active experiments are needed** (Bolles, 1997). According to Galileo, the experiments should create events easy to understand where all the common complications are removed. In this direction he was able to ignore the friction and bouncy effect of air and any other additional accidents, and found the laws for inertia and free fall in vacuum. We know that frictionless surfaces and a perfect vacuum do not exist, but **scientists consider such laws more real than common experience due to the fact that these laws can show the dominant causes in place**.

In addition, Galileo was also a creative engineer, capable of designing and building pendulum clocks, thermoscopes, lenses and telescopes. **He was not a purist**. He did something even more creative, **he brought back mathematics**. As the reader will find later, only through mathematics **WM** experts can avoid excessive empiricism.

3. DATA MINING AND ENGINEERING

Can we follow similar steps when studying the weather? Yes and no. To some extent we already followed them in randomized cloud seeding experiments, but the complex nature of the subject did not allow us to simplify until all the complications were gone. If we bypassed these undesirable complications, we oversimplified the subjects and the results would be unusable. Therefore, **WM** experts should examine the complex phenomena of weather as precisely as possible in situations as natural and simple as possible to find meaningful "basic units" of behavior; thus avoiding oversimplifications that might lead to dissect meaningless units. The basic units could be used later in the analysis of more complex situations (Ruiz and Bates, 2003a). Experts in **WM** search for frequent and regular occurrences of phenomena within a geographical area without ignoring the rare events, but creating a special classification for them. Phenomena then are described by the attributes almost always present in each class. Classes distinguish each other by contrast. Doing this, **WM** experts accept the premise that phenomenological data are adequate to study weather modification actions, **emphasizes contingency**, and does not cease the search for universal statements and stable modes into the classes. This approach could be named "data mining" and is commonly utilized in engineering. Engineers like to say "there is gold in the mountains of data" (Pyle, 1999).



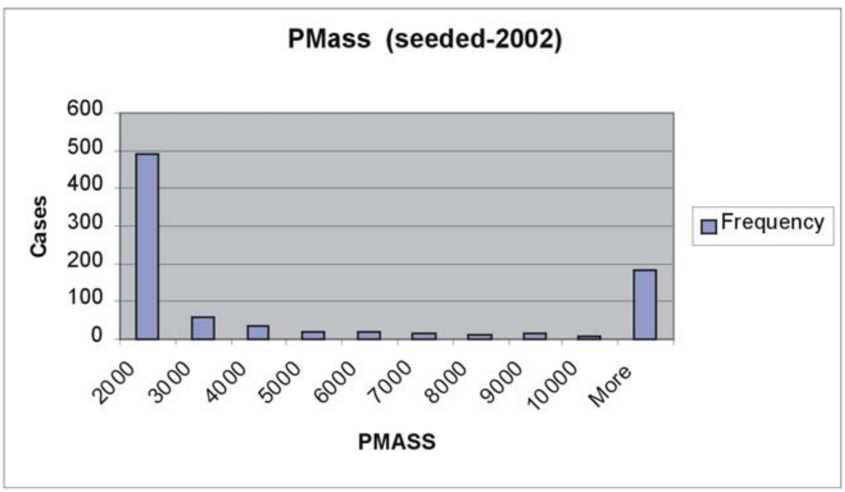
r= - 0.96, N = 6.31x 10^12 / PMass^3.13

Figure 1: Control Cases distributed by precipitation mass
r is the correlation coefficient

Convective processes deserve close attention since they usually behave as individuals and present a very high variability in their behavior. Here the aforementioned contrast among classes may be illustrated mathematically as a phenomenon of self-organizing criticality (Hergarten, 2002). Figure 1 shows the control cases (n = 841 unseeded control storms) in Texas during the 2002 season distributed according to their radar precipitation mass (PMass in kton, N is the number of cases in a particular interval). The distribution followed a potential law obtained by the method of least squares.

Seeded cases followed a similar distribution but with different parameters (regression coefficients) and a slightly smaller correlation coefficient
(Figure 2).

What does self-organizing criticality mean in these cases? First, these graphics show the global structure of two ensembles that appear to organize into systems that do not have explicit concern with the outside environment. The constraints in organization in both systems seem to be internal. Second, both histograms are very similar but there are smaller cases in Graphic 1 than in Graphic 2 and greater cases in the later with an apparent increase in intermediate cases at expense of the smaller ones. For the control cases, doubling the precipitation mass implies a reduction in a factor near nine in the amount of cases, whereas for the seeded cases, the reduction factor is near five (use the equations to figure these factors). Self-organizing criticality might be a new way to detect significant seeding signals. It is certainly a way to develop a systemic study of weather modification actions.



r= - 0.94, N = 8.32x 10^9 / PMass^2.29

Figure 2: Seeded cases distributed by precipitation mass,
r is the correlation coefficient

4. THREE-COMPONENT KNOWLEDGE

Engineering is not excessive empiricism since mathematical considerations allow engineers to always have a theory about experience. Then the theory leads to new scientific experiments, which may or may not corroborate the premises. The scientific experiment is guided by the theory, which asks questions and interprets results. Furthermore, engineering does not underestimate daily experience but uses it to make its creative realizations. As the readers can feel, engineering is a dialectic game, which searches for a balanced correlation between the empirical basis and the theoretical constructions. In this game the explorer must use his/her scientific background together with commonsense reasoning. A question now arises: **What is the logic behind commonsense reasoning?**

Deductive reasoning, which is the process of demonstrating conclusions from general statements, is usually identifies as prime logical reasoning.

However, in science, inductive reasoning (from cases to general statements) plays a major role since concrete data are always particular manifestations of patterns to be recognized through generalization. The so- called hypothetico-deductive method combines both types of reasoning to test hypotheses by the confirmation of their conclusions. Nevertheless, there exists a different type of reasoning called **abductive reasoning,** defined as the inference to the best explanation, which has gained space lately in diagnostic tasks (Josephson and Josephson, 1994). **Abduction** is considered by epistemologists as a third alternative which allows the creation of new hypotheses and the selection of the best one by comparison of explanations. It is obvious that in this kind of reasoning the background knowledge plays a prominent role. Abductive reasoning is the basis of commonsense knowledge, and for scientific purposes its principal feature is the capability to lead to new information. Science is mainly an abductive-inductive enterprise.

The structure of abductive reasoning could be expressed as follows:

Premise 1: **If A then B**
Premise 2: **B**

Abductive conclusion: **Probably A**

In this case it is clear that deduction cannot say a word since we have **B** in premise 2, which is a necessary condition for **A** but not a sufficient one. Notice that the abductive conclusion is only probable since we only have the conclusion of premise 1.

This situation is very common in scientific tasks and even more common in **WM** where decision-making is usually done without enough information and under the pressure of time. Later, during the evaluation of cases, experts should consider this to fairly evaluate the decisions made.

Abductive reasoning brings an interpretive component since selecting the best explanation implies the rejection of other alternatives, which are not logically excluded. This interpretive component has a contrastive essence that adjusts perfectly with the contrastive nature of **WM** knowledge. In **WM** we usually compare target units versus control units, looking for signals of modification that do not follow totally random patterns. However, our **WM** knowledge certainly uses deductive and inductive reasoning. **Rational knowledge,** expressed by conceptual and physical-mathematical models, is directly related to deductive reasoning and can help us in decision making although it is usually not sufficient on its own. **Behavioral knowledge,** expressed by the analysis of particular cases, is related to inductive reasoning and can help us in the identification of patterns. It can also trigger abductive reasoning, which at the end offers **interpretive (or abductive) knowledge** (Fontrodona, 2000).

These three components are always present in **WM** knowledge. To some extension **WM** could become a paradigm for epistemologists because of the necessary interpenetration of the three aforementioned approaches. In WM the comprehension of what is singular is as much an aim as the explanation of general uniformities. It is precisely this focus in contingency what makes this discipline a special case.

5. TEXAS WEATHER MODIFICATION PROGRAM

The previous general considerations support the operations in the current Texas Weather Modification Program. The operations in this program are done on seedable convective clouds, whereas the volume-scan radar data are handled through a set of software utilities called TITAN, which also has an evaluation software package that matches seeded clouds with similar unseeded clouds (Bates and Ruiz, 2002; Mittermaier and Dixon, 2000). The Texas Program could be classified as a well controlled operational program which approaches with its structure the style of previous experimental approaches (Ruiz-Columbié et al, 2003b). Those randomized experiments created a methodology based precisely on the comparison between target and control samples. The resulting conclusions had a contrastive nature with a clear interpretive component.

The intrinsic complexity of the weather objects and their interactions does not permit opportunities for reductionism; hence, ideal laboratory conditions are never reached. The point is clear: **uncertainties are inevitable when dealing with clouds and precipitation since the processes are never clear-cut and without undesirable noise.** Additionally, uncertainties come from non-ideal information sources and from limitations and ambiguities in our rational knowledge. Overcoming this noise becomes a “titanic” task.

However, it is possible to create tools that help to detect improvements within the three-component knowledge model. For instance, since year 2001 in Texas the managing system, based in a scientific approach, has been able to assess the operational performances by using the comparisons between seeded and unseeded control clouds. Apparent increases in different variables, specifically precipitation leaving the clouds, have been reported. Now the system is capable of monitoring different factors that describe accurately the quality of performance and is seen as **a quality control tool** (Ruiz-Columbié et al, 2003a, 2003b; Ruiz-Columbié, 2004). The main factors under control are:

i) Positions where the seeding material is delivered;
ii) Amount of material;
iii) Cloud portions affected by the operations;
iv) Seeding times;
v) Missed opportunities.

Knowing these factors allow us to determine for every seeded case whether or not the seeding material is delivered at the right time and position, and with the appropriate dose. A high correlation between performance and apparent target responses has been detected, and after three years of scientific management we are convinced that **the greater the performance in cloud seeding operations the greater the responses**. This conclusion supports the idea that the seeding material acts as a **contributory cause** for the production of additional increases in the process of precipitation formation. The current critics (NAS, 2003), about the lack of scientific proofs of cause-and-effect relationships in **WM** results, should consider that the phenomenon of causation may present different nuances when dealing with complex events. The concept of contributory cause (Riegelman, 1981) is one example that needs to fulfill only two main criteria:

1) The condition referred as the cause must be shown to precede the effect;

2) Altering only the cause must be shown to alter the effect.

These two conditions seem to be fulfilled in well done **WM** operations in Texas.

We are now in a process to improve our management with the introduction and use of a new software system called "**N**owcast **D**ecision **S**upport **S**ystem" (**NDSS**), which comprises TITAN in its structure and utilizes NEXRAD level II data from multiple Doppler weather radars and other weather data streams. These weather data streams include sounding, rain gauge, wind profile and lightning data, (Weather Decision Technologies, 2003). During the operations the new system will give us more precise information than ever before. Later **NDSS** will allow us to improve the evaluations. On the other hand it is true that we still do not know the details of the chain of physical events that take place in a seeded cloud, but the results seem to indicate that **when the seeding operations are properly performed the dynamics of seeded units appear to improve in comparison with the control units** (Finnegan and Chai, 2003; see also Woodley and Rosenfeld, 1993).

The reader could now understand the insistence here on the rational-behavioral-interpretive character of **WM** knowledge since there is always a comparison between seeded and control cases. Sometimes the control cases are real units, sometimes they are mere models, but the conclusions are always reached through a contrastive method.

We hope that the introduction of the new technology and engineering will help us to enhance the results, ameliorate our interpretations and in time, demonstrate that our weather modification actions produce the expected effects on the ground.

6. ACKNOWLEDGMENTS

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THE WEATHER MODIFICATION ASSOCIATION'S RESPONSE TO THE NATIONAL RESEARCH COUNCIL'S REPORT TITLED,

"CRITICAL ISSUES IN WEATHER MODIFICATION RESEARCH"

Report of a Review Panel

Panel Members: Bruce Boe, George Bomar, William R. Cotton,
Byron L. Marler, Harold D. Orville (Chair), and Joseph A. Warburton

January 2004

Preface: Last fall the National Research Council of the National Academy of Sciences published a report entitled, "Critical Issues in Weather Modification Research". One of their conclusions was that *"there is still no convincing scientific proof of the efficacy of international weather modification efforts. In some instances there are strong indications of induced changes, but this evidence has not been subject to tests of significance and reproducibility."* The report was very disappointing, with little support for operational cloud seeding. It showed little support for hail suppression and it was extremely short on its review of winter orographic cloud seeding.

At the WMA semi-annual executive board meeting held in Reno, Nevada on October 17, 2003, there was a lively discussion about the report but little detail was known. It was concluded that the WMA needed to respond to the report and its conclusions. The board voted to charge Rick Stone, its president, with forming an ad-hoc committee to review the report and develop a statement reflecting the WMA position on the report. This was done in early November, with Bruce Boe, George Bomar, William Cotton, Byron Marler, Harold Orville and Joe Warburton being appointed as members.

The committee solicited input from all members of the WMA before its meeting in early December in Fort Collins. The first draft was distributed to all members and further input invited. The committee received numerous comments and many additions and changes were made. The final report was completed in early February. A press release was issued in March. This WMA report is intended to provide an informed review to the membership and to the public and is now published on the WMA web page (www.weathermodification.org) as well as being published in this current WMA Journal. In addition the report has been sent to various political leaders, policy makers, and scientists in the U.S. and abroad.

Harold Orville (Committee Chair)

1. EXECUTIVE SUMMARY

The Weather Modification Association (WMA) is an association of scientists, engineers, economists, water management professionals, government and private business people, and others who have spent and continue to spend their careers working in the field of weather modification. The members, having read the National Research Council's report "Critical Issues in Weather Modification Research", issued last October 13, have helped prepare this response to that report. The NRC panel was asked to identify critical uncertainties limiting advances in weather modification science and *operations* and to identify future directions in weather modification research and operations for improving the management of water resources and the reduction in severe weather hazards, among other things. They were to do this even though the panel members collectively had very limited experience or knowledge in weather modification operations, especially in recent years.

This current panel was organized to prepare a WMA response to the NRC report concerning issues having operational impact or scientific consequences on operational projects and to provide additional information to the members of the WMA and the public. The national press seized on the conclusion of the NRC panel that there was no convincing scientific proof that cloud seeding worked, not realizing that the panel had opted for a definition of scientific proof that few atmospheric problems could satisfy. On the other hand, the NRC panel concluded, "there is ample evidence that inadvertent weather and global climate modification (e.g., Greenhouse gases affecting global temperatures and anthropogenic aerosols affecting cloud properties) is a reality". We think, however, that global climate change and inadvertent weather modification would both fail the level of proof applied to planned weather modification. We nevertheless strongly support the NRC's recommendation to establish critical randomized, statistical experiments along with the necessary physical measurements and modeling support to reduce the many uncertainties that exist in the science of weather modification.

In addition, the NRC panel cited a much earlier NRC report (NRC, 1964) which suggested that the initiation of large-scale operational weather modification would be premature. We think that it is inappropriate for a national academy panel, with very limited operational weather modification experience, to make such a judgment. Citation of the very dated 1964 report suggests that little has changed since that time. The NRC panel notes operational programs in 24 countries and at least 66 large-scale operational weather modification programs in the U.S. The WMA believes large-scale operational programs have produced and continue to produce positive effects for society. The WMA does not agree with the NRC suggestion that implementation of large-scale operational programs would be premature. This response details the myriad changes and advances that have been made, but that were largely neglected by the current NRC report.

This WMA panel has added information on hail suppression, winter orographic cloud seeding, summer operational programs, and numerical modeling of cloud seeding effects to fill in for obvious gaps and weaknesses in the NRC report. A few other topics are also commented upon.

We support many of the recommendations of the NRC panel, but add several of our own:

- We support the NRC recommendation that there be a renewed commitment to advancing our knowledge of fundamental processes that are central to the issues of intentional and inadvertent weather modification.

- We support the NRC recommendation that a coordinated national program be developed to conduct a sustained research effort in the areas of cloud and precipitation physics, cloud dynamics, cloud modeling, laboratory studies, and field measurements designed to reduce the key uncertainties that impede progress and understanding of intentional and inadvertent weather modification. *But, we argue that the coordinated national program should also support exploratory and confirmatory field studies in weather modification. It should capitalize on operational cloud seeding programs, and use them as a basis for testing models, and developing new statistical methods for evaluating the efficacy of those operations.*

- We support the NRC conclusion that a coordinated research program should capitalize on new remote and in situ observational tools to carry out exploratory and confirmatory experiments in a variety of cloud and storm systems.

- The Board on Atmospheric Sciences and Climate workshop report (BASC, 2001) recommended that a "Watershed Experiment" be conducted in the mountainous West using all of the available technology and equipment that can be brought to bear on a particular region which is water short and politically visible from a water resource management perspective. We strongly support this earlier recommendation that was not then included in the NRC report. Such a "Watershed Experiment" should be fully randomized and well equipped, and be conducted in the region of the mountainous West of the U.S. where enhanced precipitation will benefit substantial segments of the community, including enhancing water supplies in over-subscribed major water basins, urban areas, and Native American communities, for ranching and farming operations, and for recreation. This research should include "chain-of-events" investigations using airborne and remote sensing technologies, along with trace chemistry analysis of snowfall from the target area. Model simulations should be used to determine optimum positioning and times of operation for ground-based and aircraft seeding. The work should include evaluations of precipitation, run-off, and recharge of ground water aquifers. Also, it should include environmental impact studies including water quality, hazard evaluations such as avalanches, stream flow standards and protection of endangered species. Research is also recommended on seeding chemical formulations to improve efficiencies and on improving technology used in seeding aerosol delivery systems.

- We recommend the application of existing and newly developed numerical models that explicitly predict transport and dispersion of cloud seeding agents and activation of cloud condensation nuclei, giant cloud condensation nuclei, and ice nuclei, as well as condensation/evaporation and collection processes in detail, to the simulation of modification of clouds. We concur with the need to improve and refine models of cloud processes, but existing models can be used as a first step to examine, for example, the possible physical responses to hygroscopic seeding that occur several hours following the cessation of seeding. In addition, existing models can be used to replicate the transport and dispersion of ground-based and aircraft-released seeding agents and the cloud and precipitation responses to those seeding materials in winter orographic clouds. Existing models can also simulate static and dynamic seeding concepts for fields of supercooled convective clouds. Moreover, existing models can be used to improve the efficiency of the operation of weather modification research projects and operational programs, and be deployed in the assessment of those programs.

- We recommend that a wide range of cloud and mesoscale models be applied in weather modification research and operations. This includes various microphysics techniques (both bin and bulk-microphysical models have their uses) and various approaches in the dynamics (all dimensionalities - one, two, and three dimensional models - offer applications). The application of hybrid microphysical models should be especially useful in simulating hailstorms and examining various hypotheses and strategies for hail suppression.

- We recommend that a concerted effort be made in the field and through numerical modeling, which includes simulations of hailstone spectra, to study hailstorms and the evolution of damaging hailstones as well as examine potential impacts of modified hailstone spectra on the severity of storms. Because operational programs regarding hailstorms are currently being conducted in the U. S., we encourage the "piggybacking" of research on such projects. We also encourage active cooperation with international hailstorm projects to elicit data and information concerning suppression concepts and technology.

- We recommend that an instrumented armored-aircraft capability (storm penetration aircraft, or SPA) be maintained in the cloud physics and weather modification community. This is essential for the in situ measurements of severe storm characteristics and for providing a platform for some of the new instruments described in the NRC report.

- We recommend that support be given for the development of innovative ways to evaluate operational cloud seeding projects. This is particularly important for the establishment of the physical basis of various cloud seeding methods and for establishing the possible range of cloud seeding effects.

- We recommend that evaluation techniques presently being applied to operational programs be independently reviewed, and as necessary revised to reduce biases and increase statistical robustness to the extent possible. Recognizing that randomization is not considered to be a viable option for most operational seeding programs, we acknowledge that there is much room for improvement in most present evaluations, many of which are presently done in-house.

- We recognize that much of the cloud seeding conducted today, and likely in the future, is done in situ by aircraft. A limited weather modification pilot training curriculum presently is in place at the University of North Dakota (two semesters). This program should be expanded under the auspices of the national research program to improve the breadth of training provided, emphasizing flight in IMC (instrument meteorological conditions) and including actual hands-on, in-the-cockpit seeding experience. Correct targeting is mission-critical, yet nationally, many pilots presently working on operational programs receive only limited training, many not having the benefit of any formal training whatsoever. When pilots are undertrained, project results are likely to suffer. A certification program for pilots by an organization such as the WMA, which, in addition to formal university instruction might include periodic recertification and/or recurrency training, would significantly improve the overall abilities and capabilities of the operational weather modification pilots.

We encourage the scientific and operational communities in weather modification to cooperate and work together whenever and wherever possible to solve the many problems slowing progress in the field. The future should not involve solely operational programs or research efforts. The two should be coupled whenever possible, to work together toward the many common goals.

2. INTRODUCTION

The National Research Council (NRC) released a report on 13 October 2003, titled "Critical Issues in Weather Modification Research" (NRC, 2003). The national press highlighted one of the committee's conclusions that "there still is no convincing scientific proof of the efficacy of intentional weather modification efforts. In some instances there are strong indications of induced changes, but the evidence has not been subjected to tests of significance and reproducibility". The NRC report makes a case for the decline of coordinated, sustained funding of research in weather modification during the last three decades. This decline in funding is cited as both an effect of and a cause of a lack of scientific proof of the effectiveness of cloud seeding. The panel was careful to say that, "this does not challenge the scientific basis of weather modification concepts. Rather it is the absence of adequate understanding of critical atmospheric processes that, in turn, lead to a failure in producing predictable, detectable and verifiable results".

The Weather Modification Association (WMA) is an association of scientists, engineers, economists, water management professionals, government and private business people, and others who have spent and continue to spend their careers working in the field of weather modification. The WMA's executive committee believes that it is the association's responsibility to review the NRC report and to offer scientific and operational perspectives, supplemental information, rebuttal, and further recommendations. Taking this action is consistent with the WMA's vision, mission, and charter; see http://www.weathermodification.org/organization.htm. The executive committee charged the president, Richard Stone, to appoint a panel of WMA members to provide an assessment and response to the NRC report, to update the members and provide additional information to the public. A balanced panel was formed in early November composed of six members with expertise in hail suppression, winter orographic cloud seeding, precipitation enhancement, and numerical modeling.

The panel met in Fort Collins on December 5 and 6 to begin to prepare this report. All members except George Bomar were able to attend the meeting. He participated via e-mail and phone calls. In addition the members of the WMA were asked to provide information and ideas to the panel and to review an early version of the draft response. Many WMA members provided input. The panel takes full responsibility for the contents of this response. The members of the WMA panel and their backgrounds are given in the Appendix.

The statement in the NRC report of "no convincing scientific proof…." depends on their definition of scientific proof that involves randomized experiments, strong statistical support, extensive physical measurements and understanding, and replication. This is a very high standard for a system as complex as the atmosphere. They conclude, "There is ample evidence that inadvertent weather and global climate modification (e.g., Greenhouse gases affecting global temperatures and anthropogenic aerosols affecting cloud properties) is a reality". They are thus clearly maintaining "higher bar" criteria for acceptance for planned weather modification. In our opinion, all should be evaluated with the same criteria. If inadvertent modification of weather and climate were held to the same standards of assessment as planned weather modification, they would have to conclude "that the limitations and uncertainties of the models and the lack of physical evidence, and the inability to assess cause and effect statistically, leads one to conclude that there is no convincing proof that human activity is affecting weather and climate". *Indeed, if the NRC panel were to hold inadvertent weather modification and climate change theories to the same high standard, they could only conclude that there is "no convincing scientific proof" for either.* This having been noted, there is convincing scientific evidence of positive effects in several areas of weather modification, which will be cited below.

The NRC report, in its conclusions, quoted a statement from an NRC 1964 report, stating that the initiation of large-scale operational weather modification programs would be premature. We believe that this is a political statement made by a scientific panel with little recent experience or background in operational weather modification programs. Even the scientist who has asked for better scientific proof has encouraged the continued pursuit of cloud seeding programs where they are scientifically and operationally appropriate (Silverman, 2003, p 1227). In any event, this panel believes it to be inappropriate for a national scientific panel to make such judgments on a technological industry that has been in existence for nearly fifty years and has provided much scientific evidence, much of it in the refereed scientific literature, concerning weather modification and cloud physics.

The recent NRC report leaves much to be desired in a review of research and operations in weather modification. This is not unexpected, inasmuch as the NRC committee had no members from the operations community and lacked depth in weather modification research. The absence of expertise in hail suppression and orographic cloud seeding was especially notable, as was the lack of experience in the modeling of cloud seeding effects. These deficiencies resulted in a report that emphasized the NRC committee's expertise, i.e., experience in weather modification through the 1970's, convective cloud seeding via hygroscopic seeding methods, and the advances in instrumentation that bode well for future research projects.

In the following review we discuss the basis for hail suppression, the capabilities in cold season cloud seeding projects, some additional information on summertime cloud seeding projects, the ability of cloud and mesoscale models to simulate weather modification experiments and operations, and other perceived omissions or misstatements in the NRC review. We close our main response with our conclusions and recommendations.

3. SUPPLEMENTAL INFORMATION TO THE NRC REPORT

3.1 Hail suppression

Extensive research has been accomplished regarding hailstorms and hailstone growth since the 1970's. The National Hail Research Experiment (NHRE), conducted from 1972 through 1976, produced two volumes devoted to the topic (Knight and Squires, Eds., 1982). Volume I concentrated on the general aspects of hailstorms of the central High Plains and Volume II on several case studies of hailstorms observed during NHRE. Many field projects and scientific studies were conducted in western Canada during the Alberta Hail Project (Renick, 1975) in the 70's and 80's. In Switzerland the Grossversuch hail experiment was run for five years during this period and produced many research papers (Federer et al., 1986). Numerous studies of convective storms continued through the 80's and 90's with several hailstorms among the sampled storms in the Cooperative Convective Precipitation Experiment (CCOPE), the North Dakota Thunderstorm Project (NDTP), and the North Dakota Tracer Experiment (NDTE) programs. Studies of these storms and the growth of hailstones within the storms have led to the refining of several of the hail suppression concepts that guide most current operations. A recent review of hailstorms by Knight and Knight (2001) concentrates on the growth of hailstones. A worthwhile review panel response follows that review, and elaborates on several of these hail suppression concepts. The Knights point out that there are nearly 1500 literature citations keyed to hailstorms and hailstones in the period from 1976 to 1996.

3.1.1 Hail suppression concepts

The NRC review panel failed to discuss the rationale and any conceptual model for hail suppression. We provide such a discussion here, basing it largely on a World Meteorological Organization (WMO) report (WMO, 1996), and the Board on Atmospheric Sciences and Climate (BASC, 2001) report, which in turn depended on the many research studies and field experiments reported in the literature in the past 30 years.

Three ingredients are necessary to produce hail: (1) the raw material from which the stones develop (supercooled liquid water, or SLW), (2) nascent hail embryos (commonly graupel and/or frozen raindrops), and (3) updrafts of sufficient magnitude to support the growing hailstones. If any of the three are absent, hail does not develop. When all three are present, the hail growth is limited by the available SLW, and/or the updraft strength. It logically follows that ample SLW and updraft, coupled with limited numbers of hail embryos, will result in the largest hailstones the updrafts can support. When the hailstones grow to the maximum mass supportable by the updraft, they begin to descend. If the stones are not too large and the subcloud layer warm, significant melting occurs during descent, and those hailstones reaching the ground are likely to be small.

Thus, the most often cited hail suppression concept is intended to increase the numbers of nascent hail embryos, and thus, through competition, reduce the amount of supercooled liquid available to grow hail. Instead of growing hailstones large enough to survive the transit through the warm subcloud layer, the available SLW is depleted by the formation of greater numbers of smaller ice particles (smaller hailstones) that are more likely to melt during descent. This concept is known as *beneficial competition*.

Beneficial competition is produced by the introduction of additional hail embryos to the flanking cells of a hailstorm. In theory this would lead to more numerous and smaller hailstones, which would melt more, or perhaps entirely during their descent. A risk is that too few embryos could be added to some inefficient storms and more hailstones could be produced.

Another concept, *early rainout*, is based upon the initiation of the ice-phase precipitation process earlier in the lifetimes of supercooled convective clouds. For example, if ice-phase hydrometeors can be made to form when cloud top temperatures are $-5^{o}C$ rather than $-15^{o}C$, precipitation can form earlier in the clouds' lifetimes. When this is made to happen within the flanking line, several positive effects may result.

First, precipitation falls from what would have otherwise have been rain-free cloud base, possibly in areas of low-level storm inflow. This could impede or retard the moisture flux into the storm, which in turn could lessen the condensate (and eventually SLW) in the stronger updrafts.

Second, conversion of SLW to ice in the smaller turrets reduces the net SLW available for hail growth in the larger turrets, where updrafts are stronger and more conducive to the growth of larger hailstones.

Third, the earlier release of latent heat fuels the buoyancy of the smaller, less vigorous turrets.

Fourth, the total area receiving precipitation from the storm may be increased, while the intensity and amount of precipitation produced within the main storm core may be slightly lessened.

Early rainout is theoretically achieved by the same seeding strategy as that used for beneficial competition. In successful early rainout modification, the precipitation falls from the cells before ingestion into the mature main cell. If the ice hydrometeors produced by seeding do not grow large enough to precipitate from the rain-free cloud base, the number of nascent hail embryos has been increased, aiding beneficial competition.

The term *trajectory lowering* is born of the notion that maximum hailstone growth occurs at higher, colder altitudes, where supercooling is very significant. Such being the case, trajectory lowering would logically slow and/or lessen hail development. One could say that early rainout is in fact also trajectory lowering. More complete knowledge of the optimum hail growth regions begs for the deployment of polarimetric radars.

Trajectory lowering might also be derived from updraft loading resulting from rapid hydrometeor development within treated flanking line turrets. The additional total water mass could slow the updraft, diminishing the storm's capacity for producing hail.

Promotion of coalescence of cloud droplets is accomplished by seeding the flanking cells with hygroscopic materials near cloud base. Such treatment may cause early rainout and/or trajectory lowering. It may also lead to the production of additional hail embryos because of the freezing of large raindrops, which could in turn enhance beneficial competition. Hygroscopic seeding promotes coalescence and is thus thought to affect hail production.

The earlier release of latent heat (see early rainout, above) would help release convective instability within the smaller turrets, collectively over a larger area than in the central mature cell. This could change storm dynamics, and as with the other concepts previously stated, would be well suited to numerical modeling and simulations.

In addition, whenever precipitation falls out of clouds, downdrafts and outflows are formed in the subcloud layer, further changing storm dynamics.

Another concept used in the past was *complete glaciation*. The aim of hail suppression by glaciation is to introduce so many ice crystals via seeding that the ice crystals consume all the available supercooled liquid water as they grow by vapor deposition and riming of cloud droplets. To be effective this technique requires the insertion of very large amounts of seeding materials in the storm updrafts. Modeling studies (Weickmann, 1964; Dennis and Musil, 1973; English, 1973; Young, 1977) have suggested that unless very large amounts of seeding material are used, the strongest updrafts remain all liquid and hail growth is not substantially affected. Therefore, the glaciation concept is generally thought not to be a feasible approach to hail suppression. The glaciation concept is also not popular because many scientists think that it may result in a reduction in rainfall along with hail. Since most hail-prone areas are semi-arid, the loss of rainfall can have a greater adverse impact on agriculture than economic gains from hail suppression.

Figure 1 depicts these concepts of seeding in a multicell thunderstorm. Developing flanking line cells with weaker updrafts are shown on the left of the figure and the mature cell with strong updrafts on the right. In multicellular storms, the developing cells of the flanking line each in turn mature, becoming the dominant cell, which eventually weakens and rains out. To better understand the figure, it is helpful to consider the horizontal axis to represent time with zero on the left and the time of the dissipating cells on the far right.

Important things to note from this discussion are that the concepts dictate that developing cloud turrets are treated, invariably cumulus congestus, rather than the main cell cumulonimbus. This means treatment of young clouds with modest updrafts, not the mature cells with strong updrafts. Also, note that precipitation development is accelerated. Promotion of coalescence is directed at liquid-phase processes primarily; the other methods are based largely on glaciogenic seeding effects. Dynamic effects result from the release of latent heat (primarily from freezing), and from redistribution of condensed water within the targeted cloud turrets.

3.1.2 Evidence of cloud seeding effects

Progress in the numerical simulation of hailstorms and hailstone evolution has occurred, and is discussed below in Section 3.4. Contrary to statements in the NRC report, there are reasonable models that simulate the development of hail in realistic hailstorm environments. Cloud seeding simulations show the effects of early rainout and beneficial competition in reducing hail from relatively efficient hailstorms, but the possible increase of hail and rain from some relatively inefficient storms. The models also show the location of hail embryos close to the forward region of the major updraft. The major growth of the ice particles occurs in high liquid water regions between -5°C and -35°C, usually between -10°C and -25°C. Trajectory analyses indicate that particles that grow to relatively large size begin their major growth cycle in a very narrow ribbon-like region in an area of weak updraft near the updraft/downdraft interface on the forward flank of the storm cells (Farley et al., 2004a, Farley and Orville, 1999), in agreement with recent observations (Thompson and List, 1999).

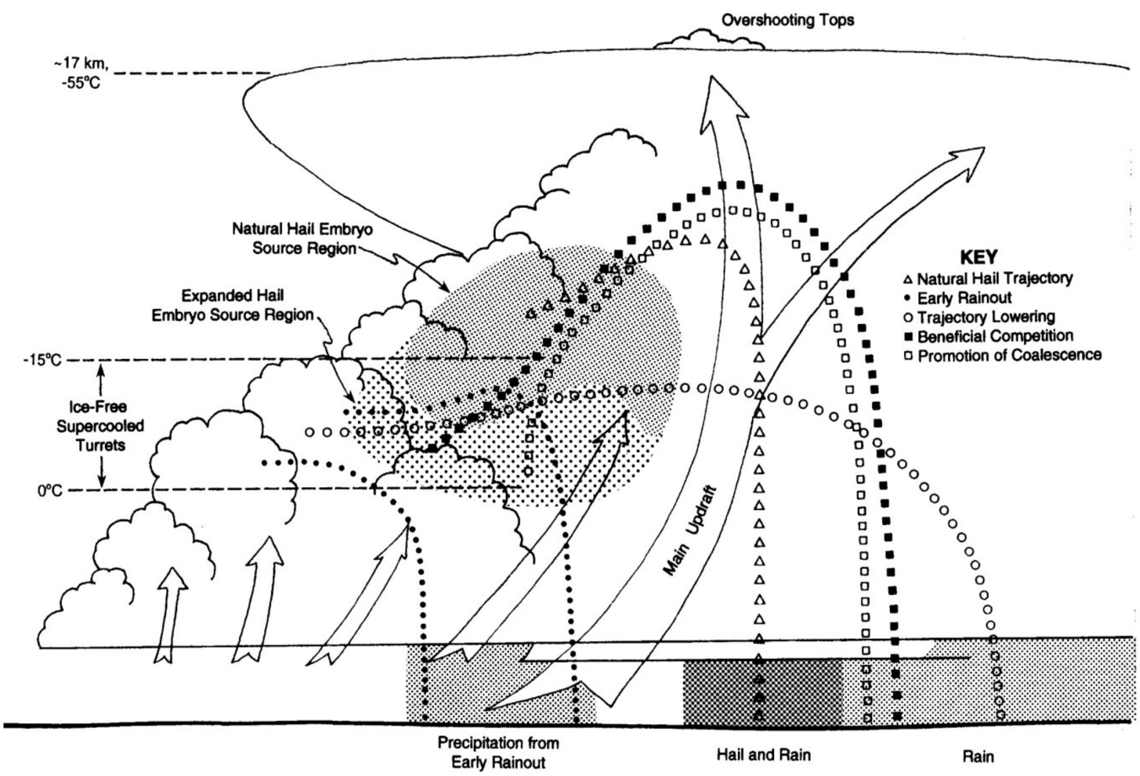

Figure 1. Hail suppression concepts, from WMO Technical Document No. 764, 1996

The NRC report quoted results from Smith et al. (1997) showing a 45% decrease in crop damage due to hail suppression in a nonrandomized operational project, but cast doubt on the results with some unpublished analysis using ratios. Further examination of Fig.2.1 in the NRC report suggests that the analyst picked a starting point that would bolster his point. In addition, the use of ratios in precipitation records requires extreme care. Normally a scientist being corrected or challenged on a conclusion is afforded the opportunity to respond. That such an opportunity was not offered here suggests a possible negative bias on the part of the NRC committee, although we realize that NRC panels do not normally invite comments and responses.

Other evidence exists indicating decreased hail damage during hail suppression efforts. Mesinger and Mesinger (1992) examined 40 years of operational hail suppression data in eastern Yugoslavia. After attempting to remove the effects of climatic fluctuations during the period, they estimated that the hail suppression projects reduced the frequency of hail between 15 and 20%. Rudolph et al. (1994) reported on results from a randomized crossover hail suppression experiment conducted in northern Greece during 1984-1988. Data were collected on 37 days from a total of 196 hailpads spaced an average 4.5 km apart. Hailstone size distributions showed clear evidence of beneficial treatment effects. Aircraft seeding using silver iodide (AgI) generators and flares, primarily on flanking feeder cells, was employed. Target hailpad counts (impacts) ranged from 38% to 100% less than control counts in all 12 size categories, with an average reduction of 55%. On an annual basis, P-values ranged from 0.002 to 0.02 Dessens (1998) in a long running operational program using AgI ground generators and hailpads in southern France found a 42% decrease in hailstone number using target-control analyses.

As in most research on operational programs in cloud seeding there are problems of targeting the seeding agent. Chemical tracers are a key to determining the extent to which a target area is covered. Linkletter and Warburton (1977) found that during the NHRE the AgI was broadly dispersed when weak, poorly organized storms were seeded, but that the seeding agent was confined to only limited regions of the more vigorous storms that had well-defined internal circulation patterns. In the 18 storms seeded in 1973 and 1974 only 50% of the 1973 storms and 70% of the 1974 storms had "seeding" silver above background concentrations. Based upon theoretical predictions, less than 10% of the storms had enough silver to represent a significant seeding effect. Further analysis of four storms in NHRE (Warburton et al., 1982) revealed that the seeding results appeared to fall into three categories; those where the AgI concentration was relatively constant over a wide range of precipitation amounts; those where the precipitation amounts were small and independent of silver contents; and those where there is a positive correlation between silver concentration and precipitation amount. In the cases with positive correlation, the seeding was associated with a precipitation increase of about 1.7 mm depth of water per square meter. Similar coverage results were found by chemical analyses in Grossversuch IV (Lacaux et al., 1985). Two cells on one day showed 7% and 25% coverage and two cells on two other days had seeding coverage of 100% and residence times, in cloud colder than -5ºC, of 500 to 700 seconds.

Another concern about hail suppression is its impact on rainfall. Because hailstorms often occur in semi-arid regions where rainfall is limited, Changnon (1977) estimated that in general, the destructive effects of hail damage are often outweighed by the positive benefits of rainfall from those storms. This is, of course, not true for certain high-risk crops such as tobacco, grapes, or certain vegetables. Modeling studies like Nelson (1979) and Farley and Orville (1982) suggested that rainfall and hailfall are positively correlated so that reductions of hailfall coincide with reductions in rainfall. Later, modeling studies with better microphysics, carried out by Farley (1987) and Farley et al. (2004b) showed less hail and more rain in the seeded cases. In addition, an evaluation of rainfall from an operational hail suppression program in Alberta, Canada by Krauss and Santos (2004) suggested that seeding to reduce hail damage also resulted in an increase in rain volume by a factor of 2.2. Consequently, the effects of hail suppression on rainfall needs further study and measurement on research and operational projects.

At present the design of a randomized hail suppression experiment involving response variables measured at the ground (with the objective of substantiating a hail suppression effect) appears to be impractical, but should be a research goal. The required size of the instrumented target area and/or duration of such an experiment are prohibitively expensive. Moreover, funding agencies are very cautious about committing their resources to supporting a program of more than 5 years duration. Randomized experiments such as Grossversuch IV were designed with the intent to discern a seeding signal in a 5-year period based on the optimistic expectation of a 60% reduction in kinetic energy of falling hail (Federer et al., 1986). Note that Mesinger and Mesinger's (1992) evaluation of the 40-year long hail suppression program in Yugoslavia suggested only a 15-20% reduction in hail frequency. Thus a funding agency would have to be committed to supporting a randomized hail suppression experiment for 10 years or more! Scientific understanding sufficient to sharpen the focus of such an experiment, for example by forecasting the response variables, or to increase the efficacy of the seeding treatments, should precede any efforts to implement a randomized experiment. This also argues for numerical storm models that simulate realistic hailstone spectra for use in refining hail suppression concepts, a step that is well under way, but that needs stronger support.

These concepts, figure, and discussion represent the present state of hail suppression science. The stated concepts have been and are being used to guide operational hail suppression projects, and should help focus future research experiments on hailstorms and hail suppression. Much of the material is used in the American Society of Civil Engineers' Standard Practice for the Design and Operation of Hail Suppression Projects. One of the prime lessons for future operational hail suppression projects that has been learned from past projects is that the most effective seeding is done on the smaller, younger feeder cells

3.2 Cold season orographic cloud seeding programs

3.2.1 General discussion

Although there has been no fully randomized, completely observed chain-of-events, replicated, field experiment in winter cloud seeding, there have been a number of statistically oriented projects, some with thorough physical measurements, that yield considerable evidence of positive effects of cloud seeding (Gagin and Neumann, 1974; Elliott, 1986; Reynolds, 1988; Ryan and King, 1997). Notable examples are the Israeli I experiment, the Tasmanian operation, the Climax I and II projects (Grant, 1986; Mielke, 1995), the Lake Almanor experiment, and the Bridger Range experiment, these last two to be discussed below. The NRC report does an adequate job of discussing winter glaciogenic seeding, but leaves out a number of topics and references that, in our opinion, should have been included, particularly those concerning the chemical analysis techniques, which will be discussed later.

A number of observational and theoretical studies have suggested that there is a cold temperature `window' of opportunity for cloud seeding. Studies of both orographic and convective clouds have suggested that clouds colder than -25ºC have sufficiently large concentrations of natural ice crystals such that seeding can either have no effect or even reduce precipitation (Grant and Elliot, 1974; Grant, 1986; Gagin and Neumann, 1981; Gagin et al., 1985). It is possible that seeding such cold clouds could reduce precipitation by creating so many ice crystals that they compete for the limited supply of water vapor and result in numerous, slowly settling ice crystals which sublimate before reaching the ground. There are also indications that there is a warm temperature limit to seeding effectiveness (Gagin and Neumann, 1981; Grant and Elliott, 1974; Cooper and Lawson, 1984). This is believed to be due to the low efficiency of ice crystal production by silver iodide at temperatures greater than -4ºC, and to the slow rates of ice crystal vapor deposition growth at warm temperatures. Thus there appears to be a `temperature window' of about -5ºC to -25ºC where clouds respond favorably to silver iodide seeding (i.e., exhibit seedability). Dry ice (frozen carbon dioxide) seeding via aircraft extends this temperature window to temperatures just below 0ºC.

Orographic clouds are less susceptible to a `time window' as they are typically quasi-steady state clouds so they offer a greater time opportunity for successful precipitation enhancement than cumulus clouds. A time window of a different type does exist for orographic clouds which is related to the time it takes a parcel of air to condense to form supercooled liquid water and ascend to the mountain crest. If winds are weak, then there may be sufficient time for natural precipitation processes to occur efficiently. Stronger winds may not allow efficient natural precipitation processes but seeding may speed up precipitation formation. Even stronger winds may not provide enough time for even seeded ice crystals to grow to precipitation before being blown over the mountain crest and sublimating in the sinking subsaturated air to the lee of the mountain. A time window related to the ambient winds, however, is much easier to assess in a field setting for orographic clouds than for cumulus clouds.

Orographic clouds in the mountainous western states are often associated with passing synoptic scale storm systems. Wind flow over a mountain barrier causes the orographic lift to produce the cloud. Other types of clouds associated with frontal boundaries, convergence bands, and convective instability are also present during these storm systems, thus the orographic cloud scenario is often complicated by the dynamics of the storm system (changing winds, temperatures, and moisture).

It has been recognized for many years that achieving adequate transport and dispersion (T&D) of the commonly used ground-released silver iodide seeding agent is a key problem in seeding winter orographic clouds (Rangno, 1986; Reynolds, 1988; Super, 1990; Warburton et al., 1995a,b). Failure to document that clouds are actually being seeded continues to seriously hamper the development of this promising technology.

If SLW clouds upwind and over mountain barriers are routinely seeded to produce appropriate concentrations of seeding ice crystals, exceeding 10 to 20 per liter of cloudy air, snowfall increases can be anticipated in the presence or absence of natural snowfall. It has been repeatedly demonstrated with physical observations that sufficiently high concentrations of seeding agent, effective at prevailing SLW cloud temperatures, will produce snowfall when natural snowfall rates are negligible. Seeded snowfall rates are usually light, on the order of 1 mm/hr or less, consistent with median natural snowfall rates in the intermountain West (Super and Holroyd, 1997).

Weather modification scientists are well aware that AgI effectiveness is strongly dependent upon cloud temperature. Little physical (as opposed to statistical) evidence exists that AgI seeding has produced meaningful snowfall when treated SLW cloud temperatures were warmer than -8°C to -9°C except for the special case of forced condensation-freezing where seeding crystals may form near -6°C near the generators. But even in such special cases the crystals are carried to higher, colder SLW cloud regions. In order to be effective, the seeding material must be routinely transported into sufficiently cold SLW cloud and dispersed through large volumes of cloud, in sufficiently high concentrations. Both calculations and observations have shown that concentrations of effective artificial ice nuclei must exceed at least 10 per liter for detectable snowfall increases at the surface (Super and Boe, 1988; Super 1994; Holroyd and Super, 1998). The classic paper by Ludlam (1955) suggested that 10 to 100 seeding crystals per liter would be needed within cloud. Higher concentrations may be required for moderate seeded snowfall enhancement. For example, Super and Holroyd (1997) presented clear physical evidence of an AgI-seeded snowfall increase of 0.04 inches per hour (1.02 mm per hour) with an associated seeded ice crystal concentration of about 140 per liter. Median hourly snowfall rates are typically about half that rate at high elevations in the intermountain West.

3.2.2 Static seeding of winter orographic clouds

There are strong statistical suggestions of seeding effects from at least two randomized programs, the Lake Almanor Experiment (Mooney and Lunn, 1969) and the Bridger Range Experiment (BRE) as reported by Super and Heimbach (1983) and Super (1986). Such suggestions from exploratory analyses should not be considered absolute proof by themselves. However, these particular experiments used high elevation AgI generators, a seeding approach which has been shown to routinely result in transport and dispersion of AgI plumes into the SLW zone. Moreover, both experiments have considerable supporting physical evidence in agreement with the statistical suggestions. Some physical evidence was collected during the BRE (Super, 1974; Super and Heimbach, 1983) and some later by cloud physics aircraft (Super and Heimbach, 1988). Convincing physical evidence, based on trace chemistry analysis of snowfall, was reported for the Lake Almanor target well after the randomized experiment, as reported by Chai et al. (1993) and Warburton et al. (1995a,b). The results of Warburton et al. (1995a) are in particularly good agreement with earlier statistical suggestions of seeding success with cold westerly flow, and further demonstrated that failure to produce positive statistical results with southerly flow cases was likely related to seeding affecting control stations (mis-targeting). Both experiments had evidence suggesting that the condensation-freezing mechanism resulted in the formation of high seeding crystal concentrations just downwind of the generators. This mechanism (Finnegan and Pitter, 1988) was not understood at the time of the experiments, but may have been a major factor in their promising results when AgI was released directly in-cloud at temperatures less than -6°C. Both experiments had evidence of the largest increases in snowfall within about 12 miles of the generators, and for colder cloud temperatures. The panel is unaware of other winter orographic randomized experiments from the western U.S. that have *both* strong statistical suggestions and considerable physical evidence to support those suggestions. According to the review by Reynolds (1988), only the Bridger Range Experiment had such dual evidence at that time.

These two randomized experiments strongly suggest that higher elevation seeding in mountainous terrain can produce meaningful *seasonal* snowfall increases. These suggestions are based on *both* statistical and physical evidence. Although the experiments were run decades ago, they are still worth reviewing in the absence of more or equally impressive results from the limited number of more recent randomized winter orographic cloud seeding experiments.

The studies of Warburton and Wetzel (1992), Warburton, et al. (1995a), and Super and Holroyd (1997) are pertinent. The Warburton and Wetzel paper showed how 8mm wavelength radar was used in conjunction with microwave radiometer measurements for assessing snowfall augmentation potential. The second paper reported on studies in Lake Almanor regarding the targeting and tracking of silver iodide in the precipitation which demonstrated that the transport and dispersion problems are significant and can lead to a much weakened capability of detecting seeding effects by precipitation statistics. The work of Super and Holroyd showed marked increases in ice particle concentrations produced by cloud seeding in Utah.

3.2.3 Additional research accomplish-ments; static seeding of winter orographic clouds

1) One of the most exciting accomplishments in recent snowpack augmentation research is the establishment of the direct link between the seeding activity and the water reaching the ground in the form of snow. The mm/hr increases in precipitation caused by silver iodide seeding have been documented several times in the reviewed scientific literature between 1988 and 1999. The link has been established by physical and chemical techniques. The snow precipitated at particular targeted sites is connected directly to the seeding material and to concurrently released chemical tracers in that snow. The big advantage of snowpack work is that the scientists are dealing with solid-state precipitation that can be sampled during and after storm events and stored in the frozen state until analyzed. The methodologies used to establish this direct linkage have been described by Warburton et al. (1985, 1994, and1995a,b) Super and Heimbach (1992), Chai et al. (1993), Stone and Huggins (1996), Super and Holroyd (1997), and McGurty (1999).

2) A second significant accomplishment in the snowpack augmentation studies provides a chemical explanation for the apparent failure of some larger scale randomized seeding experiments to achieve statistically significant increases in precipitation. Warburton et al. (1995b) have shown that, on the average, only 20% of the snow, which precipitated to the ground during the seeded periods of the Sierra Nevada Truckee-Tahoe project, showed evidence of being impacted by the silver iodide seeding. The results indicate that it would be necessary to produce very substantial changes in the limited areas where seeding material is detected, to yield a statistically acceptable change over the entire snowfall target area. Further studies of this type were conducted by Stone and Warburton (1989) in other Sierra Nevada regions seeded from ground-based aerosol generators.

3) Current physical and chemical evidence for these two significant accomplishments comes from research projects in the northern and southern Sierra Nevada and the Carson and Wasatch ranges of California, Nevada and Utah. Dual-channel microwave radiometers, short wavelength radars, ice-nuclei counters, sulfur hexafluoride gas and combinations of ice nucleating and non ice-nucleating aerosols (silver iodide and indium sesquioxide), have enabled scientists to identify the locations and the quantities of supercooled liquid water in winter storms and to track the seeding aerosols from their points of release to the targeted snowfall sites, as noted above.

4) The locations within winter storm clouds where ice-phase water capture occur have been studied by Warburton and DeFelice (1986) and by Warburton, et al. (1993). These studies and others in the Sierra Nevada and in the Australian Alps showed for the first time that the stable oxygen and hydrogen isotopic composition of ice-phase precipitation are related to the microphysical processes within the clouds in which the precipitation has formed. The work demonstrated that when orography dominated during the post-frontal storm period, the ice-phase water substance was being captured in the clouds between –5ºC and -14ºC with a peak around –11ºC temperature. This type of information has been found very useful in the design of ground-based mountain area seeding projects.

5) Latest state-of-the-art remote sensing systems are a basic requirement for conducting successful snowpack augmentation programs. They can locate and measure in real time the distributions of cloud water and ice as well as wind flow patterns related to seeding aerosol transport. The wind profiler, the dual-channel microwave radiometer and the polarimetric radar have found substantial use in specific snowpack augmentation programs in Nevada, California, Utah and Arizona prior to 1995.

3.2.4 Additional evidence of wintertime cloud seeding effectiveness

There is a broad body of evidence in the literature and in company reports describing the results from various operational projects involving winter orographic clouds. Some projects in California have been in existence from the 1950's and 1960's. The Kings River project in southern California has been operational for 48 years and has produced an average 5.5% additional runoff per year (Henderson, 1986, 2003). An operational project run for the past 25 years or so in Utah has published results for 13 and 19 years of operations that indicate 11-15% increases in seasonal precipitation (Griffith et al., 1991; Griffith et al, 1997). Add to these results the San Joaquin River project showing at a minimum 8% increase in target area seasonal precipitation using trace chemistry studies of snowpack (McGurty, 1999), the Climax project indications of 10% increases, and the Tasmanian results of 10% increases in seasonal precipitation when storm cloud top temperatures are in the range of -10ºC to -12ºC and the evidence becomes very convincing that cloud seeding conducted under proper conditions increases precipitation in winter orographic situations. These findings and statements are in accord with the American Meteorological Society policy statement on weather modification regarding capabilities of winter orographic cloud seeding (AMS, 1998).

Most of the evaluations have utilized target-control regression techniques or snowcourse water content and precipitation storage data. Most of the evaluations of long-duration projects have provided evidence of increases in streamflow amounting to 5 to 10 percent of the natural flow (NRC 1966, 1973). More recent evaluations using precipitation or snow water content information have shown increases in the 10-15% range (Griffith et al., 1991). Conversion of these increases in precipitation into streamflow indicates increases in streamflow on the order of 10% (Stauffer, 2001). The consistency of results is encouraging.

Statisticians have questioned the validity of p-values obtained from sets of non-randomized data. Of particular concern is the fact that the seeded and non-seeded cases are drawn from different historical periods, instead of being interspersed in a random fashion. Gabriel and Petrondas (1983) have investigated this point with actual rainfall data, and confirmed that p-values from evaluations of non-randomized projects need to be adjusted for such effects, but not to the extent that the analyses are rendered invalid. Considering the hundreds of project-seasons of data that are now available, it appears that the latest NRC report should have confirmed, and even extended, the encouraging conclusions presented in previous reviews, rather than retreat to the position that it is premature to conduct operational projects.

3.2.5 Primary concerns in winter orographic programs

(a) Transport and Dispersion: One of the most significant uncertainties in larger scale seeding projects is the transport and dispersion of the seeding aerosols across the project areas. Results from several studies have revealed that most of the precipitation falling in the targets during seeded periods has not been impacted by the seeding process, assuming that the absence of the seeding chemical in the snowfall can be used for making such a deduction. New fully automated ground-based generators can be located in often not very accessible locations in the higher terrain of mountains thus reducing the problems of getting seeding materials into targets. Trace gases can also be used to track the seeding material through the target and if it occurs through the control areas.

(b) Remote Sensing: Although the wind profiler, the dual-channel microwave radiometer and the polarimetric radar and other short wavelength radars have found substantial use in specific snowpack programs prior to 1995, it is unfortunate that very few of these devices are available to the scientific or weather modification community outside of government agencies. There is a great need for resources and actual construction of such apparatus for new scientific research efforts.

(c) Statistical Analysis Methods: Because of the opportunity to shift the design of larger-scale seeding experiments to the use of physical and chemical assessment methods and to continue to satisfy the requirement of unbiased randomization, there is now a special need for new statistical approaches that are coupled with physical observations enabling comparisons to be made between those portions of the snowpack which have been impacted by the seeding during a seeding period and those which have not. For example, can snow samples that contain no seeding materials be considered as a "no-seed" comparison set?

(d) Trace Chemical Facilities: It will be essential to ensure that adequate trace chemical laboratories are available for analyzing the snowfall for silver, indium, cesium and other tracer materials used in these snowpack augmentation studies. A few such laboratories do exist in the U.S. most of which have not been involved in weather modification.

(e) Environmental Impacts of Cloud Seeding Programs: Nearly all orographic weather modification programs in the western U.S. involve public lands. All agencies both governmental and private that engage in these weather modification programs are confronted from time to time by concerned citizens and environmental groups with questions about the environmental impacts of weather modification and the chemicals used in these programs. In cases where seeding aerosol generators are to be located on public lands, the land manager (e.g., U.S. Forest Service) is required to issue an environmental assessment and negative declaration prior to issuing special use permits for generator sites. Public agencies such as municipal utility districts, and state water agencies are often required to issue environmental assessment, environmental impact statements and declarations of negative impacts, to meet governing charters and law. These environmentally driven requirements involve much time and resources. Thus research on environmental impacts of weather modification programs and seeding agents is also a definite need. The development of a programmatic approach in this area could be very beneficial.

(f) Seeding Agent Chemistry and Improvements in Delivery Systems: Modern formulations of seeding chemicals can start producing significant numbers (10^{12} particles per gram of active agent) of effective ice nucleation at temperatures colder than about -4ºC. However, winter orographic clouds in much of the western U.S. have significant amounts of time when there is SLW at temperatures in the 0ºC to – 4ºC range. Can improvements be made in the seeding chemistry to achieve effective ice nucleation at these warmer temperatures? Ground-based seeding aerosol generator designs have been improving in recent years toward more reliable remote operation. Optimization of atomization, flame temperatures, flow volumes, power consumption and data telemetry are areas recommended for continuing improvements.

3.2.6 Watershed experiment

The BASC Workshop report (BASC, 2001) included a strong recommendation that a "Watershed Experiment" be conducted in the mountainous West using all of the available technology and equipment which can be brought to bear on a particular region which is water short and politically visible from this water-short viewpoint. The NRC report did not include this recommendation, but this response re-introduces this recommendation. The "Watershed-sized Project" should be designed to demonstrate that snowfall could be augmented over a watershed using scientifically acceptable statistical and physical measurement strategies. The methodology should include following the hypothesized "chain-of-events" using airborne and remote sensing technologies. Model forecasts and remote sensors should be used to determine optimum positioning of ground-based generators and the optimum times for their operation. The investigations should include evaluations of snowpack melting, run-off, stream flow and recharge of ground water aquifers. In addition, it should include environmental impact studies within the region, including water quality, stream flow standards and protection of endangered species, while at the same time satisfying the overall water requirements of the inhabitants of the watershed such as Native Americans, ranchers, farmers, residents of local townships and industry.

There are several western states watersheds that are worthy of consideration for such a program. One of these would encompass portions of the McCloud River and Pit River basins of northern California. This watershed covers approximately 800 square miles, offers high elevation terrain extending from Mt Shasta (14,000 ft. elevation) eastward for approximately 40 miles, by southward approximately 20 miles, and produces more than 1 million acre-ft of water annually. This area is relatively isolated from other weather modification programs. Pacific Gas and Electric (PG&E) is considering implementing a weather modification program in this region. PG&E calls this "The Upper McCloud and Lower Pit River Aquifer Recharge Program", and the intent would be to maintain and increase long-term hydrostatic pressure in the aquifers, which supply sustained base flows that continue into and through California's frequent dry years. Potential direct beneficiaries of a program in this basin include the 4 million electric customers of Pacific Gas and Electric (PG&E) Company, and the 32 million citizens of California (McCloud-Pit Rivers are main tributaries that feed USBR's Lake Shasta and this is one of the largest water supplies for agriculture and public uses in California). Such a research program could potentially leverage financial resources and technical expertise from PG&E, from the state of California, from the USBR, and from Atmospheric Sciences departments at a number of universities in California, Nevada and Oregon

A second candidate for the watershed study is the Walker Rivers catchment areas of the Sierra Nevada. This would also be an excellent choice for such a watershed experiment, having a catchment area of 1200 square miles at elevations above the snowline of 6000 ft. They contain two principal rivers feeding substantial ranching and farming activities, three townships, and terminating in a desert lake downstream of an Indian reservation.

The McCloud-Pit and Walker watershed candidates are offered here as examples and not as the final candidate list. Other suitable watersheds exist in western states, including Utah, Colorado and Idaho. An ultimate selection would be determined based on many factors, including proximity to nearby projects, that matrix toward achieving a program of greatest value.

This review panel recommends that a “Watershed Experiment”, fully randomized and well equipped, be conducted in one of these regions of the mountainous, water-threatened West, because it will benefit substantial segments of the community, including Native Americans, urban water users, ranching, and farming communities, and recreation interests.

3.3 Summer operational programs

The NRC report (p 68) touts the potential for hygroscopic seeding of warm season convective clouds, and encourages further investigations in this area. While we agree that considerable potential does exist for hygroscopic seeding, we do not agree with the NRC finding regarding glaciogenic seeding that there “ is recognition of the lack of credible scientific evidence that applying these concepts will lead to predictable, detectable, and verifiable results.” There are many situations in which hygroscopic seeding is not feasible, and we believe that glaciogenic seeding still has much to offer, even though more complete evidence of cause and effect is desirable.

Progress has been made. For example, the initial objective of weather modification research work in Texas focused on formulating a conceptual model for rain enhancement. The High Plains Experiment (HIPLEX) sponsored by the U.S. Bureau of Reclamation, and based in Big Spring from 1975-1980, led to the identification of experimental units, seeding hypotheses, covariates, and response variables for subsequent fieldwork conducted a decade later as part of the NOAA Atmospheric Modification Program (AMP), discussed below. The Texas HIPLEX led to the conclusion that seeding for dynamic effects may have substantial impact on convective cloud clusters, deemed to be the most favorable candidates for the “experimental units” in subsequent exploratory research (Riggio et al., 1984). While precipitation is often initiated in west Texas clouds through the warm rain process, the ice phase was observed to dominate during much of the subsequent cloud development, with the rapid development of greater ice particle concentrations being a consequence of an active ice multiplication process. With radar observations of merging cloud echoes, particularly clusters, suggesting an interaction between individual convective towers with the mesoscale systems, it was deduced that additional cloud growth could be facilitated through the seeding of turret clusters.

Additional field work, consisting of the collection of 34 experimental units over a number of weeks during four summers in the latter half of the 1980s, led to refinement of the seeding conceptual model. Randomization of the seeding allowed comparisons to be made between the behavior of treated and unseeded convective systems using C-band weather radar. Results of the analyses indicated seeding with silver iodide more than doubled the amount of rain volume produced by the clouds (Rosenfeld and Woodley, 1989). Moreover, the seeded systems lived on average 36 percent longer than their untreated counterparts, expanded to produce rainwater over an area 43 percent larger, and tended to merge with adjacent convective cells nearly twice as often. Intriguingly, the seeded clouds grew only marginally taller (about 7 percent) than the unseeded ones. (Both rainfall and merger statistics were significant at better than the 5 percent significance level.) These results confirm earlier results from the Dakotas (Dennis et al., 1975) that show broader and longer lasting echoes from the seeded cells in that region. In addition, the extra growth in height in the seeded clouds was an average 600 m, or less than 10% of the cloud depth. These last authors commented on the fact that both dynamical and microphysical changes appeared to be important in producing the increases in rainfall from the seeded cells.

With a new conceptual model suggesting seeding for dynamic effect can also produce a substantial increase in rainfall without causing a sizeable increase in the maximum height of the seeded cloud (Rosenfeld and Woodley, 1993), further research in Texas in the 1990s documented the physical processes operative within the vigorous supercooled convective towers at the time of treatment with glaciogenic material. In addition to finding that the internal cloud structure is strongly dependent upon cloud base temperature, evidence was produced strongly suggesting seeding works well in clouds having an abundance of supercooled water, especially where such water in a vigorous, supercooled updraft region is available for artificial nucleants having a greater cross-sectional area for accretion of cloud water (Rosenfeld and Woodley, 1997). It was also observed that the time to reduce the maximum amount of cloud water in seeded convective towers to half of its initial value was lessened by some 2 to 3 minutes from that in the unseeded cases.

Additional exploratory research in the Montana HIPLEX (1975-1980), and later in North Dakota (1987-1993) further examined the precipitation processes in cumuliform clouds. In the North Dakota work, many of the new technologies cited in the NRC report were applied. In addition to the tracer techniques cited in the brief review of the NOAA Atmospheric Modification Program (AMP) elsewhere in this response, the North Dakota researchers used dual-channel microwave radiometers, in situ cloud microphysical measurements, including within hailstorms themselves (Detwiler et al., 1994a, b), and numerical cloud models. Some of the modeling was done in real-time, for predictive purposes, much else was done *post hoc*, to gain a better understanding of the observations made, and to allow further improvements to the models. These modeling efforts are also discussed elsewhere within this response.

Our point here is two-fold. First, contrary to the implications of the NRC report, there has been quality research in conjunctions with ongoing operational programs published in the refereed literature. Secondly, the research ceased only when federal involvement at a significant scale ended. We wholeheartedly endorse the NRC recommendation that a renewed long-term research effort be undertaken, and agree that a number of critical issues remain to be fully answered.

We also maintain that coupling physical experiments with ongoing operational programs for exploratory experiments would be a productive, cost-effective approach to answering many of the questions posed in the NRC report. We acknowledge, however, that only conducting randomization apart from existing operational programs will afford the strength of statistical design necessary for confirmatory experiments.

3.4 Cloud modeling of cloud seeding effects

This has been a continuing effort conducted by a few cloud modeling groups over the past thirty years. Simulations of many types of cloud seeding experiments have been accomplished. Much of the work depended on simplifications of the microphysics and of the dynamics, but even so basic effects were evident that will likely stand the test of more sophisticated treatments suggested in the NRC report. Some of the findings are listed below.

The NRC report failed to critically review the development of cloud models over the past 20 to 30 years, with respect to cloud seeding simulations, and with respect to natural cloud precipitation simulations. No NRC committee member was particularly active in the modeling field, except in the dynamics of clouds. The report concentrated on the future use of complex microphysical and three-dimensional, time-dependent research cloud models that in general are of little use in operations now. They failed to evaluate what has been developed and what could be applied with current computer power and model capabilities on operational projects.

Bulk-water microphysical techniques were used in most of the cloud models in the early days and are currently being used in large-scale weather prediction models. This process, assumes zero terminal velocity for the cloud water and cloud ice, relatively small terminal velocities for snow content, modest values for rain, and the largest vertical velocities for graupel and hail. The velocities vary with the quantity of precipitation content at a grid point. Such a framework allows for the production of rain from cloud water, the formation of cloud ice at appropriate observed temperatures, the production of snow from supercooled water and cloud ice or the depositional growth of cloud ice, and the production of graupel/hail from frozen rain (via probabilistic freezing) or interactions between the liquid and ice contents. If rain does not form from cloud liquid (as is the case in many higher latitude clouds) then it forms later in the lifetime of the cloud through melting of ice particles. The growth of the graupel/hail considers both wet and dry growth processes. Nearly thirty interactive processes among the various water processes (such as accretion, collection, aggregation, etc.) are simulated. The paper by Lin et al. (1983) describes the early development that is the basis for many of the models.

It has become more common in recent years for bulk microphysics schemes to predict two moments such as hydrometeor mixing ratio and concentration (Ferrier et al., 1995; Meyers et al., 1997; Reisner et al., 1998). A somewhat different paradigm is to emulate an explicit bin model by prescribing basis functions for the drop size distributions such as gamma or log-normal distributions (Clark, 1976; Clark and Hall, 1983) and explicitly predict the evolution of those basis functions by vapor deposition/evaporation, stochastic coalescence, and sedimentation. Tzivion et al. (1994) predict three parameters that fully define the basis functions: mixing ratio, number concentration, and a third moment. Milbrandt and Yau (2004) have implemented such a model for application to hailstorm simulations. This model does a much better job of representing hail processes than the earlier bulk-water microphysical methods without the expense of a full-bin-resolving model and can readily be implemented in three-dimensional storm models.

To better model the precipitating ice, Farley developed a hybrid method that utilizes twenty categories (now twenty-one), or bins, for these particles. The sizes range in diameter from 100 μm to 5.0 cm (recently increased to 7.0 cm by adding the extra bin). Bulk-water microphysical methods are used for the cloud liquid, cloud ice and rain fields, hence the hybrid terminology. The dynamic framework for the microphysics has been a two-dimensional, time-dependent cloud model and a three-dimensional, time-dependent, cloud-resolving mesoscale model developed by Clark (1977, 1979), Clark and Farley (1984) and Clark and Hall (1991). The IAS two-dimensional framework has been used to simulate hail formation and fallout in an Alberta hailstorm (Farley, 1987) in both seeded and unseeded conditions, and in a North Dakota hailstorm (Farley et al., 1996, 2004a,b). Good agreement with radar observations was obtained in the Alberta and North Dakota hailstorms. This model framework allows the type of hailstone embryos, either frozen raindrop or graupel, to be identified (Kubesh et al., 1988). A critical component of the Kubesh study was the data provided by the armored T-28 aircraft involving particles types and sizes inside the strong updrafts of a supercell storm. Both model and observations indicated the importance of shedding from graupel and hail particles to produce rain for fallout and for hailstone embryos in the rich supercooled liquid water environment.

In addition, the three-dimensional Clark model has been used to simulate snow and rainfall over the Black Hills of South Dakota and Wyoming (Farley et al., 2000) during a four-day storm period. Simulation of the cold precipitation period produced reasonably accurate precipitation patterns, but not as accurate for the warmer, weakly forced situation. This last result indicated that a simulation of a drizzle process should improve the rainfall comparisons, as was also called for in the NRC report. A simulation of ground-generator cloud seeding of the storm system was reported in Farley et al. (1997), which showed that the cloud seeding was effective on only one of the four days. Other orographic simulations of precipitation formation and the effects of cloud seeding are found in Meyers et al. (1992, 1995).

Some success has also been obtained in the three-dimensional modeling of convective clouds and storms. The 3D cloud-resolving model of Clark (with the bin ice microphysics of Farley) has been used to simulate hailfall in northern Italy (Wobruck et al., 2000) and in southern France (Wobruck et al., 2003). This last study showed good agreement with observations of the hailstone spectrum at the ground. Johnson et al., (1993) simulated the 2 August 1981 CCOPE supercell with both liquid water microphysics (LWM) only and with a hail category version (HCM) of the model (similar to the hail formulation of Farley). The ice microphysics was shown to be important for the better comparison with the actual storm, but the LWM simulation reproduced some of the important dynamics of the supercell storm. The T-28 armored aircraft provided critical information from inside the storm that was used for the comparisons. Farley et al. (1992) used the 3D Clark model with bulk-water microphysics to simulate a moderate size rain shower in the CCOPE field study. Several characteristics of the actual storm were captured in the simulation.

A three-dimensional framework is preferable, but sometimes not practical. The two-dimensional cloud models have been tested in several WMO workshops (WMO, 1985, 1988, 1994) and reported in the literature (Tuttle et al., 1989; Helsdon and Farley, 1987a; Hjelmfelt et al., 1989). The models simulated satisfactorily many of the characteristics of cloud and storm systems, including the development of realistic radar signatures and the production of microbursts. Their greatest disadvantage is the too rapid development of rain from coalescence of the cloud water in the bulk-water models. (This is more of a concern in weaker cloud situations than in strong, convective continental type clouds where the ice processes dominate and rain forms predominantly from the melting of graupel or hail.) Their advantage over one-dimensional models is that they simulate realistic airflows and water contents to produce reasonable simulations of rain or hail in the cloud and fallout at the ground. They can and have been used in real-time forecasting to analyze the potential of an atmospheric sounding to support the production of precipitation (Tuttle et al., 1989; Kopp and Orville, 1994). This was done during the NDTP in 1989, and to a lesser extent in the NDTE in 1993.

Separate from these microphysical discussions is the fact that the cloud modeling of the past two to three decades has indicated the importance of including the effects of larger scale convergence and the heating and evaporation at the earth's surface in the simulations (Chen and Orville, 1980). Observations and modeling results indicate that convergence or divergence values of order 10^{-5} s^{-1} may affect significantly the degree of cloud development and should be included in models trying to predict or simulate real clouds. The convergence has an effect on the frequency of cloud merger. Similarly, the inclusion of reasonable heating and evaporation rates at the ground can be very important to the amount of rainfall predicted. Thus there are many things in addition to the microphysics that should be considered to produce realistic predictions and simulations of clouds and storm systems.

Atmospheric electricity modeling. The NRC report speculated about the possible influence of atmospheric electricity in natural precipitation and in cloud seeding results. Helsdon and Farley (1987b) published the first simulation, including atmospheric electricity effects, of a cloud that produced lightning. Further work has advanced to simulations in the 3D Clark/Farley model that include the actual simulation of the lightning flashes in the storms and more refined atmospheric electricity modeling (Helsdon et al., 1992, 2001, 2002; Zhang, et al., 2003). The models are too complicated for real-time application in cloud seeding operations at this time. Bulk-water microphysics has been used to develop the theory.

Following are some of the findings and predictions from cloud models employing realistic cloud seeding and storm simulations. Background material for most of the statements can be found in Orville (1996) and in the references listed therein.

Convective-type Clouds (cumulus congestus to cumulonimbus)

a) Dynamic seeding effects have been simulated, primarily the increased updrafts associated with the freezing of supercooled liquid water. Of particular importance here was the demonstration that near instantaneous freezing of the supercooled water was not possible (but had been used in the one-dimensional, steady-state cloud models). Much of the latent heat of freezing is released over the period of a few minutes by the accretion of the supercooled water by larger ice particles.

b) Microphysical or "static" seeding effects have also been simulated; they show an effect on the cloud and environmental airflow and emphasize that static seeding has dynamic effects. The primary effect here is the early fallout of the seeded precipitation and the generation of new cloud cells. Downdrafts in the cloud and in the subcloud layer are affected.

c) The interactions of the precipitation with the internal circulations of the seeded cloud and the environmental airflow are often crucial to the total precipitation from a cloud and cloud system.

d) Greater seeding effects occur in moderate size convective clouds (cloud depths in the 3 to 7 km range, tops -10º C to -25ºC). The one-dimensional cloud models have been key in demonstrating this feature. Field studies in Cuba and in Texas have also shown such effects (Koloskov et al., 1996; Rosenfeld and Woodley, 1993).

Stratiform-type Clouds (often orographic clouds)

e) "Dry" as well as "wet" clouds may respond to dynamic seeding, yielding more vigorous circulations in the cloud and greater precipitation on the ground. This is caused by the transformation of the heavily seeded cloud region to saturation with respect to ice instead of saturation with respect to liquid water (Orville et al., 1984, 1987). The production of embedded cells in orographic upslope airflow may be caused in some instances by these effects.

f) The "Goldie-locks" effect is evident, i.e., some conditions are too warm, some too cold, and some just right for ice-phase seeding to be effective.

g) Transport of the seeding material to proper parts of the clouds may not be possible in some situations, but may be predictable by cloud-resolving mesoscale models that include conservation equations for the seeding agent.

Hailstorms

h) Hailstone spectra within the storm are being simulated and the effects of seeding modeled. Observations of hailfall at the ground appear reasonably similar to that predicted in an unseeded case.

i) Hailstorm cells with an active coalescence process react more positively to ice-phase seeding than do more continental-type cloud cells, in some situations.

j) The location of favorable regions for hail embryos that produce the larger hail can be identified.

k) The type of embryo, rather frozen rain or graupel, can be identified, and the proportion of each that are used to produce hailstones.

l) The importance of shedding from graupel and hail to produce rain is demonstrated.

General Results

m) Seeding agents (such as silver iodide and hygroscopic material) and dry ice seeding have been simulated in cloud models. Conservation equations need to be used for the seeding methods instead of making arbitrary decisions as to when and where to change the ice crystal concentrations.

n) The seeding material generally affects only restricted portions of the clouds.

o) Hygroscopic seeding affects the coalescence process, and accelerates the glaciation of the cloud. Consequently, hygroscopic seeding has the very real possibility of providing both warm rain and cold rain modification effects.

p) Redistribution of the precipitation occurs in some of the seeding simulations. Whether this occurs or persists over the duration of a field project needs to be determined by observations and additional mesoscale simulations.

q) The amount of precipitation simulated or predicted by cloud models depends sometimes on the proper amount of larger scale convergence and/or surface heating and evaporation prescribed in the models, which can be obtained by observations.

r) Cloud particle initiation processes, although extremely small in magnitude, need to be retained in the model microphysical equations. Otherwise, the critical paths to precipitation (either liquid or ice) will not be captured correctly.

These results have come from cloud models of varying complexity. The grid resolution is relatively fine, normally 100 to a few hundred meters. Bulk-water microphysics is used to produce most of the results, although bin microphysics is being used for the precipitating ice in the hail models (and is necessary for the prediction of cloud seeding effects on hail spectra). Such models could be used to help in operational cloud seeding projects, identifying those days that might be more susceptible to cloud seeding attempts. Moderate computing power could provide near real-time results. The NRC report is short on a discussion of possible modeling support for operational projects.

The NRC report emphasizes the use of bin microphysics in three-dimensional, time-dependent cloud and mesoscale models. The report takes little note of the development of simpler models and simpler domains. The fact that there are unknown parameters in the bin models means that there are possibly hundreds of interactions that will be affected. This argues for the development of bulk-water microphysical models that have far fewer unknown parameters. The bin-microphysical models will be very useful in developing the best parameterizations for the bulk-water microphysical models. Climate change theory would have progressed very slowly if only the most complete and complex models had been accepted. Every thing from one-dimensional to three-dimensional models has been used. The same needs to be done in weather modification, and particularly in the support of operational projects.

4. ADDITIONAL TOPICS AND OTHER MODIFICATIONS TO THE NRC REPORT

4.1 <u>The NOAA Atmospheric Modification Program</u>

The NRC report stated that very little research had been done on operational programs. From 1986 through 1995, the NOAA Federal-State Atmospheric Modification Program (AMP) funded weather modification research, first in Illinois, Nevada, North Dakota, and Utah, and in the latter years, also Arizona and Texas. This funding, on average about $500K per year per state (2 to 3 million dollars per year), was used to bring research components to ongoing operational cloud seeding programs in these states. Federal funds were never used to conduct any actual seeding, but allowed radars, radiometers, instrumented aircraft, and other physical and scientific (human) resources to be focused on those issues deemed to be of greatest concern. Three of the states, North Dakota, Illinois, and Texas, focused their available resources on warm season weather modification research. The other three focused their efforts on wintertime orographic cloud seeding.

The executive summary of the NRC reports notes that, "Advances in observational, computational, and statistical technologies have been made over the past two to three decades that could be applied to weather modification." During the AMP, when funding *was* available, many of these technologies *were* brought to bear. North Dakota was able, with NOAA and NSF support, to field two significant field programs. The first, in 1989, was the North Dakota Thunderstorm Project (NDTP), and included the deployment of NCAR CP-3 and CP-4 C-band Doppler radars, the NOAA-ETL X-band circular-polarized Doppler radar, and instrumented aircraft from the University of North Dakota, the University of Wyoming, the South Dakota School of Mines and Technology, and the NCAR Sabreliner (Boe et al., 1992). A NOAA WP-3D "Hurricane Hunter", and a tracer release aircraft provided by Weather Modification, Inc. augmented these aircraft. A similar but smaller scale program was conducted in 1993 (Boe, 1994), the North Dakota Tracer Experiment (NDTE, referenced only briefly by the NRC report).

Both of these programs utilized Doppler radars, in situ cloud sampling, numerical modeling (see Section 3.4), and atmospheric tracers (chaff and sulfur hexafluoride) to study the transport and dispersion with actively growing convective cloud turrets, and established unambiguous linkages between seeding with glaciogenic agents and the subsequent cloud glaciation (e.g. Detwiler et al., 1994a,b; Huston et al., 1991; Martner et al., 1992; Reinking and Martner, 1996; Stith et al., 1996; Stith et al., 1993; and Stith et al., 1990). Figure 4.3 of the NRC report is from this research in North Dakota (Reinking and Martner, 1996), but the NRC report does not acknowledge it as having been weather modification research. This is not to say that this work is completed; to the contrary, only the first steps have been taken.

The other states experienced similar successes. Some of the initial funding obtained under this program was used to build two new dual wavelength microwave radiometers and one short wavelength radar for use in the research programs in Utah, and Nevada. These research funds were also partly used for upgrading the trace chemical analysis facilities in Nevada. The research results obtained from these financial expenditures are described in a substantial number of publications listed at the end of the sections of this critique describing the research activities on snowpack augmentation orographic programs in Utah, Nevada and California.

The breadth of the various research efforts and list of all resulting publications is far too lengthy to include here. All of the programs utilizing these new tools were studying operations or processes directly related to operations, so the NRC report assertion that little research has been done on operational programs in recent years is less than accurate, except perhaps for the period since the AMP was terminated in the later 1990s. It is worth noting that papers from AMP era field efforts are still being published; e.g., Farley et al. (2004a, b).

Funding for the AMP was terminated along with many other programs in the NOAA budget after changes in congressional leadership following the 1994 elections. Some federal funding has been re-established in 2003 and is being administered by the USBR.

4.2 Other items

The NRC panel provided an excellent summary of existing technology that can be applied to the measurements of clouds. They described several in situ measuring devices for cloud particles, updraft velocities, water contents and other devices, but then failed to note that the observations normally require in-flight penetrations of the clouds and storms. The discussion and references above show the valuable observations acquired by the armored T-28 aircraft. Certainly, that type of capability should be maintained in the future to make the critical measurements needed in both seeded and natural cloud environments.

The NRC panel missed an opportunity to support an example of innovative evaluation of an operational project. The Woodley-Rosenfeld radar evaluation of a Texas program is being published soon (Woodley and Rosenfeld, 2004), but was available earlier to the panel. The technique uses radar estimates of rainfall (checked against rain gauges) in both target and surrounding area to estimate the cloud seeding effect in the target areas. Selection of control cases is done entirely objectively. The apparent effect of seeding was very large. The most conservative and credible estimates of seeding effects were obtained from control matches drawn from outside the operational target within two hours of the time that each unit was seeded initially. Under those circumstances, the percentage increase exceeded 50% and the volumetric increment was greater than 3000 acre-feet (3700 kilotons) per target unit. It is regrettable that several lay persons and two meteorologists (neither with any cloud seeding experience) were able to convince the public that the drought conditions they had been experiencing were due to negative cloud seeding effects and to close that project for the remainder of the 2002 season and in 2003.

The NRC panel should have recognized that much of the work they recommend could be helped by the conscious use of cloud seeding agents, but instead they advised researchers to stay away from applications. When researchers have agents that can change the microstructure of clouds, the use of them during research projects can indicate whether they understand the natural processes.

We are concerned with the NRC's procedure in the course of such a difficult review process. Only two of the nine committee members had extensive weather modification experience, none in hail suppression. Some had excellent backgrounds in technologies used in weather modification. The committee cited the extent of their interaction with the "community" and listed those participating in one of the report appendices. A few of us on this WMA committee were listed in that community. Our personal experience and those of at least one other modeler listed is that, in some instances, the contact was of the briefest kind, perhaps a phone call to obtain a reference or a passing conversation in the hall at work. Consequently, the appearance of broad community participation in the NRC report is exaggerated.

4.3 Additional WMA perspectives on cloud seeding technology

Despite the difficulty in objectively quantifying the absolute values of seeding effects, the large body of positive indications reported by many (see, for example, Todd and Howell (1985)) and other references in this report, and a multitude of analyses in the literature constitute a collective positive signal. Objective consideration of the entire body of evidence, ranging from *a-posteriori* analyses in operational project reports to carefully designed and conducted research-oriented operations and analyses leads us to the conclusion that cloud seeding, when properly conducted, can, in appropriate atmospheric conditions, have a positive effect on precipitation. This position is supported by one of the observations of the NRC report noting an increase in operational cloud seeding programs in many parts of the world in recent years with a dramatic decrease in research funding for such programs. However, we would recommend that research be strengthened to help evaluate and optimize the operational programs.

The sponsorship decision to support an operational cloud seeding program can perhaps best be viewed as a risk management assessment. What is the risk of making the wrong decision weighed against the potential benefit/cost ratio? Numerous studies have demonstrated that a 10-15% increase in precipitation can provide sizable benefits to a variety of beneficiaries (irrigated agriculture, hydroelectric production, municipal water supplies) at very favorable benefit cost ratios of 5-10/1 or higher. For example, if a potential sponsor of a cloud seeding program, following careful deliberation, decided they had an 80% likelihood of obtaining a 10% increase in precipitation that would yield a benefit/cost ratio of 10/1, they would probably chose to support the program.

The other part of the dynamic driving the increase in operational programs, especially those involving precipitation enhancement, is related to increasing populations and either stable or declining (pollution, drought, depletion of ground water, etc.) water supplies. This factor, coupled with the relative ease with which cloud seeding programs can be designed, implemented and operated and stopped without long term commitments and large capital investments make cloud seeding a very attractive alternative for water managers to consider. In addition, existing storage facilities, pipelines, and canals can be used to store and distribute additional water produced through cloud seeding at little or no additional cost.

Given that the number of operational programs will likely continue to increase with time we urge that modern advancements in equipment and seeding strategies be used on operational projects and that independent evaluations be performed, whenever possible.

Additional information on the capabilities of planned weather modification technology can be found at WMA's website:
http://www.weathermodification.org/.

5. CONCLUSIONS AND RECOMMENDATIONS

The WMA has responded to the NRC report concerning issues having operational impact or scientific consequences on operational projects. The

WMA strongly supports the NRC's recommendation to establish critical randomized, statistical experiments along with the necessary physical measurements and modeling support to reduce the many uncertainties that exist in the science of weather modification.

The NRC panel conclusion that there was no convincing scientific proof that cloud seeding has worked (with a few exceptions), applied a definition of scientific proof that few atmospheric problems could satisfy. On the other hand, the NRC panel concluded, "there is ample evidence that inadvertent weather and global climate modification (e.g., Greenhouse gases affecting global temperatures and anthropogenic aerosols affecting cloud properties) is a reality". Differing levels of proof have been applied by NRC panel to planned weather modification versus global climate change and inadvertent weather modification. A "higher bar" criterion was applied to planned weather modification.

The NRC panel cited a much earlier NRC report (NRC, 1964) and concluded that the initiation of large-scale operational weather modification would be premature. We think that it is inappropriate for a national academy panel, with very limited operational weather modification experience, to make such a judgment. Citation of the very dated 1964 report suggests that little has changed since that time. The NRC panel notes operational programs in 24 countries and at least 66 large-scale operational weather modification programs in the U.S. The WMA believes large-scale operational programs have produced and continue to produce positive effects for society. The WMA does not agree with the NRC suggestion that implementation of large-scale operational programs would be premature. WMA's response details many examples of successful operational programs, and provides information on the myriad of technological advances that have been made, but that were largely neglected by the current NRC report.

This WMA report has added information on hail suppression, winter orographic cloud seeding, summer operational programs, and cloud modeling of cloud seeding effects to fill in for gaps and weaknesses in the NRC report. A few other topics are also commented upon. We support many of the recommendations of the NRC panel, but add several of our own as follows:

- We support the NRC recommendation that there be a renewed commitment to advancing our knowledge of fundamental processes that are central to the issues of intentional and inadvertent weather modification.

- We support the NRC recommendation that a coordinated national program be developed to conduct a sustained research effort in the areas of cloud and precipitation physics, cloud dynamics, cloud modeling, laboratory studies, and field measurements designed to reduce the key uncertainties that impede progress and understanding of intentional and inadvertent weather modification. *But, we argue that the coordinated national program should also support exploratory and confirmatory field studies of in weather modification. It should capitalize on operational cloud seeding programs, and use them as a basis for testing models, and developing new statistical methods for the evaluating the efficacy of those operations.*

- We support the NRC conclusion that a coordinated research program should capitalize on new remote and in situ observational tools to carry out exploratory and confirmatory experiments in a variety of cloud and storm systems

- The BASC 2001 workshop report recommended that a "Watershed Experiment" be conducted in the mountainous West using all of the available technology and equipment that can be brought to bear on a particular region which is water short and politically visible from a water resource management perspective. We strongly support this earlier recommendation that was not in the NRC report. Such a "Watershed Experiment" should be fully randomized and well equipped, and be conducted in the region of the mountainous West of the U.S. where enhanced precipitation will benefit substantial segments of the community, including enhancing water supplies in over-subscribed major water basins, urban areas, and Native American communities, for ranching and farming operations, and for recreation. This research should include "chain-of-events" investigations using airborne and remote sensing technologies, along with trace chemistry analysis of snowfall from the target area. Model simulations should be used to determine optimum positioning and times of operation for ground-based and aircraft seeding. The work should include evaluations of precipitation, run-off, and recharge of ground water aquifers. Also, it should include environmental impact studies including water quality, hazard evaluations such as avalanches, stream flow standards and protection of endangered species. Research is also recommended on seeding chemical formulations to improve efficiencies and on improving technology used in seeding aerosol delivery systems.

- We recommend the application of existing and newly developed numerical models that explicitly predict transport and dispersion of cloud seeding agents and activation of cloud condensation nuclei, giant cloud condensation nuclei, and ice nuclei, as well as condensation/evaporation and collection processes in detail, to the simulation of modification of clouds. We concur with the need to improve and refine models of cloud processes, but existing models can be used as a first step to examine, for example, the possible physical responses to hygroscopic seeding that occur several hours following the cessation of seeding. In addition, existing models can be used to replicate the transport and dispersion of ground-based and aircraft-released seeding agents and the cloud and precipitation responses to those seeding materials in winter orographic clouds. Existing models can also simulate static and dynamic seeding concepts for fields of supercooled convective clouds. Moreover, existing models can be used to improve the efficiency of the operation of weather modification research projects and operational programs, and be deployed in the assessment of those programs.

- We recommend that a wide range of cloud and mesoscale models be applied in weather modification research and operations. This includes various microphysical techniques (both bin and bulk-microphysical models have their uses) and various approaches in the dynamics (all dimensionalities - one, two, and three dimensional models - offer applications). The application of hybrid microphysical models should be especially useful in simulating hailstorms and examining various hypotheses and strategies for hail suppression.

- We recommend that a concerted effort be made in the field and through numerical modeling, which includes simulations of hailstone spectra, to study hailstorms and the evolution of damaging hailstones as well as examine potential impacts of modified hailstone spectra on the severity of storms. Because operational programs regarding hailstorms are currently being conducted in the U. S., we encourage the "piggybacking" of research on such projects. We also encourage active cooperation with international hailstorm projects to elicit data and information concerning suppression concepts and technology.

- We recommend that an instrumented armored-aircraft capability (storm penetration aircraft, or SPA) be maintained in the cloud physics and weather modification community. This is essential for the in situ measurements of severe storm characteristics and for providing a platform for some of the new instruments described in the NRC report.

- We recommend that support be given for the development of innovative ways to evaluate operational cloud seeding projects. This is particularly important for the establishment of the physical basis of various cloud seeding methods and for establishing the possible range of cloud seeding effects.

- We recommend that evaluation techniques presently being applied to operational programs be independently reviewed, and as necessary revised to reduce biases and increase statistical robustness to the extent possible. Recognizing that randomization is not considered to be a viable option for most operational seeding programs, we acknowledge that there is much room for improvement in most present evaluations, many of which are presently done in-house.

- We recognize that much of the cloud seeding conducted today, and likely in the future, is done in situ by aircraft. A limited weather modification pilot training curriculum presently is in place at the University of North Dakota (two semesters). This program should be expanded under the auspices of the national research program to improve the breadth of training provided, emphasizing flight in IMC (instrument meteorological conditions) and including actual hands-on, in-the-cockpit seeding experience. Correct targeting is mission-critical, yet many pilots presently working on operational programs receive only limited training, many not having the benefit of any formal training whatsoever. When pilots are undertrained, project results are likely to suffer. A certification program for pilots by an organization such as the

WMA, which, in addition to formal university instruction might include periodic recertification and/or recurrency training, would significantly improve the overall abilities and capabilities of the operational weather modification pilots.

We encourage the scientific and operational communities in weather modification to cooperate and work together whenever and wherever possible to solve the many problems slowing progress in the field. The future should not involve solely operational programs or research efforts. The two should be coupled whenever possible, to work together toward the many common goals.

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7. APPENDIX COMMITTEE MEMBER BIOGRAPHIES

Mr. Bruce Boe Mr. Boe has worked with clouds, cloud physics, radar, and aircraft since 1974, and has logged hundreds of hours in aircraft studying thunderstorms and winter storms over much of the western U.S. Prior to assuming his present position as Director of Meteorology for Weather Modification, Inc., he was for 12 years Director of the North Dakota Atmospheric Resource Board, a division of the State Water Commission, and previously worked for the University of Wyoming, the U.S. Bureau of Reclamation, and the State of Montana. He is an active member and past president of the Weather Modification Association, presently serving as Association Webmaster. He is a member of the American Meteorological Society, and past chair of the Society's Committee on Planned and Inadvertent Weather Modification. He is an affiliate member of the American Society of Civil Engineering (ASCE). Bruce was Principal Scientist for the State of North Dakota in the National Oceanic and Atmospheric Administration's (NOAA's) Atmospheric Modification Research Program, and coordinated two significant thunderstorm research programs: the North Dakota Thunderstorm Project (1989), and the North Dakota Tracer Experiment (1993).

Mr. George Bomar Mr. Bomar has devoted nearly 30 years in State of Texas service toward the development and implementation of weather modification technologies to enhance the state’s supply of fresh water. With both undergraduate and graduate degrees in meteorology, he has worked for various Texas water agencies, administering the Texas Weather Modification Act. He was instrumental in organizing and supervising cloud-seeding research in Texas during the 1980s and 1990s, including the U. S. Bureau of Reclamation’s Southwest Cooperative Program in weather modification research and the National Oceanic & Atmospheric Administration (NOAA) Atmospheric Modification Program. Mr. Bomar helped construct a statewide rain-enhancement effort in Texas during the 1990s, which has grown from one cloud seeding project in 1994 to ten projects in 2003. The 2003 program, the largest known rain-enhancement effort in the U. S., covers over 51 million acres (or nearly one-third of the land area of the state of Texas). In administering State law governing weather modification operations, Mr. Bomar currently is responsible for licensing and permitting cloud seeding activities. He also oversees the administration of State grants for operational cloud seeding, whose cost in 2003 exceeded $4 million. He also heads up a new, federally funded research program in Texas to document convective cloud processes and test new seeding materials in 2004.

Dr. William R. Cotton Dr. Cotton is a Professor, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado. He joined the staff at CSU in December of 1974. At CSU he has received numerous awards including the Engineering Dean's Council award for excellence in atmospheric research, the College of Engineering Abell Faculty Research Graduate Program support Award, CSU Research Foundation Researcher of the Year Award and the Cermak Distinguished Graduate Advisor Award. He also served on several National Research Council Panels. In 1999 Dr. Cotton was the recipient of the Penn State University College of Earth and Mineral Sciences Charles L. Hosler Alumni Scholar Award. Dr. Cotton served as an editor for the *Journal of the Atmospheric Sciences* from 1993-1995, and as a co-chief editor from 1996-2000. He is a Fellow of the American Meteorological Society and the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University. He has published over 140 papers in peer-reviewed journals, eight chapters in books, authored one book, and co-authored two books. He has supervised over 35 Ph D. and 38 M.S. students.

His weather modification experience includes his doctoral dissertation research, as a team member on the NOAA Florida Area Cumulus Experiment, modeling studies of dynamic seeding and seeding of winter orographic clouds, and as the author of several review papers on weather modification, and co-author of several books reviewing planned and inadvertent weather modification concepts and status.

Mr. Byron L. Marler Mr. Marler has over 30 years of experience in applied meteorology. He is currently employed by Pacific Gas and Electric Company (PG&E) with headquarters in San Francisco and one of the largest service areas in the US. He supervises eight professionals, providing oversight and quality assurance on technical assignments ranging from weather modification operations, climate analyses, operational weather forecasting, air quality impact assessments, in-field measurements programs, and research projects. He is PG&E’s expert on weather modification, having worked on the Lake Almanor and Mokelumme cloud seeding projects in the Sierra Nevada since 1975. He has led PG&E research projects in weather modification technology, including effectiveness evaluations, trace chemistry studies, ice-nuclei generator technology, cloud seeding model development, and snowfall measurement. He has performed design studies for cloud seeding programs for other utility companies and has had experience in the preparation of environmental impact assessment documents for operational cloud seeding programs.

Dr. Harold D. Orville (Chair) Dr. Orville is a Distinguished Professor Emeritus in the Department of Atmospheric Sciences at the South

Dakota School of Mines and Technology. He served two terms as Interim Vice President of the University (1987, 1993) and as Head of the Department for 20 years. Dr. Orville joined the staff of the Institute of Atmospheric Sciences early in 1965. Since that time he has worked on cumulus dynamics and precipitation physics. In 1982, he served his sabbatical year as Leader of the Scientific Planning Group for the Precipitation Enhancement Project, a World Meteorological Organization sponsored activity. He served as a member of the Cloud Physics Committee, the Severe Local Storms Committee, and the Weather Modification Committee (Chairman, twice) of the American Meteorological Society, was elected a Councilor of the Society, and served on its Executive Committee. He was Chairman of the WMO Executive Council Panel of Experts/Committee on Atmospheric Sciences Working Group on the Physics and Chemistry of Clouds and Weather Modification Research from 1991 to 1999. He chaired the BASC committee in late 2000 that reviewed advancements in weather modification over the past 20 years.

Dr. Joseph A. Warburton Dr. Warburton is Executive Director Emeritus of Atmospheric Sciences at the Desert Research Institute, University of Nevada in Reno. His Ph.D is in Physics, the dissertation was "The Role of Particulates in Atmospheric Processes”. He came to the US from Australia to develop the trace chemical techniques for measuring the very low concentrations of cloud-seeding chemicals in precipitation. He has applied these specialized techniques in many of the weather modification projects in the US, Canada, Europe and Australia in studies of hail, rain and snowfall, and has published more than 20 papers on these subjects in the reviewed scientific literature. He has served on several Meteorological Society committees and chaired the Weather Modification Committee of AMS for 2 years. He served on the Editorial Board of the European *Journal of Atmospheric Research* for 10 years and has received all of the top honors and awards of the Weather Modification Association. He has specifically developed the majority of the trace physical and chemical procedures for analyzing atmospheric chemical substances in water at the parts per trillion levels of concentration, as well as isotopic methods for assessing in-cloud regimes where ice phase water capture occurs in the atmosphere. He has conducted large-scale cloud-seeding projects in Australia, Switzerland, Canada and the United States during his 30 years of research in the field of weather modification and provided professional assistance to Saudi Arabia, Iran, China, Taiwan and France in this field.

PROCEEDINGS OF THE JEMEZ Y SANGRE WATER PLANNING COUNCIL CLOUD SEEDING WORKSHOP

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Abstract. A description of the workshop including a summary of each presentation, panel discussion and breakout session. The workshop provided information to a wide variety of attendees who included both potential beneficiaries of cloud seeding and decision makers. Results of cloud seeding projects were presented and the issues related to assessment were discussed. Speakers and attendees addressed the question of how to view cloud seeding in the context of the recent NRC Report. A conclusion was reached to pursue a cloud seeding operational test and organizational structures were created to carry the project forward.

EXECUTIVE SUMMARY

The Jemez y Sangre Regional Water Plan recommended that a workshop be organized to develop partnerships, seek funding for one or more pilot cloud seeding projects, and work with ongoing state initiatives. The Regional Water Plan recognized that the effectiveness of cloud seeding in the Jemez y Sangre area would need to be demonstrated and that operational cloud seeding tests, specially designed for this area, need to be conducted to provide a credible assessment of cloud seeding potential.

A cloud seeding workshop was held, on the 22nd and 23rd of January, 2004, with the following goals:

- Educate the water planning community on the pros and cons of cloud seeding as a means for increasing precipitation
- Determine the level of local support for a cloud seeding pilot project
- Form a coalition to pursue such a pilot project/operational test

Thirteen leading speakers and panel members with local, regional, and international expertise in cloud seeding operations, cloud seeding evaluation, and climate processes were invited to the workshop. In addition to the experts on cloud seeding, personal invitations were sent to a broad group of individuals from the New Mexico Interstate Stream Commission (ISC), water planners and elected officials from local cities and countries, the Pueblos, ranchers and acequias, the ski resorts, environmental organizations, the media, professionals from local industry and academia, and local businesses and organizations with an interest in the topic.

Additionally, a pre-workshop dinner was arranged with the water planners of Santa Fe City and County, Rio Arriba County, and the City of Espanola. Dr. Conrad Keyes' Jemez Mountains cloud seeding program in 1968-1972 was the main topic of discussion at the dinner.

The workshop was open to the public. Our current count of those who participated in the cloud seeding workshop is 84. It is believed that there may have been a few others who attended the workshop without registering. This level of participation clearly shows interest in understanding cloud seeding and using cloud seeding to increase precipitation.

The workshop program was designed to allow for 1) presentation of papers, 2) panel discussions, and 3) breakout sessions. The summaries extracted from the audiotaped sessions reflect that there was essentially unanimous agreement that cloud seeding may have the potential to enhance precipitation and that the potential may be realized in a very cost-effective way. Most participants seemed to agree that the body of evidence presented at the workshop was sufficient to try cloud seeding in the area. A copy of the audiotape can be made available to the interested reader upon request.

The speakers and panelists indicated, from experience gained in ongoing cloud seeding operations elsewhere, that the estimates of enhanced precipitation due to cloud seeding ranged from 10% to 30%. The operational costs involved in cloud seeding ranged from $1 to $10 per acre foot of additional water produced. These experts also indicated that such variability in precipitation augmentation and operational costs need to be expected and may critically depend on several factors, including the nature of the local terrain of the Jemez y Sangre area.

Benefit-to-cost ratios were presented as being an effective way to relate the benefits of cloud seeding to local stakeholders in successfully launching an operational cloud seeding program. However, such estimations are not easy to make for all the beneficiaries of increased precipitation. For example, in farming areas with summer cloud seeding, calculating the benefit to cost ratio in terms of pumping costs saved is straightforward. In the Jemez y Sangre area with diversified water use and, therefore, a wide range in the value of water, such calculations will be more complex.

There was a lot of discussion about the challenges of conducting unbiased and credible evaluations of cloud seeding projects. Some participants stated we currently lack a full understanding of exactly how cloud seeding works while others argued that there does indeed exist a lot of theory and understanding of cloud seeding processes. But just as it is difficult to accurately predict the weather even in a small area and for a short period of time, it is also difficult to translate the theory of cloud seeding into detailed step-by-step predictions of cloud seeding processes. The National Research Council Committee on the Status and Future Directions in U.S Weather Modification Research and Operations recently recommended increased research into weather modification approaches in order to better understand how this technology can be best utilized. The full report, "Critical Issues in Weather Modification Research", is available at:
http://www.nap.edu/books/0309090539/html/.

Additional useful information on this topic is contained in the response of the U.S. Weather Modification Association:
http://www.weathermodification.org/new_page_6.htm.

A lengthy discussion took place on the needed level of confidence in the estimates of enhanced precipitation resulting from cloud seeding. To gain scientific acceptance, one generally needs to show a high level of confidence, 95% or above. In other words, if the confidence level is less than 95%, which is the case in many cloud seeding efforts with confidence levels typically between 80% and 90%, the precipitation enhancement resulting from the seeding efforts has a 10% to 20% chance of being a result of good fortune i.e. it just happened to rain or snow a lot.

One must then ask the question: Is a level of confidence below 95% sufficient to risk private and public funds to attempt to enhance precipitation in the Jemez y Sangre area? What weight should we place on observing a succession of cloud seeding projects with confidence levels in the 80% to 90% range? How should we interpret the occasional cloud seeding project that has failed? Most importantly, are the chances for successful cloud seeding efforts in this area as good as in other areas? It was reported that farmers and ranchers, ski resorts and water boards generally accept levels of certainty less than 95%. It was felt that a lower but still high level of certainty was sufficient to justify moving forward with an operational test of cloud seeding in this area given the upside potential of cloud seeding and the value of such enhanced precipitation.

Given the strong consensus at the workshop for going forward with a cloud seeding project, the participants turned their attention to the practical considerations of how to move forward. A number of committees and groups were recommended to be formed to get a cloud seeding effort going in the Jemez y Sangre area. These committees and groups include a:

Funding and Operations (F&O) Committee to raise money for cloud seeding and either cause to be formed a coalition to conduct cloud seeding or become that organization.

Technical Advisory Group (TAG) to provide the technical inputs into any project in this area both in the initial and operational phases of a cloud seeding project. Winter and summer cloud seeding approaches are very different. Strategies may include a focus on improving precipitation efficiency by converting super-cooled liquid water (SLW), enhance vertical air currents, or focus on enhancing the collision and coalescence of rain droplets in clouds. There are many choices of chemical and mineral agents to stimulate these processes and many choices of delivery methods for these agents. Similarly, there are many choices of methods for assessing the effectiveness of cloud seeding.

Citizens Advisory Group (CAG) to educate the public on cloud seeding and to offer a public forum to provide input into any cloud seeding programs initiated, including a forum for concerns to be raised. Some known concerns about cloud seeding programs in other areas include concerns related to the effectiveness of cloud seeding, impact on downwind areas, unexpected consequences such as floods and avalanches, potential contamination due to the seeding agents, too much precipitation at the wrong time (agricultural considerations), religious concerns about tampering with the weather, and a concern that more precipitation now might negatively impact long-term conservation efforts. Many of these concerns can be addressed by educating and by structuring the cloud seeding program in a way that reduces the risks.

New Mexico Weather Modification Association (NMWMA) to promote cloud seeding and to provide a professional society for those working in the field. Also this might be a good venue to address the economic development opportunities for New Mexico resulting from development of expertise in weather modification such as software development and modeling, radar and other equipment development, consulting both on cloud seeding operations and evaluation, and aviation.

In addition to the above committees and groups, there was recognized an immediate need for a full-time person or the equivalent to work on getting a cloud seeding project underway and an institutional framework in which multiple stakeholders can cooperate and share costs and human resources. Currently, there is no permanent Region 3 (Jemez y Sangre) institutional infrastructure. The Region 3 Water Plan was developed by an ad hoc organization, the Jemez y Sangre Water Planning Council, which continues as a volunteer organization.

A description of the program follows. It includes short summaries of each session.

Workshop Program and Summary of the Presentations, Panel Discussions, Breakout Sessions and Final Plenary Session

Thursday January 22

8:00 to 8:10 AM Welcoming Remarks by Elmer Salazar Co-chair Jemez y Sangre Water Planning Council.

The need for this workshop was recognized in the Jemez y Sangre Regional Water Plan which was prepared by a very broad-based coalition of constituencies and was accepted by the ISC on April 23, 2003. The Governor, the OSE Director, and the ISC Director are pleased that we are going to have a science-, technology-, and business-based discussion of our cloud seeding options.

MORNING—PRESENTATIONS (Each presentation was followed by ten minutes of questions and answers)

8:10 to 9:05 AM Dr. WILLIAM L. WOODLEY (President, Woodley Weather Consultants). Organizing and Assessing Cloud Seeding Programs.

The presentation began with a discussion of the importance of water to New Mexico and then raised the question whether cloud seeding might have some potential for augmenting New Mexico's water supply. A discussion followed of natural cloud processes and how seeding alters these processes to increase precipitation. Seeding with ice nuclei (e.g., silver iodide) is done to enhance the ice processes in the clouds while seeding with hygroscopic salts is done to promote the growth of raindrops. Examples of how each method is carried out were given in the context of the operational cloud seeding projects in Texas. It was emphasized that not all clouds are suitable for seeding and that seeding must be adapted to the cloud conditions in much the same way that physicians adapt their treatments to the needs of their patients.

Woodley then raised the question whether we have the right to do cloud seeding that alters the weather. He then demonstrated the many ways that humanity already inadvertently alters the weather. These ways range from the acceleration of global warming, to the alteration of the protective ozone layer in the upper atmosphere, to the suppression of precipitation by introducing into the atmosphere impurities from fires, industrial, and urban sources. Such suppression of precipitation was shown to be especially noticeable in Australia, California, Israel and much of Southeast Asia and Central Africa. The reality is that we already have weather modification whether we like it or not!

It was then noted that Mother Nature employs sea salt from evaporating sea spray to naturally seed clouds to enhance droplet coalescence and rainfall. This process taking place over the oceans cleanses the atmosphere of its pollutants and literally saves us from suffocating. Unfortunately, no such cleansing mechanism exists over the land and Woodley suggested that deliberate hygroscopic cloud seeding with common salt might be used to increase rainfall and to decrease pollution over land areas. He noted that hygroscopic seeding appears to have great potential for increasing rainfall in New Mexico.

Woodley concluded his talk by outlining a program of research and operations for New Mexico, leading ultimately to enhancement of its water supply. This program would involve both glaciogenic (with silver iodide) and hygroscopic cloud seeding, the use of cloud models to predict the seeding outcome and an ambitious field program involving aircraft, radar and satellite measurement platforms. The importance of evaluating everything that is done was emphasized, because this facilitates the refinement of approaches and improvement in results over time.

9:05 to 9:45 AM DON GRIFFITH (President, North American Weather Consultants) “Review of Cloud Seeding in the Southwest---an Operators View”

Benefits from seeding include increased surface run-off for hydroelectric plants, hail suppression, increased rainfall for aquifer recharge and crops and increased snow-pack (summer run-off) for agricultural and municipal use. Orographic (mountainous areas) seeding has been done successfully in California for 50 years. In Utah, a long-term (since 1947) program utilizing 130 ground-based generators is funded by state and local organizations. It has been producing a 15% (4% to 19%) increase in precipitation or approximately 250,000 acre feet per year. Independent analysis by a state agency has shown the cost of increased precipitation by winter seeding projects to be as low as $1.00 per acre foot. The benefit of seeding has been shown to occur 50 to 75 miles downwind. NOAA reports an increase in cloud seeding in the Southwest over the past 10 years, with 66 programs conducted in 2001. During this period there were no programs conducted in NM (with the exception of a Texas Panhandle program which included two counties in southeastern NM).

9:45 to 10:25 AM Dr. CONRAD KEYES (retired NMSU Professor and now consultant) “ A Winter Cloud Seeding Program in the Jemez Mts., 1968-1972”

The success of cloud seeding in the JyS area was demonstrated with a four-year winter seeding project which started in 1968 in the Jemez and Sierra Nacimiento Mountains. Five silver iodide ground generators sites were located along the west side of the Jemez Mountains and numerous snow gauges were placed upwind, in the target area, and downwind in the Jemez, Nacimiento, and western Sangre de Cristo Mountains. The generators were ignited as a function of wind direction and cloud top temperatures and real-time monitoring of snow gauges indicated which areas experienced increased precipitation and in what amounts.

Because it was randomized (50% of the forecasted precipitation days), the project came close to and may indeed have met the scientific standard of 95% confidence (meaning there was less than a 5% probability that the increased precipitation happened by chance). The benefit was at least a 13% increase in precipitation over the entire suggested target area.

Had all storms been seeded effectively, the increase in precipitation in the Jemez Mountains. would have been nearly 30%. Significantly, several snow gauges in the foothills of the Sangre de Cristo Mountains, about 65 miles downwind to the east (not part of the designed target area), also showed increased precipitation, although in smaller amounts. The 3-cm weather radar was moved to a high elevation for one month in the summer of 1972, and, while no clouds were seeded, radar suggested that summer seeding in the Jemez Mountains would also be successful.

Conrad suggested we consider a radar installation at a high elevation in the Jemez Mountains and a year-around seeding program. One interesting finding, based on partitioned results, of this 1969-1972 winter orographic project was what appeared to be a differential benefit of cloud seeding depending on cloud-top temperatures with the higher and lower temperatures producing better results than temperatures in the middle of the range. This information, based on two different seeding agents, might be helpful in planning projects in our geographic area.

10:25 to 1:40 AM Break and mingle

10:40 to 11:20 AM DUNCAN AXISA (Project Director and Meteorologist, SOAR) “Summer Cloud Seeding on the Great Plains”

Summer programs using aircraft with silver iodide flares were conducted in 2002 and 2003 in west Texas and southeastern NM for recharge of the Ogallala aquifer (the Southern Ogallala Aquifer Rainfall, or SOAR program). NEXRAD (NEXt generation RADar) estimates of precipitation are considered superior to rain gauges and allow for a new assessment method. The computer-based method used radar to define floating targets and used a matching procedure to compare precipitation in seeded and non-seeded areas. Although not randomized, and therefore not meeting the scientific standard of 95% confidence, the method is considered highly credible because of techniques used to eliminate bias and re-randomize calculations. This analysis indicated that the program increased average rainfall in seeded units by 52% in 2002. SOAR is considering next year doing a randomized program to assure scientific acceptance and to try hygroscopic seeding, using finely ground salts.

11:20 to Noon GEORGE W. BOMAR (Texas State Meteorologist) "How Other States Look at Cloud Seeding, Status of Research, and Plans for the Future"

Technology in cloud seeding is being pursued because we are on to something! Reports of State Agencies responsible for licensing or oversight of seeding operations are likely to be conservative and less biased.

- Colorado: winter of 2002-3 at a cost of $1,200,000 reported seasonal increase of 17%.
- Vail achieved an increase of 24.5% seeding only specific clouds
- Utah: On 5 projects (some as old as 20 years.) showed increases of 4% to 15% at a cost of $1,300,000. Also found an increase of run-off of 250,000 acre feet, a 13% increase.
- North Dakota: In 2003 there were 678 seeding flights, dispersing 162 kilograms of Silver iodide. The result was a 46% reduction in hail damage on a long-term average.
- Kansas: A comparison of target and control areas for 15 years showed a benefit/cost ratio of 37 to 1, valued at $60,000,000.
- Texas: Since 1997 the State Legislature has provided $15,000,000 in matching funds to local projects (10 in 2003) seeding 51,000,000 acres, about 30% of the State. Texas Tech calculations show that if a 21% increase in rain were achieved this would result in an agricultural gain of $350,000,000 for seventeen West Texas counties, a 70 to 1 benefit to cost ratio. Texas randomized for several summers, 34 experimental units. Individual clouds showed a production of 2.5 times over un-seeded clouds which also lived twice as long as the unseeded. In 2003 seeding only single clouds showed an increase of 250,000 acre feet at a cost of $11.50 per acre foot. With funding from the Bureau of Reclamation, Texas is leasing and equipping an airplane that will, in 2004, measure and identify seasonal changes in natural kinds of CCN. The purpose is to determine the best kind of CCN to use, when to use and how to disperse and to test new material CCN .

Conclusion: Seeding has been worthwhile. We need to do a climatology review to discover our windows of opportunity and how long they last. How many clouds reach high enough to have super-cooled water? A lot of work needs to be done in operations i.e. to determine how much seeding material is getting to clouds with super-cooled water that need a nudge. A federal WMA Board to allocate federal funds and oversee projects is proposed in a bill by Sen. Hutchinson of Texas. To be in the loop we need to communicate with the NM member of the North America Interstate Weather Modification Council. (Editors note: Doug Murray is the representative from NM). Http://www.naiwmc.org/NAIWMC/Membership.html Federal money will come through State agencies therefore it is important to gain State support.

Noon to 1:00 PM Break for Lunch

AFTERNOON—PANEL DISCUSSIONS

(Each panel member spoke for 10 minutes, followed by a 20 minute question and answer session. Panel members were speakers from the morning session, plus other experts.)

1:00 to 2:00 PM "Anticipated Benefits, Costs, and Risks of Cloud Seeding". Session Moderator: Alan Jager 1:00 to 2;00 Panelists: George Bomar, Don Griffith, Gary Walker, and Pat Sweeney

Cloud seeding programs on the south plains of Texas are designed to augment the rain and groundwater where there is no surface water. The reliance on pumping from the Ogallala aquifer has caused the water level to drop 2-5 feet per year. The Ogallala aquifer is practically non-rechargeable due to tight formations. Only 20-30 feet of saturated aquifer remains. Rainfall of 10 inches occurs during the growing season from April to September. Pumping costs are $10 per acre-inch. If a farmer gains one inch or 10% from summer cloud seeding, he immediately saves $120 per acre foot of water used. If the cost of the program is $1 per acre foot of augmented precipitation, a 120:1 benefit to cost ratio is achieved. Risks of undertaking a cloud seeding program are mainly objections by people that don't believe in cloud seeding.

Programs in North Dakota have increased snow and rain and provided hail suppression, resulting in higher wheat yields. Five-year technological transfer programs overseas have trained local individuals in meteorology, atmospheric sciences, commercial aviation, and electrical and software engineering. Costs for a New Mexico program cannot be estimated until the project size is defined. The greatest cost risk is that personnel and equipment remain idle waiting for clouds.

Silver Iodide used in cloud seeding is a negligible risk to the environment since less that 1/250th of acceptable public health levels are found in water samples from seeded areas. Cost estimates for large summer programs are generally $1 per acre or double if a cloud physics research aircraft is required. Indirect benefits are stream flow, filled reservoirs and savings of pumping costs. The number of participants can determine the size of the project and the target areas.

The importance of keeping good records was stressed for many reasons including the ability to evaluate the potential tie in with severe weather taking place anywhere in the vicinity of where cloud seeding took place.

2:00 to 3:00 PM "How Will We Assess the Results of the Pilot Project?" Session Moderator: Dr. John Brown; Panelists: Bill Woodley, George Bomar, Bruce Boe.

Presentations and discussions centered around Cloud Seeding, its terms and location definitions. Differences in techniques for glaciogenic and hygroscopic seedings were noted. Areas to be identified included "operational", "target", "control" and "buffer". Randomization was reviewed with costs, benefits and alternative methods to establish acceptable evidence of accomplishments. Data for comparison purposes from ground precipitation measures, stream flow, radar (reflectivity), micro-wave radiometry (to assess cloud characteristics), tracing, crop yield, and modeling were presented. Modeling is especially important in establishing sites for ground-based generators, defining target areas etc.

Assessment of existing conditions data is available and historic data records can include all of the above measures and the amount of silver naturally found in snow, stream and soil. Good targeting is necessary to optimize probability of success. Actual upper air soundings on locations and exploratory seedings can be used to know when you do have super-cooled water. Data sources recommended included archived weather data, satellite data, climatology, cloud directions and durations. It was emphasized that "this is a precipitation enhancement program and not a drought abatement program". Pre-operational data enables us to better understand what we are doing and maximizes benefits. New technology and data from other disciplines improve current success in cloud seeding.

3:00 to 3:15 PM Break and mingle

3:15 to 4:15 PM "Alternative Approaches to Structuring the JyS Pilot Project". Session Moderator: Doug Murray ISC Project Manager; Panelists: Conrad Keyes, Duncan Axisa, Bill Woodley, and Roelof Bruintjes

A better understanding of alternatives will be aided when the tools are known e.g. radar. The Albuquerque radar is fine but it is partially blocked in the JyS area by mountains. A new Espanola radar with 4 degree inclination can cover almost all this area. A previous radar on Antonito Peak reached all but the valley. This overlaps the Albuquerque radar. Good modern radar is needed to monitor operations, evaluate results and protect aircraft operations in clouds. Operations should be year round (winter and summer seasons) because of locations of reservoirs. Variations in where to seed will be affected by

- Desire for recharge or
- Desire for run-off.

While seeding will be upwind, wind direction etc. will vary measurement locations. Today's technology improves accuracy of measurements, which data , including aircraft instruments, can aid 3-D modeling and include measures for pollutants and silver iodide. Scientific and statistical analyses can result.

Note: Dr. Bruintjes "The National Center For Atmospheric Research panel was made up of very skeptical people but all came around to the decision that this is a very valuable field of study".

4:15 to 4:50 PM Discussion of the breakout sessions planned for Friday: Attendees interested in participating in Friday's working sessions reviewed the suggested assignments accepted them or changed them and Breakout Session Leaders met briefly with their teams.

4:50 PM End of Official Program for Thursday.

5:30 Reception

6:00 Welcoming Remarks by Estevan Lopez ISC Director

Mr. Lopez greeted the group that attended the dinner, welcomed the attendees, and expressed his interest in having more precipitation. The ISC has been given the responsibility for regulating cloud seeding. The State of New Mexico wants to explore cloud seeding but recognizes disagreement with respect to the prior results. The ISC wants to evaluate cloud seeding fully and in a way that we end up understanding what the results will be. He was encouraged that those at the workshop shared the same desire for objectivity.

6:10 Summary of Days Program by Sigmund Silber:

Cloud seeding was presented today as having great potential for providing enhanced precipitation in our area. Although there are difficulties in quantifying the additional precipitation to the level of confidence required in scientific research, as an engineering application there was a strong consensus that the technology works.

Many of the presentations and discussions demonstrated that "integration" is an important framework for thinking about cloud seeding. Success in cloud seeding depends on many factors including good modeling capability, ability to measure precipitation whether this be by traditional means or by the use of tracers which may tie in with other water management objectives, an understanding of the impacts of pollution, participation of the universities, the ability to collect additional precipitation, and the time phased requirements for additional precipitation by the full spectrum of potential users.

But just as integration is important so is phasing. Much analysis needs to be done prior to releasing a seeding agent into a cloud. These pre-seeding activities can start soon. If we can get these pre-seeding activities under way, the timeframe for being able to seed clouds and get more precipitation will be condensed.

6:25 PM Presentation of Award to Walton Chapman: Walt was the head of our fund raising committee. We decided to approach the private sector to fund this workshop because we felt they might be able to respond more quickly than the public sector and this proved to be correct thanks to Walt's leadership.

Dinner

After Dinner Presentation by David Gutzler: Climate Cycles Past Present and Projected.

Drought is hard to define, he knows one when he sees one. There are two basic types of drought:

- Meteorological drought --- lack of precipitation in the area.
- Hydrological drought --- lack of water coming downstream. In our case lack of snow pack in the headwaters of the Rio Grande. For the last 4 years the water at the Otowi gage has been below normal.

We are having both kinds of drought. One might also talk about Agricultural drought --- lack of rain during the growing season. The current drought covers the entire west with the worst being in New Mexico. This is the most extensive area of drought in this century.

The last drought period was in the 1950s. The lead in to this drought resembles that one, but we are not at the 50s yet. It happened before and it can happen again! The previous drought was at the turn of the twentieth century. The 80s and 90s were abnormally wet periods.

Droughts seem to come in cycles with the water temperatures in the Pacific Ocean having something to do with it. El Nino refers to warmer water along the equator from the international date line to the coast of South America. An El Nino usually portends a good snow pack upstream from us due to the movement of the jet stream from Japan. However the El Nino of last winter didn't help out.

There is an area in the northern Pacific called the Pacific Decadal Oscillation (PDO) which is now also thought to affect our weather. The temperature there varies on a slower time frame than El Nino. It doesn't actually oscillate, but rather flip-flops. When it flops the wrong way, El Nino is not as effective.

In order to get a long term look at the weather, growth rings in trees are studied. The wider the ring, the greater the precipitation. Growth rings were correlated with known weather data for periods in which records were kept, and a regression formula was set up. This formula was then used to compute precipitation from the growth rings of earlier periods (before 1800s).

It appears that droughts come in cycles of 50-80 years. We had a drought at the turn of the century and in the 1950s so 50 years puts us at the present.

There was a mega drought in the 16th century which covered the entire west, and lasted for decades. Since the current drought covers the entire west, we could be headed into such a drought. There was also a 13th century major drought.

Friday January 23

8 AM We Resume

8:00 to 8:10 AM Administrative arrangements for the Breakout Sessions were discussed.

8:10 to 10:30 AM Breakout Sessions.

Breakout Session A: "How to Prepare the Community for a Cloud Seeding Program". Session Leader: John Buchser, Chair Conservation Committee, Rio Grande Chapter, Sierra Club. Facilitator: Ed Moreno

Out of the discussion came the following goals:

Goal 1: Establish an Outreach Program

An outreach program is essential to building community awareness and support and to address any community concerns.

- Localized – not "this is how we did it in (wherever)"
- Focused on public officials and agencies, local, state and federal
- Includes outreach to tribes and acequias (agriculture)
- Media relations \ especially television weather meteorologists
- Informal approach – open houses rather than formal hearings
- Pro-active and patient, especially with tribes and others that may be hard to reach
- Special emphasis on communication with the National Weather Service:
  - Science Operations Officer (SOO)
  - Meteorologist in Charge (MIC)
  - Warning Coordinating Meteorologist (WCM)

Goal 2: Establish the New Mexico Weather Modification Association

The purpose and activities of the organization would include:

- Speaker's bureau
- Educational programs for the public
- Resources and information for the public and for members
- Seminars for members
- Help members establish priorities for programs
- Build credibility for weather modification
- Coordinate programs and educational activities

Members would include business, higher education institutions and others

Goal 3: Conduct Weather Modification Projects

The execution of projects would be an effective way for the public to have some experience with cloud seeding. Elements would include:

- Identifying sponsors for projects
- Securing money from federal and state sources for research
- Monitoring and evaluation of projects
- Science and projects should be kept separate

Goal 4: Engage the Regulatory Process

The Interstate Stream Commission was given regulatory authority over weather modification and is in the process of revising the applicable regulations. Now is the time for the weather modification interests to have its voice heard in the regulatory process.

Breakout Session B: "How Might We Initiate a Cloud Seeding Pilot Project"
Session Leader: Sigmund Silber; Facilitator: Seth Cohen

Although Group B was small and did not have the breadth of representation that might be considered a community consensus, those there believed that the general consensus of those attending the workshop was that an attempt should be made to initiate a cloud seeding project. This then led to the following recommendations:

1. **Identify a resource person.** This individual should be paid for his/her position. Individual could be a professional lobbyist. Individual should be culturally competent (be able to relate to surrounding communities, acequia commissions, sovereign Pueblos, etc.)

2. **Form a steering committee.** The responsibility of initiating a Cloud Seeding project needs to be shared among interested stakeholders. The steering committee should consist of interested parties who stand to benefit from the Cloud Seeding Project. Potential members include: Ski Area representatives, owners of Golf Courses, acequia commissions, Chambers of Commerce, agriculturalists, environmentalists, developers, representatives of banks, representatives from

the hospitality industry, local officials/public representatives, and Indian Pueblos.

3. **Identify a champion**: After a core group is established, the Steering Committee should identify a champion for the project and the affected region.

4. **Identify the target area**. There are still questions and concerns about the geographical area represented by the Steering Committee and the size of the committee. A maximize of 25 members was recommended. The scope of a Cloud Seeding Project could be determined by stakeholder support and funding. Again, make sure the project target area benefits all parties on Steering Committee.

5. **Utilize local Chambers of Commerce.** Initial steering committee members should utilize the support of local Chambers of Commerce to draft and send an invitation letter to potential Steering Committee members. A first step might be to set up a meeting with leaders from the four municipalities.

Breakout Session C: "How to Develop the Specifications for a Cloud Seeding Pilot Project"
Session Leader: Roy Stoesz: Facilitator: Lucy Moore

Issues discussed included:

Scientific Acceptance: The group discussed at some length the need for scientific acceptance of the design and results of a local cloud seeding program. Some felt that it was imperative to develop a program that could meet current international scientific standards, which include a confidence level of 95%. (The percentage is not a measure of the success of the program, but rather a measure of the confidence of being able to measure what you did.) Using this standard would almost certainly require a randomization program. Others felt that the program should be designed to produce precipitation, and evaluated based on those results. The 95% figure, some argued, was apparently derived from the medical field, and was inappropriate in this context.

Program Goals: Goals of the program are: 1) produce precipitation; 2) increase stream flow in the Santa Fe watershed, and perhaps the Pecos and Chama watersheds, as well; and 3) produce credible results – for either the scientific community, or public, or both.

Pre-program Preparation: Experts advised the group to gather and analyze data before designing a program. It is critical, they said, to build a physical understanding of the region and evaluate several factors, and to be clear about the goal of the program before creating the hypothesis and design for the program.

Data Needed: Baseline data needs to be analyzed. Some is available, some will need to be collected. Several people believe it may take a year to collect and interpret the data before a project could start.

Radar: The group agreed that radar installation at a key point is needed, both for a winter and summer program.

Summer Program: A summer program would benefit local agriculture, which depends heavily on unreliable summer monsoons. Acequias are fragile operations with significant political clout. Precipitation in the summer would also benefit city residents, with gardens, trees, etc. Fire and weather data, cloud process data, radar climatology, and an aircraft cloud probing program could all contribute to the database. There is no history of cloud seeding in high mountains in the region in the summer. Assessment would be based on radar, rain gauges, or stream flow measurements.

Winter Program: A winter program would require meso studies and modeling, Some said answering the randomizing question was premature for the winter program until data had been analyzed. There was a lengthy discussion of Dr. Keyes' successful four-year randomized project in the Jemez.

Reconsidering the Size of the Area: Initially the group had conceived of the area to be treated as that within the boundaries of the Jemez y Sangre water planning region (parts of Santa Fe, Los Alamos and Rio Arriba counties). However, cloud seeding would probably result in precipitation on both sides of the Sangres, producing runoff into the Pecos basin as well as the Rio Grande. The group considered redefining the area of benefit as bounded by Las Vegas, Albuquerque, Taos and the Jemez Mountains. This would bring greater support to the project, as well as benefit to a greater area. At least for the purpose of gathering baseline data and modeling, the group decided to work with this larger area. Determining the size of the area will require communicating with neighboring regional water planners.

Interstate Stream Commission Requirements: A participant reminded the group of ISC permit requirements which include a public education component and an ecological/environmental impacts component. The draft regulations will be the subject of public hearings soon.

Need for Watchdog: A participant urged the group to remember unfortunate instances in the past when desperate farmers were taken advantage of by cloud seeding promoters. He hoped that there would be an entity formed to screen contractors in order to protect the community against fraud. Cloud seeding is extremely complicated and it requires expertise to determine the qualifications of cloud seeding contractors.

Next Steps: The group identified some next steps:

- Assess where we are now
- Workshop findings and direction will be summarized
- A "gray paper" will be produced. It will outline a plan for a program, and will be refined as experts and participants review it
- A Technical Advisory Group (TAG) will be formed, including consultants and stakeholders, and perhaps a university person, and perhaps a representative from the ISC

10:30 to 10:45 AM Break

10:45 to 11:45 AM We met again as a group.
Session Coordinator: Gary Ehlert

- Breakout Session Secretaries reported on conclusions reached and proposed next steps
- Group ratified Breakout Session reports
- Decisions were made on how to move forward on Cloud Seeding Pilot Project

The first question to be asked was the existence of a consensus for going forward with a cloud seeding project. Is there a consensus? There seemed to be broad support for gong forward. No one in attendance was opposed to moving forward.

It was recognized by all three breakout sessions that we needed to create new structures to move things forward. Cloud seeding could not remain as one out of a number of projects within a committee of the Jemez y Sangre Water Planning Council and receive the ongoing attention it would need to move forward.

Four new organizations were defined to test the waters to see if a cloud seeding project can be gotten off the ground. These organizations are shown in the attached organization chart.

One such structure was called a Steering Committee. After the workshop this name was changed to the Funding and Operating Committee. Gary Ehlert volunteered to organize this committee.

The key to getting a cloud seeding project started in our geographic area is to form a coalition of those who are prepared to move such a project forward. A preliminary step in doing so is the formation of a Funding and Organizing Committee. This committee will seek funding for a cloud seeding project. It will also address the need for a full-time person to be made available to work on the task of getting a cloud seeding project off the ground. The amount of volunteer time just to make this workshop happen was probably in the range of seven to nine man-months. It will not be possible to move forward based on volunteer time alone.

We had a lot of very generous sponsors from the private sector one of which also made available their Executive Officer, Gary Ehlert, to help us with coordinating the workshop with the Hilton Hotel. Gary also helped Walton Chapman with recruiting the sponsors for the workshop. We all worked on that important task but Gary and Walt took the lead. Gary has now volunteered to organize the Funding and Organizing Committee.

He invited interested participant to join him for lunch after the formal close of the workshop. All interested in the work of the Jemez y Sangre New and Expanded Water Technologies Committee were invited to attend the next meeting which was scheduled for Tuesday of the following week.

The breakout sessions also recognized the need for technical expertise.

A second part of the team is a Technical Advisory Group or TAG. It is from this group that advice will be provided on how to design or have designed the cloud seeding operations, the very important evaluation component, and any research component the program might also incorporate. The TAG will most like continue during the entire life of the project. Roy Stoesz has volunteered to organize the TAG. At some point the TAG may need to have resources that are greater than can be reasonably expected from volunteers. Perhaps a full time person can be made available to support the work of the

TAG and the F&O Committees. How this person will be funded and how this person will be accommodated on an administrative basis remains to be determined. Will this person report to one of the six cities and counties involved? The ISC? This needs to be determined.

A Citizens Advisory Group will provide a convenient and effective way for the general public to have an impact on any cloud seeding project initiated. A cloud seeding project will need to be supported by the general public and citizens need a way to have their points of view taken into consideration. There can be legitimate concerns about cloud seeding and these concerns need to be addressed on an ongoing basis and a CAG will facilitate this. At this point we do not know who will be organizing the CAG. It may not be required immediately but the sooner it exists the better.

One of the new structures suggested, the New Mexico Weather Modification Association would study and promote cloud seeding throughout New Mexico. This may need the universities to take the lead. There exists a nationwide organization on which this might be modeled, the Weather Modification Association (WMA) http://www.weathermodification.org/ It is not clear if New Mexico can support a mini-version of the WMA.

11:45 AM Workshop Ends

SPEAKERS' PROFESSIONAL BIOGRAPHIES (In order of presentation)

Dr. William L. Woodley "Organizing and Assessing Cloud Seeding Programs". After receiving his Ph.D. at Florida State University, Bill spent 27 years with NOAA/ERL Labs in Miami, Florida and Boulder, Colorado as Group Chief, Precipitation Enhancement. He left federal service 20 years ago to form Woodley Weather Consultants, where he continued his research in weather modification and served as a scientist/consultant on projects in Illinois, Texas, California and Thailand. He has published 22 papers since 1993. Bill is an authority on cumulus clouds, having logged thousands of hours directing research flights alongside or behind the pilot into large cumulus clouds throughout the world.
Voice (303) 979-7946, fax (303) 973-3446, williamlwoodley@cs.com

Mr. Don A. Griffith "Review of Cloud Seeding in the Southwest- - - An Operator's View". Don has degrees in Industrial Construction and Management from Colorado State University, Mathematics from Westmont College and Meteorology from the University of Utah. He was a Weather Officer in the Air Force for three years, including a tour of duty in Vietnam, served for a year as a meteorologist for Booz-Allen Applied Research, Inc. and for five years was Meteorologist/Asst. Director, Atmospheric Resources Research at Fresno State College Foundation in California. He joined North American Weather Consultants 20 years ago and is now President of the company. He has operated or directed cloud seeding programs throughout the West and in a number of foreign countries, and has authored or co-authored 18 journal article and over 130 technical reports.
Voice (801) 942-9005 fax (801) 942-9007, nawc@nawcinc.com

Dr. Conrad G. Keyes, Jr. "A Winter Cloud Seeding Program in the Jemez Mountains, 1968-1972". Conrad served many years as a Professor at New Mexico State University, and for eight years was the Department Head of the combined Civil, Geological and Agricultural Engineering Departments. He received his ScD (Civil Engineering-Water Resources) from New Mexico State University and for 20 years conducted a wide variety of research projects there, including one which he will talk about today, "Jemez Atmospheric Water Management." He has twice served as the Engineer Advisor to the Texas Rio Grande Compact Commissioner and worked several years for Boyle Engineering Corp. as Branch Manager in their El Paso office. Among his many professional awards are two awards as the Outstanding Engineering Alumnus at New Mexico State University. He currently consults for the US Corps of Engineers, the New Mexico Interstate Stream Commission and Sandia National Laboratories.
Voice (505) 523-7233, fax (505) 647-1108, cgkeyesjr@zianet.com

Mr. Duncan Axisa "Summer Cloud Seeding on the Great Plains". Duncan is from the island of Malta and received his early education there, with an undergraduate degree from the University of Malta. He came to the US four years ago and graduated as a meteorologist from Texas A&M. For the past two years he has been Project Director/Meteorologist for SOAR (Southern Ogallala Aquifer Rainfall) in Plains, Texas. He has worked closely with Woodley Weather Consultants to develop weather radar monitoring systems to assess summer cloud seeding programs in West Texas and Southeast New Mexico. He has developed an active weather modification outreach program in Texas, and last year made more than 40 presentations state-wide. Voice (806) 456-2155, fax (806) 456-5655, soar@sandylandwater.com

Mr. George W. Bomar "How Other States Look at Cloud Seeding, Status of Research and Plans for the Future". Since receiving undergraduate and graduate degrees in Meteorology from Texas A&M, George has devoted 30 years to development and utilization of weather modification in Texas. He was instrumental in establishing a state-wide rainfall-enhancement program in Texas 10 years ago, which grew to a program in 2003 covering 51 million acres (30 percent of Texas), the largest rainfall-enhancement effort in the world. George is now State Meteorologist in the state of Texas, in which capacity he is responsible for licensing, permitting and monitoring all cloud seeding projects in the state. He is the author of three books on Texas weather and the impact of global warming on Texas. Voice. (512) 936-4313, fax (512) 463-1376, george.bomar@license.state.tx.us

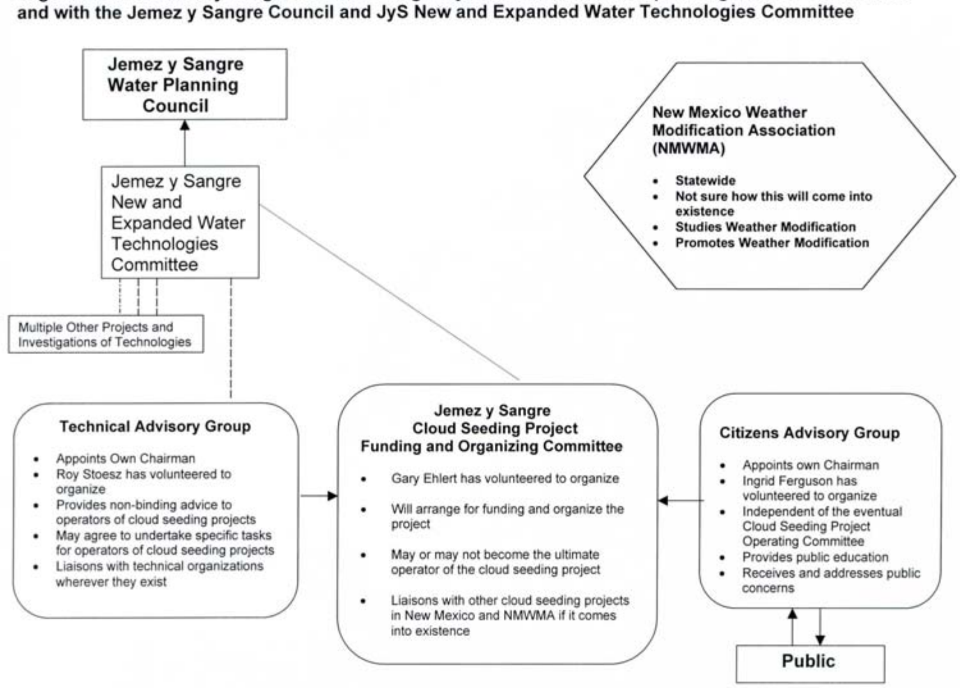
Dr. David Gutzler "History of Precipitation in Northern New Mexico". Dave received his PhD (Meteorology) from Massachusetts Institute of Technology and worked in his early career as a Staff Scientist at Atmospheric & Environmental Research, Inc. in Cambridge, Mass. and as a Physicist at the NOAA Aeronomy Lab in Boulder Colorado. Since 1995 he has been a Professor in the Earth & Planetary Sciences Department and Water Resources Program at the University of New Mexico. For seven years he was Associate Editor or Editor of *Journal of Climate* (American Meteorological Society), and for the past four years he has been a member of the New Mexico State Weather Control & Cloud Modification Commission. He has more than 50 publications to his name and is a Certified Consulting Meteorologist. Voice (505) 277-3328 fax (505) 277-8843, gutzler@unm.edu

Funding for this workshop was provided by:

- Santa Fe Association of Realtors
- Santa Fe Area Home Builders Association
- Santa Fe County Chamber of Commerce
- New Mexico Building Branch AGC
- First National Bank of Santa Fe
- Rancho Viejo de Santa Fe
- Payne's Nurseries
- Los Alamos National Bank

Members of the Jemez y Sangre Water Planning Council New and Expanded Water Technologies Committee who produced the workshop were: John Brown, Walton Chapman, Jim Corbin, Gary Ehlert, Alan Jager, Bill LeMay, Tina Ortiz , Sigmund Silber, and Roy Stoesz.

Organization of Jemez y Sangre Cloud Seeding Project and the relationship among the four Committees and with the Jemez y Sangre Council and JyS New and Expanded Water Technologies Committee



WEATHER MODIFICATION ASSOCIATION

ARTICLES OF INCORPORATION

ARTICLE I
NAME

The name of this corporation shall be the WEATHER MODIFICATION ASSOCIATION.

ARTICLE II
DURATION

The duration of this corporation shall be perpetual, unless otherwise resolved by legal proceedings.

ARTICLE III
PURPOSES

The Association shall function as a nonprofit corporation. Its purposes include, but are not necessarily limited to, the following:

(1) Promotion: Promoting research, development, and understanding of weather modification for beneficial uses.
(2) Standards of Conduct: Encouraging and promoting the highest standards of conduct including certification of individual members qualified to execute field experiments of operations in weather modification.
(3) Information Center: Serving as a clearing-house and dissemination agent for weather modification oriented literature and information.
(4) Policy Statements: Assuming an active role and maintaining a strong voice in the production and dissemination of policy statements concerning all aspects of weather modification.
(5) Journal: Publishing, annually or more frequently, as the official organ of the Association, the JOURNAL OF WEATHER MODIFICATION containing scientific articles and reports about weather modification problems and activities, and accounts of Association business.

ARTICLE IV
PRINCIPAL PLACE OF BUSINESS

The principal place of business of the corporation shall be located at 8160 S. Highland Dr., Suite A-2, Sandy, Utah 84093, but the meetings of the Board of Directors may be held at other places, provided that the place of the meeting shall be stated in the notice of the meeting.

ARTICLE V
MEMBERSHIP

There shall be six classes of membership in the Association. Each class shall be afforded the privileges of membership as indicated.

(1) Member: Any person who subscribes to the statement of purposes of the Association, upon payment of the prescribed annual dues, shall be afforded the privileges of membership. Members shall receive the Journal of the Association, and shall have the right to vote in the business of the Association and to hold any office in the Association.
(2) Student Member: Any person, engaged in a full-time program of study leading to a degree in the atmospheric sciences, engineering or other subjects related to the science of weather modification, and who subscribes to the statement of purposes of the Association, upon payment of the prescribed annual dues, shall be afforded the privileges of student membership. Student members shall receive the Journal of the Association but may not vote in the business of, nor hold office in the Association.
(3) Corporation Member: Any organization with active programs in weather modification, or with interests directly related to weather modification activities, which subscribes to the statement of purposes of the Association, upon payment of the prescribed annual dues, shall be afforded the privileges of corporate membership. Corporation members shall receive the Journal of the Association and may designate one individual to act for the corporation in the affairs of the Association. The designated individual shall have the same rights and privileges afforded members of the Association.
(4) Honorary Member: Members, or former members, of the Association who have

made outstanding contributions to the Association may, subject to the unanimous consent of the Board of Directors of the Association, be nominated for honorary membership in the Association. Election shall be by simple majority vote of the members present at any regular or special meeting. Honorary membership shall be non-expiring for the life of the member. Members so elected shall be excused from the payment of dues. They shall receive the Journal of the Association and enjoy the same privileges as members of the Association.

(5) Retired Member: The retired member must be over the age of 65, retired, and must have had 20 or more years of active membership in the WMA. These members are to receive the Journal each year, while paying only one-half of the normal membership dues.

(6) Associate Member: Primarily reserved for any organization without active programs in weather modification, which may have an interest related to weather modification activities, but not limited to them. As long as this organization subscribes to the statement of purposes of the Association, upon payment of the prescribed annual dues, it shall be afforded the privileges of a WMA associate member. WMA associates shall receive the Journal of the Association, and may designate one individual to act for the organization in the affairs of the Association. The designated individual shall have the same rights and privileges afforded members of the Association.

ARTICLE VI
DUES

All dues for the Association shall be paid on a calendar year basis. Annual dues for the various categories of membership shall be set by vote of the members present at the annual meeting, on the recommendation of the Board of Directors.

ARTICLE VII
CERTIFICATION OF MEMBERS

There shall be two classes of certification in the Association.

(1) Certified Weather Modification Manager: A person who is qualified to design, supervise, evaluate, and assume overall responsibility for field experiments or operations in weather modification.

(2) Certified Weather Modification Operator: A person who is qualified to conduct the normal day-to-day, on-site activities associated with field experiments or operations in weather modification.

Certification shall be based upon experience, knowledge and character. Certification shall be granted by the unanimous vote of a Certification Board which shall be composed of three Certified Weather Modification Managers who shall be appointed by the President. The members of the Certification Board shall each serve six years on staggered terms. Changes in procedure for certification of members shall be made only after an affirmative majority vote of the Certified Members present at any regular meeting.

ARTICLE VIII
JOURNAL

(1) The official JOURNAL OF WEATHER MODIFICATION shall be issued by the Editor, appointed to a three-year term by the Board of Directors, of which he shall become a member <u>ex officio</u>. The Editor shall have been an active Member for at least three years, and may retain, or be elected to, other office in the Association during his tenure.

(2) The Editor shall appoint, with the concurrence of the Board of Directors, an Editorial Board of five members, serving five-year staggered terms. At least one member of the Editorial Board shall hold Association certification. The Editorial Board shall elect its own chairman, and shall establish the editorial policy of the Journal. Its members may assist the Editor in evaluation of material submitted to him, acting as referees for certain articles.

ARTICLE IX
ADMINISTRATION

The administration of the Association shall be vested in the Board of Directors which shall include the elected officers and trustees of the Association as follows:

(1) President: The President shall be responsible for the administration of the Association. He shall appoint such

committees as he deems necessary for the successful accomplishment of the Association's aims. The President shall preside at all meetings and shall be a member ex-officio of all committees.

(2) President-elect: The President-elect shall succeed the President in office. The President-elect shall preside over the administrative functions of the Association in the absence, or by direction, of the President.

(3) Secretary: The Secretary shall be responsible for the minutes of each meeting and shall notify the membership of impending meetings. In the absence of both the President and the President-elect, the Secretary shall preside over the administrative functions of the Association.

(4) Treasurer: The Treasurer shall conduct the financial affairs of the Association and keep accurate records thereof. The functions of the Secretary and Treasurer may be combined in one person at the pleasure of the membership of the Association.

(5) Trustees: Three Trustees, to serve staggered three-year terms shall be elected by the membership to represent private groups, university groups, and government groups, respectively. It shall be the duty of the Trustees to represent the interests of their respective groups as members of the Board of Directors and to assist the President and other elected officers, as may be required, in the administration of the Association.

(6) Editor: The Editor of the Journal of Weather Modification shall be a member of the Board of Directors ex officio. Even if he is also an officer or trustee, he will have only one vote.

The Board of Directors may employ such other persons as may be necessary for the conduct of Association business.

ARTICLE X
ELECTIONS

Elections shall be held at the annual meeting. Officers to be elected will include a President, President-elect, Secretary, Treasurer, and one Trustee.

Nominations for elective offices shall be made by a nominating committee appointed by the President. Nominations will also be accepted from the floor, as called for, prior to balloting.

New officers and trustees shall assume their duties at the conclusion of the annual meeting, and serve until their successors assume office.

ARTICLE XI
MEETINGS

Meetings shall be held at least once a calendar year. The first meeting of each calendar year shall be the annual meeting unless otherwise designated by the Board of Directors. Advance notice of all meetings shall be mailed by the Secretary to all members at least thirty days prior to the date of the meeting.

The presiding officer and ten percent of the voting members shall constitute a quorum. The location and date of all meetings shall be determined by a majority vote of the Board of Directors.

ARTICLE XII
AMENDMENTS

These Articles of Incorporation may be amended in the following manner:

(1) The Board of Directors shall adopt a resolution setting forth proposed amendments. Written notice setting forth proposed amendments shall be submitted to the membership at least thirty days prior to the annual meeting at which they are to be considered.

The proposed amendments shall be adopted by a two-thirds vote representing a combination of all members present at the annual meeting plus any absentee ballots received up to the day of the balloting on the floor, providing that the total votes cast constitute a quorum.

Written notice or absentee ballots may be transmitted via faster communication tools than traditional postal mail. Faster communication tools include, but are not limited to, electronic mail (e-mail), televideo, tele-, or video-conferencing. Those without a faster communication tool must receive the written notice.

WEATHER MODIFICATION ASSOCIATION

CODE OF ETHICS: Standards of Conduct in Projects and Procedures for Investigating Misconduct of Members

BACKGROUND AND PURPOSE

The Weather Modification Association (WMA) has adopted this statement on standards of conduct in projects and procedures for investigating misconduct of members in order to further the purposes of the Association, which include but are not limited to:

1. Encouraging and promoting the highest standards of conduct in all weather modification activities; and,

2. Identifying those measures which the WMA reserves the right to follow if/when a member, operator, or manager clearly fails to conduct himself (herself) in a manner that reflects the dignity and honor of the profession.

Ethics and standards in the conduct of weather modification activities, and enforcement thereof through membership in the WMA, are critical to the integrity, reputation, and technical advancement of the profession. The need to articulate more refined tenets of ethical practice is of primary concern to the Association. By reviewing and reiterating these principles and defining programmatic misconduct, ethical standards can be reinforced and ambiguity can be reduced. By maintaining procedures for inquiry and investigation of allegations of misconduct, equitable treatment can be assured and self-regulation of the weather-modification community can be strengthened.

SCOPE

The policy and the associated procedures apply to all WMA members. All WMA members are expected to act in such a way as to promote the purposes of the WMA. Moreover, those members, referred to in this document as operators or managers, who direct or participate in field experiments or operations in weather modification, have a special obligation to protect the interests of the WMA, the profession, and the general public.

The WMA has a program to certify individuals as qualified to execute or manage field experiments or operations in weather modification. Certification is based upon experience, knowledge, and character. In considering applications for certification or renewal, the Certification Board will consider the degree to which each applicant has conformed to the Code of Ethics prior to the award of certification. Violation of the Code of Ethics may be cause for denial or revocation of certification.

GENERAL POLICY

The Weather Modification Association is committed to several fundamental beliefs and principles regarding ethics and standards in the conduct of weather-modification activities.

- Underlying the ethics and standards of the WMA is a commitment to the advancement of the science, technology, and practice of weather modification.

- Ethical conduct by WMA members is critical to the foundation of the weather modification profession.

- The integrity of the WMA is consonant with the integrity of its members.

- The concepts of self-regulation and trustworthiness, which are essential and rest with individual members, include the standards of open communication, respect for the rights of others, honesty, fairness, objectivity, accuracy, and healthy skepticism.

- This policy is intended to recognize and encourage, within the boundaries of good conduct, the freedom of a member to pursue and compete for business, develop, and implement new approaches and methods, and disseminate the results and findings of weather-modification activities.

- A policy, with well-defined procedures for addressing allegations of misconduct, is appropriate for the WMA.

- The rights of each member of the Association must be protected.

- All members will be appropriately apprised regarding this policy and the issue of ethical conduct in the profession.

- All members must avoid misconduct as defined by this policy.

CODE OF ETHICS

Relationships with the General Public

1. The operator or manager will comply with all laws and regulations pertaining to weather modification activities of the federal, state, and local governmental units having jurisdiction in the areas where projects are conducted.

2. The operator or manager will not knowingly participate in activities that can reasonably be expected to be detrimental to the public welfare or contribute to hardship in operational areas.

3. The operator or manager will fully divulge to clients and potential clients, upon request, all the chemical components of active seeding materials and methods used.

4. The operator or manager will make a concerted effort to comply with requests (preferably written) from the client, the regulating agency, and the general public for information about his field activities. Such efforts will not impair the ability of the operator or manager to perform assigned tasks for the client.

Relationships with Clients

5. The operator or manager will not exaggerate his capabilities (or those of the organization he/she represents), nor guarantee results in terms of future weather conditions. Claims regarding the probable effects of weather-modification projects should be compatible with such "Statements of Capabilities" as may be set forth by the WMA from time to time, unless the claims can be justified on the basis of results published in a suitable format available for review.

6. Contracts where a bonus is paid for performance, such as "production" of rainfall over and above monthly normal or other arbitrary amounts, could be detrimental to the development of a sound technology and should be contemplated only with utmost care <u>if not altogether avoided</u>.

7. The purpose of the WMA practice of certifying weather modification operators and managers is to foster "the highest standards of conduct in weather modification programs of a research or operational nature." It is recommended that those who are involved in the conduct of cloud seeding in such programs become certified by the WMA.

8. It is good professional practice for an operator or manager to offer to clients the existing documentation on laboratory field test results, "open house" events, as well as the option of in-the-field tests of seeding equipment and seeding materials to be used in the program.

9. It is good professional practice for an operator or manager to offer clients the maintenance histories of critical equipment to be used in the operation.

10. It is good professional practice to be up front about possible extra-area effects, which are possible. The known reports of such generally indicate small increases in precipitation.

Relationships with Meteorological Profession

11. The operator or manager will conduct himself/herself in a manner to reflect dignity and honor on the profession.

12. The operator or manager will stay informed of scientific and technological developments in the field of weather modification and will seek to incorporate improvements into operational and research programs.

13. The operator or manager will endeavor to contribute new knowledge to the profession

by making known significant results from operational and research programs.

14. The operator or manager will not knowingly take credit for work done by others, but will attempt to give credit where such is due.

15. The operator or manager will not unjustly criticize fellow workers in his profession, but will refer to the Association information on apparently unethical practices on the part of other operators.

STANDARDS OF CONDUCT FOR SPECIFIC PROJECTS

1. Each project should have a set of clearly-defined objectives. The operator or manager should provide as precise a statement as possible of how the objectives are to be reached.

2. The operator or manager will not undertake work in a project area where serious conflicts might arise from weather modification activities without taking steps to identify and correct such situations in advance.

3. The operator or manager will conduct each project in such a way as to minimize danger to the public and to the environment from the use of seeding devices, seeding agents, and other appurtenances of the trade.

4. Each project should be under the personal direction of a project scientist with knowledge and experience in weather-modification field projects. The project scientist should be stationed as close as practicable to the area of operations.

5. The operator or manager will ensure that project personnel have adequate and appropriate weather data and information essential to the conduct of cloud-seeding operations and the efficient use of resources committed to the project.

6. The operator or manager will establish criteria and procedures for suspending operations in the face of impending severe weather to avoid contributing to, or appearing to contribute to, damaging weather situations. It is recognized that some types of projects, e.g., hail suppression, require operations during or in advance of certain types of severe-weather situations. The suspension criteria and procedures adopted will be specified in advance in written form, and these will take into account existing water-management practices and flood control facilities.

7. Evaluations of projects are strongly encouraged. Any limitations to evaluation will be reported to the client. Procedures to be used in evaluations should be specified in advance.

SUSPENSION OR REVOCATION

The WMA reserves the right to suspend or revoke the certification of any operator or manager, or the membership of any WMA member, who, in violating specific standards as listed (above) in the "Code of Ethics" and in the "Standards of Conduct for Specific Projects: (1) fails to conduct himself, or herself, in a manner that reflects the dignity and honor of the profession, or (2) fails repeatedly to adhere to the criteria set out for WMA certification.

The procedure for investigating alleged misconduct established by this policy reflects the following:

- Innocence is presumed until proven otherwise.

- Confidentiality will be maintained throughout the investigative process.

- An inquiry will be undertaken as a preliminary step to determine whether an investigation is warranted.

- The process of verifying or resolving allegations of misconduct will provide for fair and reasonable action if an allegation is substantiated by the facts.

- When allegations of misconduct have been made, the individual has the right to due process protection. The individual will be granted the opportunity to review and comment on the allegations, evidences, and conclusions, and to cross-examine witnesses.

It is understood that all WMA members will maintain adherence to professional codes, as well as requirements of program sponsors including guidelines and contracts.

Maintaining high ethical standards and the integrity of the profession promotes the quality of work by the WMA and its reputation with sponsors, the scientific community, and the general public.

GLOSSARY [DEFINITIONS]

Allegation: any written statement addressing the possibility of professional misconduct.

Complainant: the individual or group filing an allegation/complaint.

Ethical conduct: operational or managerial activity for all WMA members which (1) is based on honesty, openness, respect for others, fairness, and trust; and (2) adheres to the "Code of Ethics" and the "Standards of Conduct for Specific Projects"

Fabrication: making up data or results.

Falsification: changing or not reporting appropriate data or results (i.e. the purposeful omission of conflicting data or information with the intent to falsify results; deceptive selective reporting).

Inquiry: actions, including information gathering and fact-finding, to determine the potential validity of an allegation and whether an allegation warrants an investigation.

Investigation: a formal process including determination of the need for a hearing and, if required, a review by the Ethics and Standards Committee to consider the allegation(s).

Integrity: the quality or state of making sound programmatic decisions based on scientific principles; uprightness, honesty, and sincerity

Retaliation: any damaging action against a person who makes an allegation of misconduct ("whistle blower") or reports information regarding alleged professional misconduct.

Manager: a person who may design, manage, evaluate and have overall responsibility for a weather modification program.

Misconduct: operational or managerial activity for all WMA members which does not adhere to the "Code of Ethics" and "Standards of Conduct for Specific Projects" and involves [means] (1) fabrication, falsification, or other serious deviation from commonly-accepted practices in proposing, carrying out, or reporting results from professional weather-modification activities; or (2) retaliation of any kind against a person who reported or provided information about suspected or alleged misconduct and who has not acted in bad faith.

Operator: a person who provides the day-to-day, on-site supervision of a weather modification field program.

Subject: the individual(s) against whom an allegation/claim has been filed.

PROCEDURES FOR REPORTING AND ADDRESSING ALLEGATIONS OF MISCONDUCT

Background

In addressing allegations of misconduct, the provisions of this policy include fair, swift, and thorough consideration of any allegations, and initiation of actions recommended after consideration of allegations is complete. All records dealing with an allegation, its review, and disposition will be treated in strict confidence. The WMA Board is responsible for investigating allegations of misconduct, maintaining the confidentiality of the investigative process, insuring equality, and providing timely, responsible action when misconduct has been alleged. A schedule is provided for conduct of all related activities, to facilitate orderly and expeditious resolution and to help insure the rights of the individual(s) against whom an Allegation has been filed (the Subject).

Reporting Allegations

Initially, members, clients, or the general public should report cases of suspected misconduct to the Chairman of the Ethics and Standards Committee or directly to the WMA President. Reports of allegations must ultimately be filed with the WMA Board of Directors. Allegations must be in writing, signed and dated by the complainant and, to the extent reasonably possible, specify the date, time, place, person, or persons involved, and the circumstances of the alleged misconduct. Allegations of misconduct will be treated in a confidential manner.

Committee's Inquiry

An inquiry is the initial step after an allegation is made. It is an informal process intended to assess the validity of the allegation and will be performed by an impartial group, selected by the WMA Board of Directors and consisting of no more than four (4) individuals. The Inquiry Group, selected by the Board, will report their findings to the Board. The Board will then instruct the selected Group to either resolve the matter on their own using appropriate means, which may include conciliating with the parties, by permitting the complainant to voluntarily drop the complaint, or by permitting the person charged to accept voluntarily the disciplinary measures. The selected Inquiry Group may summarily dismiss a frivolous complaint with notice and a statement of reasons to the complainant. Otherwise, the one against whom a complaint is filed will be notified of the allegation(s) by the Group. The person charged by the allegation(s) is guaranteed the opportunity to respond to the allegation(s).

Steps of Investigation

If a formal investigation should be initiated based on the preliminary findings and lack of informal resolution, the following steps will be undertaken.

1. The Inquiry Group recommends to the WMA Board of Directors that a full investigation be launched to resolve the matter.

2. The WMA Board of Directors then decides whether or not to authorize an investigation to determine the extent of the issues raised in the complaint. If the Board's decision is affirmative, then the Board creates a Fact-Finding Committee. Each member so appointed shall certify to the President of the WMA, or substitute, that he/she is aware of no conflict of interest in accepting the appointment and can remain impartial throughout this phase of the investigation. The individual(s) in question shall have the opportunity to object to any member of the Fact-Finding Committee. The Board of Directors may either accept, or reject, the objection.

3. The individual(s) in question shall cooperate fully with the Fact-Finding Committee and produce any tangible information relevant to the issues raised in the complaint. The individual(s) may submit to the committee any other relevant information and a written answer to the complaint.

4. After the submission of tangible evidence to the Fact-Finding Committee in instances where any issues or facts remain in dispute, and upon written request by the individual(s) in question, a hearing shall be held by the Fact-Finding Committee provided adequate notification is given to the individual(s) in question and provided the hearing would be held at a time and place convenient to the members of the Fact-Finding Committee and the individual(s) in question.

5. The hearing will be conducted by a special meeting of the WMA Board of Directors. All procedures concerning inquiry findings, disposition and appeal will be in strict accordance with this policy. Strict rules of evidence shall not apply, but the Fact-Finding Committee will accept information or evidence that is customarily relied upon by reasonable people in the conduct of serious business.

6. The Fact-Finding Committee shall make written findings of fact and shall determine if the individual(s) in question has, in the conduct of his or her profession, clearly failed to conduct himself or herself in a manner that reflects the dignity and honor of the profession. The Fact-Finding Committee would also report if any individual(s) has(have) failed repeatedly to adhere to the criteria for the award of certification as set out previously. If the Committee ascertains that the individual(s) has(have) failed in his/her(their) conduct or adherence to the criteria as aforesaid, the Committee will include in its written decision its findings on the degree of the severity of the matter and a recommendation for the imposition of sanctions.

Disposition

The following sanctions may apply to members found to have committed an act of deliberate misconduct: warning, reprimand, certification probation, permanent loss of certification, or expulsion from the WMA.

The written decision of the Fact-Finding Committee shall be sent with recommendations to the Board of Directors of the WMA. The WMA Board of Directors, after a review of the decision, shall determine in their judgment the appropriate sanction and administer the same.

Schedule

The intent of the schedule shown below is a) to insure that a person or group against whom a non-frivolous allegation has been filed (the Subject) is informed of the allegation in a timely fashion and has a known/ample period of time to respond, and b) to provide a schedule known by all parties, to facilitate an orderly process and expeditious resolution of the issues.

SCHEDULE* FOR ACTIONS
REGARDING ALLEGATIONS OF MISCONDUCT
WEATHER MODIFICATION ASSOCIATION

DAY	ACTIVITY
0	Written Allegation received by WMA President or the Chair of the Standards and Ethics Committee.
5	WMA Board notified of Allegation.
15	Inquiry Group (n members) named. Inquiry period begins.
20-25	Dismissal of frivolous allegation or decision to continue Inquiry. Subject notified of Allegation if it is deemed non-frivolous and the Inquiry is to proceed.
45	Inquiry period ends with Inquiry Group recommendation to Board. Board specifies if formal Investigation is appropriate. Subject notified of Inquiry Group recommendation and Board decision.
50	Fact-Finding Committee (n members) established. Subject notified of F-F Committee membership. Subject may challenge F-F Committee member(s) if desired.
60	F-F Committee finalized. Investigation period begins.
75	Deadline for Subject responses/inputs.
75-90	Hearing held if requested by Subject
90	Investigation period ends.
105	F-F Committee provides written report and recommendations to Board.
120	Board rules and specifies/administers appropriate sanction(s) or dismisses Allegation.

* The WMA Board reserves the right to modify or extend the schedule at its discretion as circumstances may require. Issues may be resolved, upon achieving mutual satisfaction of all parties involved, at any time during the process.

WEATHER MODIFICATION ASSOCIATION

QUALIFICATIONS AND PROCEDURES FOR CERTIFICATION

PURPOSE OF CERTIFICATION

One of the stated purposes of the WMA is to encourage and promote the highest standards of conduct. In order to further this goal and to protect the public interest, the WMA has established a certification program for individuals qualified to manage and/or operate weather modification field programs of a research or operational nature.

Two types of certification have been established: (1) a Certified Weather Modification Manager who has the character, knowledge and experience necessary to design, manage, evaluate and have overall responsibility for a weather modification program; (2) a Certified Weather Modification Operator who has the character, knowledge and experience necessary to provide the day-to-day, on-site supervision of a weather modification field program.

QUALIFICATIONS FOR CERTIFICATION

Weather Modification Manager - Certification shall be based on character, knowledge and experience. Certification shall be granted at the discretion of the Board, but the following shall be considered minimum requirements:

Category A: Eight years' (96 active months) experience in weather modification research and/or operations.

Category B: A Bachelor's Degree with at least 25 semester hours of meteorology plus five years' (60 active months) experience in weather modification research and/or operations.

Category C: A Master's Degree or a Doctorate in Atmospheric Science and three years' (36 active months) experience in weather modification research and/or operations.

The experience requirement may be fulfilled by either field work or office or laboratory studies.

In addition to the above requirements, the applicant must pass a written examination (open book type) and an oral examination by the Certification Board. The applicant must also submit a report authored or co-authored by the applicant demonstrating the extent of his or her involvement in weather modification. The report must be more than an operations report and must exhibit skills in research or the theory and practice of weather modification.

The applicant must agree to accept and abide by the current WMA Code of Ethics and any Statement of Standards and Practices that the WMA has adopted at the time of application.

Weather Modification Operator: - Certification shall be based on character, knowledge and experience. Certification shall be granted at the discretion of the Board, but the following shall be considered minimum requirements:

Category A: Twenty months' actual "in the field" experience in weather modification research and/or operations.

Category B: A degree with at least 25 semester hours of meteorology and eight months' actual "in the field" experience in weather modification research and/or operations.

The field experience must be in a project or projects designed to effect a change in the weather. Actual manipulation to produce a desired change is implied. The experience needs to be in a "responsible charge" position involving making treatment decisions and project management.

An oral examination may be required of the applicant. The applicant must agree to accept and abide by the WMA Code of Ethics and any Statement of Standards and Practices that the WMA has adopted at the time of application.

References are required from the employer, sponsor, or project manager for any field experience claimed. No experience credit will be given for any claimed time which is not supported by a favorable reference.

PROCEDURE AND FEES FOR CERTIFICATION

Persons desiring certification as individuals qualified for managing or conducting field experiments or operations in weather modification shall write to the Secretary of the Weather Modification Association requesting an application form and instructions. The completed application form shall be returned to the Secretary and must be accompanied by a check in the amount of $150.00 for a Certified Manager application and $75.00 for a Certified Operator application made payable to the Weather Modification Association. This fee will be retained by the Weather Modification Association whether the application is accepted or denied.

The Certification Board shall review the application form and all other information required and will determine whether the applicant has satisfied the requirements for qualification for certification. The Certification Board may request additional information from the applicant prior to making a final decision as to whether or not the applicant meets the criteria for certification.

After review of the application, the Chairman of the Certification Board shall notify the applicant of the decision of the Board. If the application is approved, the Chairman of the Certification Board shall give the applicant a certificate to verify that the individual has met the qualification for certification.

Unsuccessful applicants may reapply for certification not earlier than one calendar year after notification of disapproval. Each subsequent application for certification shall be accompanied by a payment of the normal fee.

PERIOD OF CERTIFICATION AND RENEWAL

Certification of a member shall be effective for a period of three years from the date of issuance. Application for renewal of certification shall be submitted prior to expiration date in writing and accompanied by a fee of $150 for a Certified Manager or $75 for a Certified Operator. The same fees apply for those seeking reinstatement after a lapsed certification. Issuance of renewal or reinstatement shall be granted by the Board if there has been no indication of violations of the WMA Code of Ethics, or the current statement on Standards and Practices, and the applicant provides evidence of a continuing involvement in weather modification during the preceding years amounting to at least 20% of his or her professional working hours, or the applicant is deemed to be knowledgeable on the current status of weather modification technology as determined by the Certification Board. If the Board does not recommend renewal or reinstatement, the case may be presented for the consideration of the certified members at any regular meeting if the applicant requests. Renewal or reinstatement shall be denied only if a majority of the certified members in attendance at the meeting indicate by secret written ballot that renewal shall be denied. The fee will be retained whether renewal or reinstatement is granted or not.

WEATHER MODIFICATION ASSOCIATION

CERTIFIED WEATHER MODIFICATION OPERATORS/MANAGERS AND HONORARY MEMBERS

- CERTIFIED OPERATORS -

Cert. No.	Name	Affiliation or Location
12	Thomas J. Henderson	Atmospherics Incorporated, CA
19	Don A. Griffith	North American Weather Consultants, UT
22	Conrad G. Keyes	NMSU Emeritus Professor and Dept. Head, NM
37	Albert Schnell	AIRAO Enterprises, CO
47	David L. Newsom	Atmospherics Inc., CA
50	Mark E. Solak	North American Weather Consultants, UT
51	Danny A. Risch	North American Weather Consultants, UT
57	Ray Pat Jones	Big Springs, TX
59	Patrick H. Sweeney	Weather Modification Inc., ND
62	Hans Peter Ahlness	Weather Modification Inc., ND
65	Mark D. Schneider	Weather Modification Inc., ND
66	Aaron A. Gilstad	Weather Modification Inc., ND
68	David A. Beer	Western Kansas Groundwater District No. 1, KA
69	Fred M. Remer	Fargo, ND
71	Thomas P. DeFelice	Raytheon, ITSS, NPOESS
72	Chad Allen Hahn	La Moille, IL
73	David P. Yorty	North American Weather Consultants, UT

- CERTIFIED MANAGERS -

Cert. No.	Name	Affiliation or Location
6	Thomas J. Henderson	Atmospherics Incorporated, CA
8	Don A. Griffith	North American Weather Consultants, UT
9	Edward E. Hindman	City College, New York City, NY
10	Mark E. Solak	North American Weather Consultants, UT
11	James A. Heimbach, Jr.	University of North Carolina, NC
12	Bruce A. Boe	North Dakota Atmospheric Resource Board, ND
13	Terry W. Krauss	Weather Modification Incorporated, Alberta, Canada
14	Darin W. Langerud	North Dakota Atmospheric Resource Board, ND

- HONORARY MEMBERS -

Marion N. Bruce (deceased)	South Dakota Weather Control Comm., McIntosh, SD
Stuart A. Cundiff (deceased)	California Electric Power Company, San Bernadino, CA
Charles J. Dommes (deceased)	Los Angeles Dept. of Water & Power, Los Angeles, CA
William A. Lang (deceased)	Southern California Edison Company, Los Angeles, CA
Vincent J. Schaefer (deceased)	State University of New York, Albany, NY
Robert D. Elliott (deceased)	Montecito, CA
Thomas J. Henderson	Atmospherics Incorporated, Fresno, CA
Wilbur E. Brewer (deceased)	Bowman, ND
Keith J. Brown	Port Ludlow, WA
Bernard Vonnegut (deceased)	Albany, NY

WEATHER MODIFICATION ASSOCIATION AWARDS

- THE SCHAEFER AWARD -

The **Schaefer Award** is the most coveted award presented by the Weather Modification Association. The recipient is chosen by the Executive Committee and Awards Committee during Annual Meetings with candidate suggestions by committee members and from the general membership. It is not mandatory the award be given each year. The honored recipient receives a plaque which is inscribed with the following:

"FOR SCIENTIFIC AND TECHNOLOGICAL DISCOVERIES THAT HAVE CONSTITUTED A MAJOR CONTRIBUTION TO THE ADVANCEMENT OF WEATHER MODIFICATION"

RECIPIENTS:	Vincent J. Schaefer (deceased)	1976	Los Angeles, California
	Bernard Vonnegut (deceased)	1977	Salt Lake City, Utah
	Robert D. Elliott	1978	Tucson, Arizona
	Joanne Simpson	1979	Reno, Nevada
	William G. Finnegan	1980	Santa Barbara, California
	Abraham Gagin	1982	Fresno, California
	Joseph A. Warburton	1985	Monterey, California
	Roscoe R. Braham, Jr.	1987	Albuquerque, New Mexico
	Lewis O. Grant	1991	Ontario, California
	Harold D. Orville	2003	Rapid City, South Dakota
	Thomas J. Henderson	2003	Rapid City, South Dakota

- THE THUNDERBIRD AWARD -

The **Thunderbird Award** is a sacred and honored presentation which recognizes fundamental and continuing contributions to the art and science of weather modification. The recipient is chosen by the Awards Committee, composed of three previous recipients of the Thunderbird Award. The award is presented each year at the Annual Meeting. The honored individual receives a beaded neck piece and replica of a historic North Plains Indian Medicine Bundle reputed, as recounted by the late Marion N. Bruce, to confer great rainmaking powers on the bearer. The recipients of the Medicine Bundle must add a sacred object of his own choice and pass this bundle to the next recipient.

RECIPIENTS:	Robert D. Elliott	1973	Austin, Texas
	Pierre St. Amand	1974	Huntington Beach, California
	E. C. (Taffy) Bowen	1975	Santa Barbara, California
	Bill Lang	1976	Los Angeles, California
	Thomas J. Henderson	1977	Salt Lake City, Utah
	Ray Jay Davis	1978	Tucson, Arizona
	Archie M. Kahan	1979	Reno, Nevada
	Conrad G. Keyes, Jr.	1980	Santa Barbara, California
	Paul C. Summers	1981	Ft. Collins, Colorado
	Emilio Perez-Siliceo	1982	Fresno, California
	Arnett S. Dennis	1983	Champaign, Illinois
	Merlin C. Williams	1984	Bismarck, North Dakota
	Keith J. Brown	1985	Monterey, California
	Stanley A. Changnon	1986	Arlington, Virginia
	Arnold Court	1987	Albuquerque, New Mexico
	John W. James	1988	Costa Mesa, California
	Arlin Super	1989	Park City, Utah
	Wallace E. Howell	1990	Sparks, Nevada
	Harold D. Orville	1991	Ontario, California
	William L. Woodley	1992	Denver, Colorado
	Don A. Griffith	1993	Scottsdale, Arizona
	Paul L. Smith	1995	Durango, Colorado
	Robert Czys	1996	Monterey, California
	James R. Miller	1997	Las Vegas, Nevada
	Bruce A. Boe	1998	Park City, Utah
	Roger F. Reinking	1999	Banff, Alberta, Canada
	William G. Finnegan	1999	Banff, Alberta, Canada
	George W. Bomar	2000	Lubbock, Texas
	Daniel Rosenfeld	2001	Oklahoma City, Oklahoma

WEATHER MODIFICATION ASSOCIATION AWARDS (cont'd.)

Joseph A. Warburton	2002	Reno, Nevada
James H. Renick	2003	Rapid City, South Dakota

- WEATHER MODIFICATION ASSOCIATION INTERNATIONAL AWARD -

Commemorative medallions presented to the WMA at the 1985 meeting in France, and now permanently displayed in a lucite box, serve as the centerpiece for this rotating International Award. It is presented to a special individual or group who has performed outstanding services in the area of cooperative efforts toward any aspect of weather modification at the international level. The recipient is chosen by the Executive Committee from candidates suggested at their annual meeting. It is not mandatory the award be given each year.

RECIPIENTS:	John W. James	1986	Arlington, Virginia
	Roger Serpolay	1986	Arlington, Virginia
	John Dessens	1987	Albuquerque, New Mexico
	Harold Orville	2000	Lubbock, Texas

- THE BLACK CROW AWARD -

The **Black Crow Award** is presented to those individuals who for one reason or another have found themselves plagued with an extraordinary number of adversities or mishaps. Of course, the true cause of these adversities can frequently be traced directly to the recipients themselves. The "Crow" is presented at each Annual Meeting in partial recompense for those misfortunes suffered during the previous year. The recipient is chosen from candidates suggested to the Awards Committee.

RECIPIENTS:	Hoyt Hart	1973	Austin, Texas
	Keith J. Brown	1974	Huntington Beach, California
	Thomas J. Henderson	1975	Santa Barbara, California
	Stanley A. Changnon	1976	Los Angeles, California
	Conrad G. Keyes, Jr.	1977	Salt Lake City, Utah
	Ray Jay Davis	1978	Tucson, Arizona
	William Carley	1979	Reno, Nevada
	Paul Mielke	1980	Santa Barbara, California
	Larry Davis	1981	Ft. Collins, Colorado
	Merlin Williams	1982	Fresno, California
	William G. Finnegan	1983	Champaign, Illinois
	R. Lynn Rose	1984	Bismarck, North Dakota
	Ralph Papania	1985	Monterey, California
	Wilbur E. Brewer	1986	Arlington, Virginia
	Barbara Welles	1987	Albuquerque, New Mexico
	Larry W. Rowe	1988	Costa Mesa, California
	Robert D. Elliott	1989	Park City, Utah
	Maurice Roos	1990	Sparks, Nevada
	John C. Lease	1991	Ontario, California
	Joseph H. Golden	1992	Denver, Colorado
	Keith J. Brown	1993	Scottsdale, Arizona
	Don A. Griffith	1994	San Antonio, Texas
	Mark E. Solak	1994	Salt Lake City, Utah
	Arlin B. Super	1995	Durango, Colorado
	Dennis W. Sundie	1996	Monterey, California
	Bruce A. Boe	1997	Las Vegas, Nevada
	George W. Bomar	1998	Park City, Utah
	No award given	1999	Banff, Alberta, Canada
	Rick Stone	2000	Lubbock, Texas
	Roger Tilbury	2001	Oklahoma City, Oklahoma

WEATHER MODIFICATION ASSOCIATION AWARDS (cont'd.)

Thomas P. DeFelice	2002	Reno, Nevada
Joe Busto	2003	Rapid City, South Dakota

WEATHER MODIFICATION FIELD METEOROLOGIST DISTINGUISHED SERVICE AWARD

This **Distinguished Service Award** is presented to exemplary weather modification field meteorologists who have provided outstanding services in the conduct of weather modification operations and/or research. The award recognizes their dedication, skills and professionalism which contribute significantly to the success of field programs, and reflects well on the profession and the WMA. Recipients are chosen by the Awards Committee from nominations directed to the Committee. It is not mandatory that this award be presented each year.

RECIPIENTS:	David L. Newsom	2003	Rapid City, South Dakota

WEATHER MODIFICATION PILOT/TECHNICIAN DISTINGUISHED SERVICE AWARD

This **Distinguished Service Award** is presented to exemplary weather modification pilots or technicians who have provided outstanding services in the conduct of weather modification operations and/or research. The award recognizes their dedication, skills and professionalism which contribute significantly to the success of field programs, and reflects well on the profession and the WMA. Recipients are chosen by the Awards Committee from nominations directed to the Committee. It is not mandatory that this award be presented each year.

RECIPIENTS:	James M. Wood	2003	Rapid City, South Dakota
	Hans P. Ahlness	2003	Rapid City, South Dakota

2003 WMA Annual Meeting
Rapid City, South Dakota

Joe Golden and Dale Bates

Tom Henderson and Rick Stone

Joe Warburton and Hilda Duckering

Harry Orville, Arlen Huggins, and Laura Orville

Andy Detwiler and Dan Breed

Madeline Dessens, Roger Reinking, Jean Dessens, and Joe Warburton

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The *JOURNAL OF WEATHER MODIFICATION*, published since 1969, has documented major and minor developments in this important field. The 36 issues to date include articles by most of the leading theoreticians, experimenters and commercial operators throughout the world. Published once a year during its first six years, the *Journal* appeared twice during 1975 and again in 1976. Volume 7, No. 1, included 19 papers on operational programs, public opinions, and the progress of several research projects. The issue was dedicated to Marion Nelson Bruce, a true American pioneer who was strongly influential in the development of modern cloud seeding technology in South Dakota. Volume 7, No. 2, contains papers on hail suppression from the first WMA meeting outside the U.S., at Calgary, Alberta, in September 1975.

Volume 8, No. 1, contains nine papers on a wide variety of weather modification subjects including inadvertent modification, cloud seeding experiments, hail suppression, and nuclei. Volume 8, No. 2, was a special Silver Anniversary issue dedicated to Dr. Vincent J. Schaefer, the discoverer of the use of dry ice as an ice nucleating material in 1946 and the "father" of modern cloud seeding science and technology. Volume 9 contained 18 papers on a broad range of subjects from inadvertent weather modification to operational programs, social issues, and research programs. Volume 10 was distributed at the Spring Meeting in Tucson, Arizona, April 1978, and contains 9 papers on projects outside the U.S. and 11 papers on environmental aspects of silver iodide, a summary of U.S. programs in CY1976 and 1977, USBR Skywater information, and a few legal aspects of weather modification.

Volume 11 was distributed at the Spring Meeting in Reno, Nevada, April 1979. This was the first issue of *JWM* with sections for both reviewed and non-reviewed papers. The volume contains information on hail suppression, numerical simulation, radar applications, economic aspects, and a listing of projects conducted in the U.S. during CY1978. Volume 12 was circulated at the Spring Meeting in Santa Barbara, California, April 24-25, 1980. A significant landmark was the addition of a color cover. Five papers appeared in the reviewed section and 11 in the non-reviewed section. Volume 13 was available at the Spring Meeting in Ft. Collins, CO, 9-10 April 1981. Publication was large at 262 pages. There were 18 reviewed and 8 non-reviewed papers covering programs in the U.S. and seven other countries. Volume 14 contained 12 papers in the reviewed section; 7 dealt with projects in countries outside the U.S., China, Chile, and southeast Asia and were newcomers to the *Journal*. The new Certification Program became an official part of WMA.

Dr. Bruno Federer passed away in December 1982 and his accomplishments were noted in Vol. 15. This issue carried 14 reviewed papers from the U.S., France, Italy, and Yugoslavia. The decline of weather modification operations and research in the U.S. was noted along with the increase in worldwide activities. Volume 16 was circulated at the meeting in Bismarck, ND, July 1985. It carried 8 reviewed and 4 non-reviewed papers, plus all of the general information material on projects at national and international levels. The issue was dedicated to Mr. Olin H. Foehner. Volume 17 noted the first time in the 35-year history of the WMA that a meeting was organized in any country beyond the U.S., Canada, and Mexico. Special appreciation was extended to the hosts in France. Ten reviewed papers and 3 non-reviewed papers were published. Volume 18 carried 27 reviewed papers with several coming from the various groups in France following the 1985 WMA Meeting in Clermont-Ferrand and Toulouse. The new WMA International Award evolved from this meeting.

Volume 19 was distributed at the April 1987 Annual Meeting in Albuquerque, New Mexico. This issue included 17 reviewed papers covering such subjects as precipitation augmentation, hail suppression, program design, and numerical simulations. The international aspect was furthered by a paper from China. Volume 20 included 13 papers covering the subjects of liquid water, ice nucleation, crop production, hail suppression, results from operation programs, and legal aspects. It was distributed at the annual meeting held at Costa Mesa in April 1988, and dedicated to Abe Gagin, a strong force in weather modification at the international level. Volume 21 contained 14 reviewed papers on a broad range of topics from operational programs to cloud models. A major topic at the annual meeting held at Park City, Utah, in May 1989, focused on Weather Modification in the 1990s, including future strategies for the Association's *Journal*.

Volume 22 continued the tradition of a color cover and included 19 reviewed papers and 3 non-reviewed articles on a variety of scientific research programs and operational projects in the U.S. and other countries, plus a summary of cloud seeding activities in the U.S. as tabulated by the Dept. of Commerce. It was the largest issue since 1981 and was distributed in May 1990 at the Annual Meeting in Sparks, Nevada.

Volume 23 commemorated the 40th Anniversary of the WMA and the 23rd year of *Journal* publication, all 23 years under the editorship of Thomas J. Henderson. The volume contained 9 reviewed papers on various aspects of applied weather modification. The cover and several photographic pages illustrated some of the individuals who played a strong role in the formative years of the Association. A eulogy was included for Dr. Patrick Squires, a pioneer in atmospheric science, who passed away on 15 November 1990.

Volume 24 contained 11 reviewed papers and 3 non-reviewed articles. The cover photos were from Utah and reflected activities and scenes related to 3 papers discussing the Utah Federal/State cooperative research program sponsored by NOAA. Volume 25 contained 7 reviewed papers and 2 non-reviewed articles. Three papers were related to the Illinois State Water Survey's 1989 exploratory cloud seeding experiment (one modeling and two analysis papers); two papers, to winter orographic situations; one paper presented an analysis of hail suppression cloud seeding effects on weather observations in Yugoslavia; and one paper reviewed some of the consequences of the 1972 Rapid City, SD flood. Copies of the WMO, AMS, and WMA statements regarding weather modification were reproduced for the perusal of the membership. Cover photos were provided by Bruce Boe. A tribute to Wilbur Brewer's retirement was provided by Bruce Boe with a few "ancient" related photos furnished by Tom Henderson.

Volume 26 was dedicated to the memory of Vincent J. Schaefer (1906-1993). Mr. Thomas J. Henderson provided a nice photo-history for this purpose. Fifteen articles were included in Volume 26 (14 reviewed, 1 non-reviewed), and other topics made up the issue. A good representation from both the U.S. and other countries was included. The cover photo was provided by T. Henderson. Thanks to Ward for his input. Volume 27 contained 6 reviewed papers and 3 non-reviewed articles. Dr. Arlin Super and his colleagues were to be commended for contributing heavily to that issue of the Journal. The retirement of Dr. Ray Jay Davis was celebrated on the last pages (photos by Tom Henderson). A memory page was included for Lawrence "Bud" Youngren. Volume 28 contained 8 reviewed papers and 2 non-reviewed articles; models, observations, downwind effects, and remote sensing were among the topics presented.

Volume 29 was dedicated to the memory of Bernard Vonnegut (1914-1977). It contained 8 reviewed papers and 6 non-reviewed articles. Volume 30 contains 5 reviewed papers and 2 non-reviewed articles. The "In Remembrance" for Dr. Graeme Mather was prepared by P.L. Smith. Volume 31 contains 11 reviewed papers (one comment and reply to a previous paper), and one non-reviewed. The "In remembrance" for Clem Todd was prepared by Wally Howell. Also included are an activity report provided by Joe Golden, and an updated AMS Policy Statement on Weather Modification.

Volume 32 contained 6 papers in the reviewed section and 4 in the non-reviewed section. It was dedicated to Wally Howell and Arnold Court, two well-known scientists involved in related weather modification research. Volume 33 contains 3 papers in the reviewed section and 3 in the non-reviewed section. Volume 33 was dedicated to Mr. Ray Jay Davis, the Weather Modification Association's "legal eagle". Volume 34 had 4 papers and a comment and reply in the reviewed section of the *Journal* and 9 non-reviewed contributions. Volume 35 was dedicated to the memory of Robert D. Elliott. It contained 2 reviewed papers and 4 articles and a comment and reply in the non-reviewed section.

Volume 36 contains one paper and one reply in the reviewed section, and seven non-reviewed articles.

Pages of the *Journal* are 8.5 x 11 inches (216 x280 mm). Covers are sturdy paper-board. Total pages in each issue are:

VOL.	1	2	3	4	5	6	7:1	7:2	8:1	8:2	9	10
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YEAR	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
PAGES	225	116	262	109	103	116	104	180	163	182	158	230

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PAGES	170	158	135	161	140	120	152	154	179	120	108	141

VOL.	35	36
YEAR	2003	2004
PAGES	127	158

ISBN 0739-1781

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Number 2 December 1975

EDITOR'S NOTE
Volume 7, Number 2, is a special edition of THE JOURNAL OF WEATHER MODIFICATION. The publication arose from the high interest in the program developed for the Fall Meeting held in Calgary, Canada, 4-5 September 1975. Formal papers and comments presented at that meeting were considered by the membership to be of sufficient importance for assembling in a single volume of JWM. The Publication Committee appreciates that response from those who presented information at that meeting and organized their presentations for publication.

For purposes of this volume, the various presentations are reprinted exactly as the authors submitted their material.

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NOTE:
The following papers were scheduled for presentation at the Silver Anniversary Meeting of the Weather Modification Association but were not available for publication in this issue:

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JOURNAL NOTES

A CHARGE OF $50.00 PER PAGE WILL BE APPLIED TO EACH PAPER, ARTICLE AND NOTE ACCEPTED FOR PUBLICATION IN VOLUME 37, TO BE PUBLISHED IN APRIL 2005. A SUPPLEMENTAL SURCHARGE OF $120.00 PER PAGE IS APPLIED FOR COLOR PAGES. PAPERS FROM SOURCES OUTSIDE THE UNITED STATES WILL ALSO BE REQUIRED TO PAY THESE PAGE CHARGES (U.S. CURRENCY).

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WMA ANNUAL MEETING - 2004

April 29-30, 2004 Piccadilly Inn (Airport)
Fresno, California

WMA ANNUAL MEETING - 2005- To be announced

INSTRUCTIONS AND FORMAT FOR PREPARATION OF CAMERA-READY MANUSCRIPTS ACCEPTED FOR PUBLICATION IN THE 2005 JOURNAL OF WEATHER MODIFICATION

Abstract. To give authors more control over the arrangement and format of their papers and reduce production costs, so as to avoid any increase in page charges, each author is asked to provide a final version of his paper, typed in two columns on regular sized (8.5" x 11") paper, 1-inch margins (top, bottom, left and right), with 1/2-inch between the two columns, using **10-point** serif type (as shown here). This version will incorporate any changes suggested by the Editor or his referees after consideration of the original manuscript. Details of format and arrangement, and of style and referencing, are given in the following text and example.

1. ANNOUNCEMENT

Effective with Vol. 13 for 1981, the *JOURNAL OF WEATHER MODIFICATION* adopted a **double-column reduced typescript format.** After editorial review and acceptance, each article will be returned to its author for final typing on **8.5" x 11" paper, two-column format, in 10-point type with 1-inch top, bottom, left and right margins and 1/2 inch between the two columns.**

These procedures have been adopted by the Editorial Board of the Weather Modification Association to improve the appearance of the *JOURNAL* while also increasing the number of words per page. They should also result in a more compact page and better arrangement of articles, in addition to reducing the workload and expenses in the editorial office.

The system will provide authors with almost complete control over the composition and arrangement of their papers, subject to the basic style rules of the *JOURNAL*. These procedures are similar to those used by various professional societies for conference preprints. The formatting instructions (style sheet) will be sent to each author with their notice of paper acceptance and reviewers' comments.

2. REQUIREMENTS

Upon acceptance, each article is to be typed on **8.5" x 11" paper, using 10-point serif type, in double column format (1/2-inch between columns)**. For authors who cannot arrange such final typing, the *JOURNAL* editorial staff will provide this service for a modest typing charge.

Line drawings and photographs with good contrast can be mounted directly on the final pages, with legends typed below them, preferably in *italics*. Please use photographs sparingly, because these entail extra printing costs, require halftone negatives or "screened" photos. Tables and figures should be incorporated into the papers at suitable places. Use paste or rubber cement to attach columns, figures, or tables -- DO NOT USE TAPE. Text will be in a normal two-column format, with 1/2-inch between columns, which can be broken for formulas, tables, and figures. Please allow extra space at the top margin to allow for addition of the page headers.

2.1 Style Details

Titles of papers should be informative but short (preferably less than 10 words) and should be centered **1 inch below the top border** of the first page. Each author should be identified by affiliation, with a minimal postal address. Two authors should be listed in parallel boxes across the page.

An informative abstract of 50 to 200 words must precede each paper (formatted as shown above). It should contain numerical results and all conclusions, not just a description of the problem and methodology. Abstracts will not contain equations or acronyms.

The pages should be divided into sections of 300 to 1,000 words each, with an arabic-numbered heading, flush left, in capital letters. Subsection headings may be decimally numbered, capital and lower case, underlined, flush left. Leave one blank line before and after all headings, between paragraphs, and place one blank line between each of the references in the reference listing. [The layout of these instructions follows the WMA format rules.]

Acknowledgments. Acknowledgments (of financial support, provision of data, loan of equipment, advice, etc.) should be given in a final section, preceding references.

2.2 Units and Measures

In general, the International System of Units is standard in *JOURNAL* publications. SI units (m, kg, s, K) should be used throughout but not at the expense of clarity (Anon, 1974).

Since authors will be responsible for the final typing of any formulas or mathematical expression, they must be prepared to present Greek letters or other symbols by typewriter, hand lettering, or stick-up. Expressions should be properly arranged and spaced for ready comprehension. Formulas and equations may be numbered, at the extreme right end of the line, for further reference: "Substitution of Eq. (3) into Eq. (5) yields...." Formulas not mentioned should not be numbered.

2.3 References

Each reference should be generally available, as in the library of a large university. Contract reports, conference preprints, in-house publications, and similar material may be cited only if available through NTIS (with number given), or if the author guarantees to supply copies.

Every reference should have been cited at least once in the text, table notes, or figure descriptions. References should give author (last name first for first author only), year, title, journal or publisher, volume and inclusive pages. Well-known journals may be abbreviated (*J. Wea. Mod., J. Appl. Meteor., Bull. Amer. Meteor. Soc., Amer. Geophys. Union*, etc.), but others should be given in full.

For any reference in a foreign language, the title should be in the original language, with an English translation in parentheses. Place and year of first publication should be given, with any reprinting identified in parentheses.

3. PROCEDURES

To submit paper:

Draft papers for the reviewed section should be double-spaced, and three copies provided to the Editor by 15 November 2003 for adequate review prior to the next April publishing date. Draft papers or Notes for the non-reviewed section should be double-spaced and two copies provided to the Editor by 15 January 2004.

Upon acceptance by the Journal:

Only the original of the **final** typed version, typed in double columns, need be returned to the editorial staff, but authors should retain photocopies for safety. The final typed version must be single-spaced. A diskette copy is required in Microsoft Word for Windows or Word Perfect.

To implement these procedures and still publish by April, the original unfolded manuscripts should be sent to reach the WMA editor in Reno, NV, by **March 1, 2005.** This will permit orderly handling, preparation, printing, etc.

4. REFERENCES

Anon, A. A., and B. B. Jones, 1974: SI units to be used in AMS journals. *Bull. Amer. Meteor. Soc.*, **55**, 916-930.

[Note: Last name first for **first author only!**]

APPENDIX I: SAMPLE FOR PAPER TITLES AND AUTHORS

INTERCOMPARISON OF MEE AND NCAR ICE NUCLEUS COUNTERS AND THE CSU ISOTHERMAL CHAMBER

and

G. Langer
National Center for Atmospheric Research
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D. Garvey
Colorado State University
Fort Collins, CO 80523

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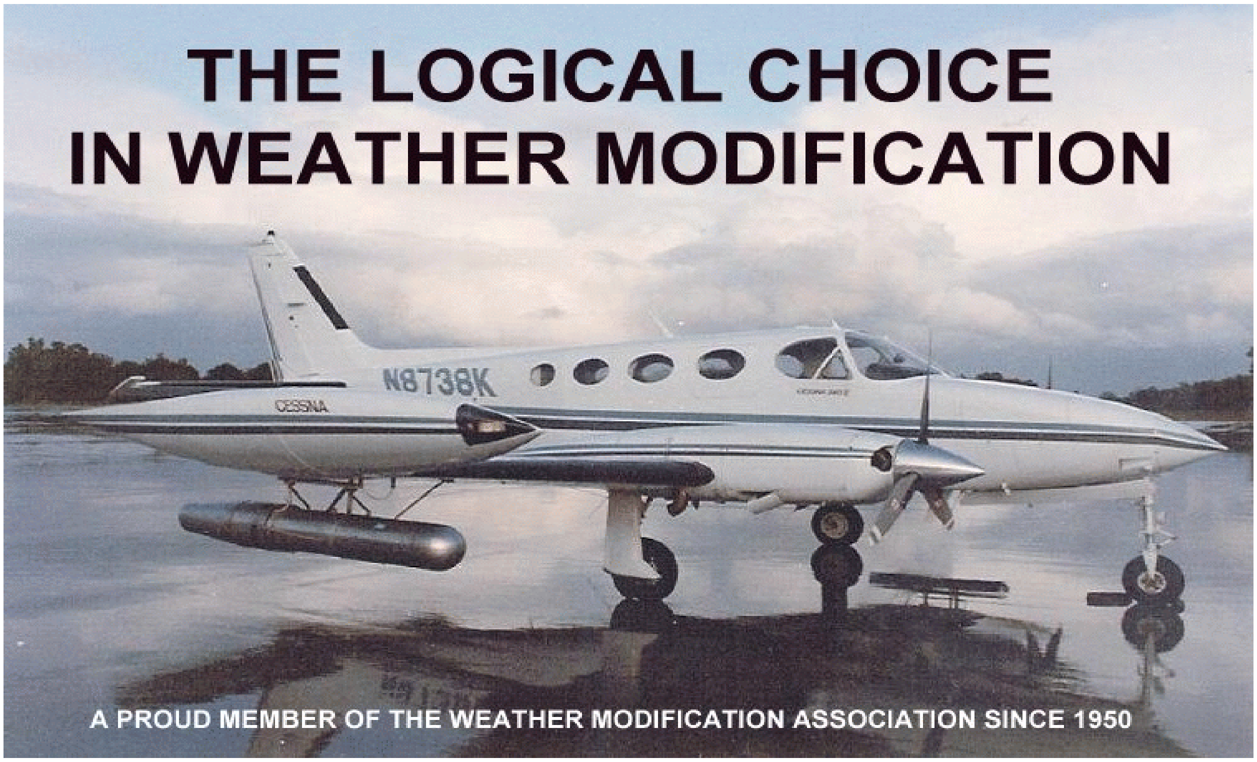

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