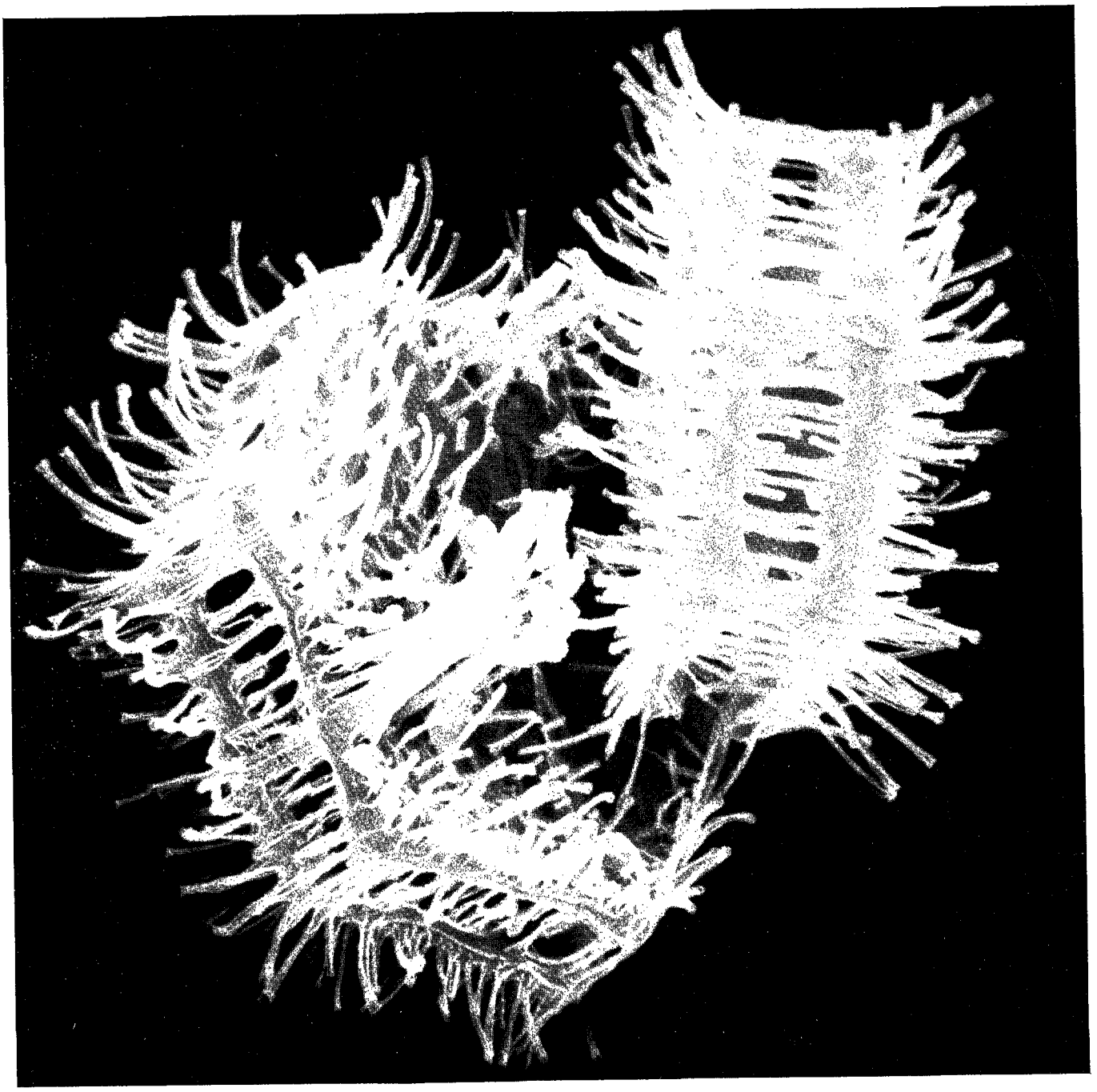
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The Journal of Weather Modification

Volume 6 Number 1 April 1974



Cover Photograph

Two ice crystals, replicated while airborne, show detailed "whisker" growth features. The form is similar to a small capped column with thin caps spaced 10μm apart. The whisker concentration bridges the gap between the caps. The distribution of the whiskers and the geometry determine the deposition of the whisker collected water onto the crystal surface.

These rapidly grown ice crystals were replicated with methyl 2-cyanoacrylate while still airborne. The vapor replication technique incapsulates the ice crystals minimizing the migration of water to reduce the surface area and produce crystals with a smooth surface. The replica was coated with platinum and photographed with a scanning electron microscope. Total width of the photograph is approximately 90μm.

Official U. S. Navy Photograph
Submitted by Dr. Kirk Odencrantz
Earth & Planetary Sciences Div.
Naval Weapons Center
China Lake, California





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- THE JOURNAL OF WEATHER MODIFICATION -

WEATHER MODIFICATION ASSOCIATION

Volume VI Number 1 April 1974

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WEATHER MODIFICATION OUTLOOK - 1985 PROJECTION[1]

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1. INTRODUCTION

When first approached to project some views on the state of affairs of weather modification to 1985, a temptation arose to stop at "1984." All sorts of Orwellian fantasies and contrived situations came to mind that might liven such a discourse. Indeed many skeptics would argue that weather modifiers have already indulged in considerable fantasy. However, the temptation was resisted because the somewhat tarnished discipline still possesses substantial scientific excitement; secondly, it would not be fair to the many dedicated researchers over the years who have made valuable contributions to our understanding of weather modification and related cloud physics.

It might be well to recall McDonald's (1958) account of the very slow progress being made in cloud physics during the 1900's when such research was considered only of academic interest. He stated:

> "When, after 1946, there seemed to exist some prospect of control over a natural phenomenon whose economic value is so high, support of cloud physics research jumped by, what I would estimate must surely have been a factor of two to three orders of magnitude . . . "

To some that would represent sufficient raison d'etre, even if not a single drop of rain were coaxed from a cloud or not one storm suppression concept proved feasible.

Weather modification emerged as a science in 1946 with the discoveries at the General Electric Research Laboratory that dry ice and silver iodide could modify supercooled clouds (Schaefer, 1946; Vonnegut, 1947). Earlier activities, with the exception of hygroscopic treatment of fogs (Houghton and Radford, 1938), generally relied more on faith than sound physical principles.

Thus the period of "enlightenment" has covered a time span only slightly in excess of a quarter century. Unfortunately, this recent period too has witnessed a share of poorly conceived programs, unqualified operators, and debatable results. The efforts often have suffered from a lack of continuity, attributable in part to sporadic funding and low priorities. Never-

[1]Portions of this paper were previously prepared at the request of the American Meteorological Society for its use.

theless, considerable progress has been made in understanding and evaluating certain weather modification concepts and the basic cloud physics principles underlying them. Many would still subscribe to the concluding statement of the 1967 American Meteorological Society statement on Weather and Climate Control: ". . . weather and climate modification present opportunities for achieving great benefit to mankind. They deserve the continuing attention and understanding of scientists and the general public." This continuing concern was illustrated by the recent WMO International Conference on Weather Modification (October 1973) in Tashkent, Russia, where some 400 participants from 30 countries were represented.

Weather modification activities can be categorized in several ways, the following being one convenient representation:

(1) Rain or snowfall enhancement

(2) Severe storm amelioration

a. Intensity reduction
b. Redistribution of precipitation

(3) Fog and stratus cloud dissipation

(4) Inadvertent weather and climate modification

It is helpful also to distinguish between supercooled cloud conditions, where some substantial modification results have been obtained, and warm clouds, where positive results to date have been meager.

The following assessment will attempt to describe, though perhaps not evenly, the major concepts being investigated today. While not discussed at length, more attention in the future will be devoted to the social, economic and legal aspects of weather modification because of the growing constraints that they can impose. There is perhaps prophetic truth in the following comment of the 1971 Interdepartmental Committee for Atmospheric Sciences (ICAS) report:

> "What the public thinks about weather modification, rather than what scientists know about it, will play the dominant role in the future of this science."

It is my view that the likelihood of conducting weather modification programs diminishes as the population density increases, quite apart from any question over scientific promise or lack thereof. The reasons for this "population rule" are rather obvious:

a. The larger the city or territory involved, the greater are the commercial interests represented. This diversity leads to differing weather and climatic needs such that certain groups are apt to resist weather modification, even if it holds promise of benefitting the majority. It has been demonstrated time and again that a vociferous minority can have the impact of an army.

b. A large population density in itself often implies weather conditions that are generally favorable so that modification concepts are subtle and perhaps difficult to substantiate.

Of course, there are exceptions to the above, such as diminishing catastrophic weather and eliminating fog at airports - few would object to these goals providing no adverse side effects are involved or imagined. The statement holds best, though not exclusively, for rain making experiments.

2. WEATHER MODIFICATION CONCEPTS

Despite a two decade search for more effective nucleating agents for supercooled clouds, silver iodide (AgI) continues to be the most commonly used material. It can be dispersed in several ways (combustion generators, pyrotechnic flares, charges, etc.), a well designed unit producing as many as 10^{15} ice nuclei per gram at -15C. While some organic compounds are being discovered that possess a somewhat warmer ice-activation threshold (Fukuta and Mason, 1963), the nucleus output per gram of AgI and handling qualities give it a substantial edge over rival agents. Dry ice is more effective at warmer temperatures (0 to -7C), but at progressively colder temperatures some 2 to 4 orders of magnitude more material is required to produce the same concentration of ice nuclei as obtained with AgI.

For the seeding of warm clouds and fogs, hygroscopic nuclei head the list. Sodium chloride, calcium chloride, urea, phosphates, various polyelectrolytes, etc. have been employed. While cheap and reasonably easy to handle, salts such as NaCl will experience continuing disfavor for at least heavy localized use because of their corrosiveness and society's growing ecological concerns. Water as a warm cloud stimulant is theoretically but not practically feasible because of the inefficient mass required. Polyelectrolytes, long chain molecules whose proponents maintain can charge droplets and enhance coalescence, are under study but the results to date are conflicting and dubious.

The basic premise behind augmenting precipitation or of reducing storm severity is that the number of efficient nucleating particles naturally present is generally inadequate. For cold clouds this deficiency presumably can be remedied by the addition of ice nuclei which promotes the Bergeron ice-crystal growth mechanism; overseeding, it is argued, should produce numerous small crystals that might inhibit hail development and lightning. Warm nonprecipitating clouds are analogously deficient in giant nuclei, the addition of which might stimulate the coalescence of drops and precipitation.

In recent years it has been learned that these assumptions do not always hold. For example, in large rainmaking experiments in Arizona (University of Arizona), Australia (C.S.I.R.O.), Missouri (University of Chicago) and Switzerland, the seeding of supercooled cumuliform clouds often led to decreases in rainfall rather than increases. It is now evident that certain clouds possess adequate natural nuclei, and also that seeding at an inappropriate time in a cloud's life cycle may cause the

cloud to prematurely dissipate before reaching its maximum potential. In short, future weather modification efforts will have to place greater emphasis on examining the natural microphysical and mesoscale characteristics of a weather phenomenon before attempting to perturb it. Along the way, the discrepancy between ice nucleus concentrations and ice crystal concentrations (generally much higher) in clouds will have to resolved (Mossop, 1970).

The acceptable verification of weather modification experiments has been a subject of considerable debate. Early exaggerated claims have now been mostly discredited. More recent experiments suggest, in general, maximum overall seeding effects of 10 to 30%, values that are within the natural variability of a weather system. Consequently statistical methods, involving a target area and a control area, are frequently employed with regression equation values expressed at some level of confidence. The target-controlregression method is not without bias so that the incorporation of a randomization process is advisable. With a sufficient number of cases, one ultimately can correlate the effects on seed and no-seed days. The crossover method of alternating the target and control areas is now suspect owing to an apparent residual seeding effect of substantial duration reported by some investigators. Until this suspicion - which seems to defy physical reasoning - can be established, the crossover method remains appealing in that it substantially reduces the time to accumulate sufficient test results.

With any statistical evaluation technique, it turns out that much data are needed unless the effect is large in order to establish conclusions with confidence. Programs of 5 years duration or longer generally are required (Changnon, 1973).

An alternate evaluation approach is offered by computerized physical models. The formulation of reliable models of, say, cloud development that are capable of predicting observed characteristics of seeded and unseeded clouds provides a seemingly excellent means of verifying weather modification attempts. Each case in itself yields evaluation data as well as providing more physical insight into the problem than purely statistical means. The work of Simpson (1970) on cumulus cloud modification and Weickmann et al.(1970) on redistribution of Great Lakes snowfall constitute promising examples of this approach. Perhaps the ideal approach, adequate support permitting, is to utilize both physical modeling and statistical evaluation as is planned for the National Hail Research Experiment (Swinbank, 1971).

3. WEATHER MODIFICATION PROGRAMS

a. Precipitation Augmentation

There is reasonable agreement that the seeding of layered supercooled clouds over orographic terrain can produce precipitation increases of the order of 10 to 20% (National Academy of Sciences, 1966). The Colorado River Basin Project (Grant and Mielke, 1967) represents a current and well

controlled experiment that substantiates this view. Similarly, a 19% increase in overall precipitation was reported (Smith, 1967) in the Australian Snowy Mountains experiment. Windward mountain slopes provide for a sustained updraft, widespread cloudiness, and better targeting of seeding agents from ground generators.

The seeding of cumulus clouds brings into play more cloud and environmental variables and less predictable results (Neiburger, 1969). Positive results were reported each year of the 1961-1966 Israeli rainfall stimulation experiment with an average increase of 18%; when considering the interior regions of the seeded areas, 27% increases were noted. The Swiss hail-suppression project led to rainfall increases of 21% on seeded days, although subsequent analyses (Neyman and Scott, 1967) revealed that the percentages varied widely because of unintentional forecaster bias in selecting seedable days. Simpson and Woodley (1971) reported cases of explosive growth of seeded maritime clouds with perhaps a doubling of precipitation at cloud base level as revealed by radar. Conversely, extensive programs involving the seeding of summer cumuli from aircraft in Arizona (Battan, 1966) and in Missouri (Project Whitetop; Braham, 1966) revealed significant decreases in precipitation on seeded days.

Clearly not all supercooled clouds can be made to precipitate, and many basic questions must be answered in the next decade to clarify the diverse results reported. These tenuous areas include (a) the nature and abundance of ice nuclei naturally available to clouds and the effects of artificial increases thereto, (b) seeding potential based on cloud water content, convective activity and temperature, (c) critical mesoscale environmental conditions of humidity, thermal instability, and vorticity, and (d) puzzling downwind seeding effects (up to 300 miles away from the target) presumably not connected with nuclei drift (Bowen, 1970).

When these questions are finally answered, I suspect that rainfall stimulation in selected regions still may not greatly exceed 10-30%, by no means an inconsequential increase. However, we then can hope to quantitatively rule out those portions of the globe, cloud systems, and periods of time when seeding will have either no effect or negative consequences. Overall, I further suspect that the resultant "seeding window" for rainmaking will be rather narrow. For warm clouds, the window may close considerably, perhaps to an inconsequential crack.

b. Severe Storm Modification

The coming 10 to 15 years will probably witness more efforts aimed at ameliorating rather than stimulating weather systems. Part of the shift may merely reflect the fact that less has been done to date in the former category. In addition, however, there is perhaps more societal concern and periodic impetus for reducing catastrophic or economically costly weather effects. These areas include:

(1) hail suppression

(2) lightning suppression

(3) hurricane modification

(4) heavy precipitation redistribution

(5) tornado modification (eventually)

A high priority has been assigned to hail modification in this country. The National Hail Research Experiment (NHRE) is being conducted in northeastern Colorado over a 5 year period. This field effort, supported by the National Science Foundation involves NCAR (lead group), government weather agencies and several universities. Their principal objectives are aimed at fundamental understanding, modeling, and possible modification of hail producing storms.

The Soviet Union has reported crop damage reduction of up to 90%* by massive injection of silver iodide nuclei in hailstorms (Sulakvelidze et al., 1967). Their work, to be duplicated in part by NHRE, utilizes radar to detect the zone of maximum accumulation of supercooled water and rockets to deliver the seeding agent at the critical time. Several other countries, including Canada, France, Switzerland, Italy, Germany, Argentina, Hungary, and Africa have sponsored hail modification experiments. Obviously, it is a widespread problem of great economic consequence that will receive much attention in the coming decade. The Russian tests, though not randomized and more optimistic than reports of other countries, give hope that some relief may be forthcoming. (Annual U.S. agricultural losses due to hail approximate $200 million dollars). The underlying premise that overseeding can deplete the liquid water, create numerous smaller crystals, and prevent the formation of large hail appears sound.

Lightning is the principal cause of forest fires in the western and mid-western United States. The Skyfire Project, conducted by the U.S. Forest Service, has attempted to overseed thunderstorms with AgI released from ground generators. Positive results are thus far suggested, though not unequivocally, in contrast to negative results obtained in an earlier 1958-59 program in California (State of California, Division of Forestry). In the latter case, when the frequency of lightning strokes apparently increased in seeded storms, much less seeding material was used. A possible explanation may be contained in the preliminary findings of Schleusener (1968), indicating that AgI seeding rates higher than 2 kg per hour per storm cloud can mitigate hail damage, whereas seeding rates less than 1 kg per hour tend to enhance convective activity.

Another concept considered is that of discharging an electrified cloud by introducing large quantities of metallic chaff into the cloud (Kazemir, 1972). Preliminary tests suggest that chaff seeding causes an increase in conductivity inside the cloud and consequently a decrease

---

*Recent reports by Burtsev, et al. (1973), indicate lower values of about 70%, still sufficiently effective to have increased the crop acreage under protection to more than four million hectares currently.

in the electric field. Still another concept being explored by the New Mexico Institute of Mining and Technology is that of introducing space charge into the atmosphere to alter a cloud's electrical behavior (Vonnegut and Moore, 1958; Bradley and Semonin, 1968).

While the energy contained in a hurricane would seemingly intimidate any of the tools of science, intensive studies and field efforts on Project Stormfury* suggest that hurricane modification may not be hopeless. Numerical models (Simpson, 1970; Rosenthal, 1971) indicate that heavy seeding with AgI well beyond the radius of the intense eye wall clouds could release considerable latent heat and set up a secondary circulation. The desired net effect is a relaxation in the strength of the primary wind vortex, with even a small percentage reduction considered capable of substantially decreasing hurricane damage.

In 1969 Hurricane Debbie was heavily seeded with AgI over an 8-hour period (Gentry, 1970). Aircraft penetrations made before and after seeding indicated a 30% reduction in wind speed, subsequently followed by a regeneration of storm intensity. A second seeding 2 days later suggested a 15% wind velocity reduction. Because of the stringent safety criteria imposed to qualify as a seedable storm, many years of data are required to test the hypothesis fully. Plans to operate in the Pacific, where the frequency of operable typhoons is greater, have been advanced. The potentially high benefit-to-cost ratio and the demonstrated success in executing complex operational procedures on a large scale favor the program (but not sufficiently to prevent a temporary termination of the project, as described subsequently).

Attempts to redistribute heavy snowfall to the lee of the Great Lakes have been made by NOAA (Weickmann et al., 1970). The early winter storms involved are highly supercooled with much of the precipitation falling as rimed snowflakes and graupel along the populated lee shores. By seeding with sufficient ice nuclei, it should be possible to reduce riming and produce lighter crystals that advect further inland. Numerical models (Lavoie et al., 1970; Jiusto, 1971) and initial NOAA experiments over Lake Erie suggest that the concept is valid, despite indications that snowflake aggregation (crystal-crystal attachment) may limit the degree of redistribution possible. Related snowfall targeting in orographic regions of Washington State is also being tested (Hobbs and Radke, 1973).

Somewhat similarly it has been proposed that seeding maritime clouds on the west coast of Oregon with condensation nuclei might alter rainfall patterns (Elliott, 1971). Theoretically, seeded clouds should consist of smaller more numerous droplets that might sufficiently delay the coalescence process so that more of the precipitation would carry inland beyond the Western Cascade Mountain region of torrential rainfall. Methods of generating large concentrations of condensation nuclei are known so that a test

---

*Joint NOAA-Navy Program including the participation of the USAF and other groups.

program could be designed and executed.

Realistic concepts for modifying tornadoes have as yet to be developed. Further, their small dimensions and sporadic nature pose severe limitations on practical methods of combating tornadoes. However, as the nation's population density grows, these devastating storms will take an ever increasing toll of lives and resources. The public will become sympathetic to (and perhaps even demand) more study of tornadoes, better forecasting techniques, and means of possibly ameliorating them. NOAA's Severe Storms Laboratory is actively engaged in all but the latter area.

Doppler radar has long been recognized as a unique tool in detecting and analyzing tornado behavior, although its full potential has yet to be realized. A more active program is not unlikely toward the end of the seventies, bringing into play some of the observational (and perhaps modification) techniques learned in the national hail program and hurricane modification program.

Unfortunately, the past year has seen several of the of the above projects severly hampered by budgetary problems. Despite scientific merit, funding limitations have resulted in indefinite postponement of Project Stormfury and NOAA's Great Lakes snowfall project; an approximate one-third cut in the National Hail Program; and a sharp reduction in the Bureau of Reclamation's program of orographic snowpack enhancement. Other reputable groups in this country also have been forced to postpone efforts just when the promise of more definitive evaluation of concepts seemed reasonably good. Despite the temporary setbacks, it is essential that the instinctive desire to survive (not restricted to weather modification) not foster a tendency to ignore inconclusive results and to stress the positive cases. Particularly in this discipline, negative results are as important as positive findings in the long run.

c. Fog Dissipation

Airlines in particular are adversely affected by fog, with the United States annual loss due to disrupted schedules estimated at over $75,000,000. Despite improved navigation aids at airports, cloud ceilings and ground visibilities less than about 200 ft. and 0.5 mi., respectively, can bring air transportation to a standstill.

A capability has been achieved for dissipating supercooled fog with freezing agents such as dry ice, liquid propane and silver iodide. If the supercooled fog is not too thick too warm or moving too rapidly, a clear hole in the overcast can be produced. Among the groups that have used this technique effectively are the U.S. Air Force and Army at northern locations, the United Airlines in the northwestern United States in winter, the French at Orly Airport and the Russians at several sites.

However, supercooled fogs are not the common type in the United States; they account for only about 5% of all fog occurrences. So-called warm fogs, constituting the large balance, have tended to defy a practical solution. Recently some encouraging experiments on warm fogs have been con-

ducted and there is hope that an operational dispersal system will be developed at some airports to modify at least the less intense fogs.

Numerous warm-fog modification schemes have been attempted that generally fall into one of the following categories: (1) heating of the air to evaporate the fog, (2) drying of the fog with chemical agents, (3) mechanical mixing of the fog with surrounding drier air, and (4) enhancing droplet coalescence by electrical or mechanical means. The above listing is perhaps not an unreasonable ranking of the eventual probability of success of the methods. The USAF continues to be involved with virtually all of these techniques (Appleman and Coons, 1970; Silverman, 1971; Weinstein and Silverman, 1973).

Renewed interest in warm fog modification took place in the late 1960's with a substantially improved version of the Houghton-Radford salt seeding concept of the thirties (Jiusto et al., 1970). Dry salt particles of carefully prescribed sizes (10-20 μ) were injected into fogs with only slight reductions in relative humidity called for to improve visibility in radiation type fogs. Despite the Chinese proverb, "Don't try to dissipate fog with a fan," the Air Force and Army (Plank et al., 1971) demonstrated that helicopters hovering above thin fogs could propel enough dry air downward to create holes in the fog. However, the clearing of entire runways in this manner proved far more formidable. Though heating of fog dates back to World War II (British FIDO technique), it would not be surprising if an updated ground heating method eventually proves the most feasible single approach. Inherently it is environmentally clean, the least complicated, and relatively safe.

It is not yet apparent that any of the warm-fog dispersal techniques can cope with thick advection fogs that move rapidly and possess considerable turbulence. In high winds it is difficult to vector the treated area over an airport; also, more seeding material or dissipating energy is required. In turbulent dense fog it seems that new fog can form or close in faster than it can be dispersed. Thus, it would appear naive to expect any system to be effective, say, 80-90% of the time or to work equally well at all locations.

While the expectation of circumventing fog by means of automatic landing systems dates back to at least 1940, it may finally become reality. The British have incorporated such systems in their newer aircraft and this country is making progress. For example, the L-1011 Tristar aircraft is now equipped with automatic landing equipment, its utilization pending installation of appropriate ground equipment and pilot training. The need for fog modification at airports will depend upon the degree of success of these landing systems and their acceptance by pilots and the public. Primary interest in fog modification may shift to major coastal highways, a growing problem indicated by the recent New Jersey Turnpike catastrophe involving over 100 vehicles.

d. Inadvertent Weather Modification

There is a growing realization that the weather modification challenge

of the future will be posed by inadvertent weather and climate modification (Schaefer, 1969; Roberts, 1970). Man's efforts to manipulate weather by design may well pale by comparison with his ability to affect environmental changes en masse. Extensive research efforts will be needed to understand and then to control intricate and significant changes in weather patterns and climate. Some of the areas of concern are as follows:

(1) Sprawling urban areas - their mesoscale effect on convection patterns, temperature, and downwind precipitation.

(2) Gas composition changes in the atmosphere (e.g. CO_2, SO_2, H_2O, etc.) and their influence on the radiation budget, climate, and ice ages.

(3) Similar effects of particulate loading of the atmosphere including cloud nucleation particles (condensation and freezing).

(4) Air quality and corresponding global monitoring of key atmospheric gases and particulates.

Without resorting to doomsday prophesies, one could write chapters on these subjects, as has been done. The two references cited above provide a good survey of tempered scientific concerns. The Laporte, Indiana study (Changnon, 1968) provided perhaps the first concrete evidence that precipitation was being significantly affected downwind of a city - the steel-mill complex of Gary, Indiana. A safe prediction is that many other significant man-made influences on weather will be revealed over the globe. As is well known, NOAA has recorded a 0.2% per year increase in carbon dioxide for the past 10 years at Mauna Loa Observatory; such a continued increase could have a profound influence on worldwide climate. The possible contamination of the upper atmosphere, with its long residence time for gases and small particles, by supersonic aircraft is a potential hazard cited by the National Academy of Sciences (1973).

The problem will demand our best efforts on a number of fronts. Cooperative global monitoring of gases and particulates at the surface will be needed, as well as upper-level aircraft surveys of these components over continents and over the oceans. Numerical models of global climate must become more refined and allow for testing the impact of various perturbations. The local weather effects produced by the release of heat, water vapor, nucleating particles and a variety of gases will require clarification, as will the specific sources and sinks of these constituents.

4. PRIORITIES

In order to accelerate progress in certain promising areas of weather modification, ICAS (June 1971 report) recommended that appropriate national programs be instituted. These programs are listed in Table 1.

The program areas included have all been touched on. To the list one might well add international programs in (a) air quality monitoring and

study and (b) inadvertent weather and climate modification. These two topics were appropriately included in the 1971 National Academy of Sciences report, "The Atmospheric Sciences and Man's Needs - Priorities for the Future."

Table 1.

National Weather Modification Programs Proposed by the Interdepartmental Committee for Atmospheric Sciences (ICAS)

a. National Colorado River Basin Project for Snowpack Augmentation

b. National Hurricane Modification Project

c. National Lightning Suppression Project

d. National Cumulus Modification Project

e. National Hail Research Experiment

f. National Great Lakes Snow Redistribution Project

g. National Fog Modification Project

In Table 2, an estimate is made of the priority of given weather modification endeavors during the next decade and a half. It should be understood that this outline constitutes a personal judgement that may prove no better than long-range weather forecasts. (These estimates, made almost two years ago, have not been altered to reflect the possible impact of recent budgetary decisions.)

Table 2.

Estimates of Given Weather Modification Priorities in Coming Years (1:High; 2:Moderate; 3:Low; +:Potential Established)

	1975	1980	1985
1. Rainmaking	2	2	3
2. Snowpack Augmentation	1	2	3
3. Precipitation Redistribution	2	2	2
4. Hurricane Modification	1	1	2
5. Hail Modification	1	1	+
6. Lightning Suppression	2	2	3

Table 2., continued

	1975	1980	1985
7. Tornado Modification	3	2	1
8. Fog Modification			
a. Supercooled Fog	+	+	+
b. Warm Fog	1	2	+
9. Inadvertent Weather Modification			
a. Global Air Monitoring	2	1	1
b. Local and Mesoscale Effects	2	1	1
10. Inadvertent Climate Modification	2	1	1

5. CONCLUSIONS AND RECOMMENDATIONS

Weather modification has advanced considerably as a science over the last two to three decades. Progress has not been steady as there are always backwaters, particularly in an area that is controversial and sometimes emotion ridden. What has emerged is a realization that field programs are complex and must be accompanied by sound physical concepts, laboratory tests, numerical models, and unequivocal statistical and/or reliable physical verification.

To date we perhaps have learned more about the limitations of weather modification than of quantum jump benefits. Either way, the spin off benefits to basic atmospheric physics understanding has been considerable. For the period ahead (to 1985 or so), I see continued interest, despite funding lapses, and hopefully definitive evaluations of several concepts. The following specific projections may not fall too wide of the mark:

(a) A succession of national or joint weather modification programs that will attack concepts on a sufficiently intensive scale to obtain definitive answers in a reasonable period of time.

(b) Priorities established in accordance with the needs of society and where the likelihood of some success is greatest.

(c) A shift in emphasis from rainmaking activities to severe storm amelioration, with hail and hurricane modification being intensively studied early in the period and tornado modification somewhat later.

(d) Quantitative resolution of what magnitude changes can be effected with certain modification concepts, including fog modification, hail suppression, snowpack augmentation, and precipitation redistribution.

(e) A falling by the wayside of several weather modification concepts on the basis of scientific evidence showing sub-marginal benefits in relation to costs and area (or frequency) of applicability; conversely, benefits that surpass present expectations in a few selected programs or areas that we cannot now delineate.

(f) A growing use of sophisticated computer models in the testing of weather modification possibilities.

(g) Inadvertent weather and climate modification research gradually but steadily overshadowing planned modification as the global population increases.

The last item (g) cannot be stressed too heavily. Extensive research will be needed on: surface and air sampling of particulates and gases throughout the world; correlation of such data with synoptic patterns and source-sink factors; clarification of inadvertent mesoscale and macroscale effects on weather patterns; and computer modeling of possible climate perturbations.

Toward the end of the period and beyond 1985, the complexion of weather modification is likely to be quite different. The problems should be equally challenging, more rigorously pursued and of even greater impact to society. There should be no lack of intellectual excitement and controversy.

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TRENDS IN WEATHER MODIFICATION LEGISLATION

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INTRODUCTION

During the quarter century of scientific weather modification legislators have been called on to assess this new technology. Except for reporting provisions, Congress has talked a lot about regulation of cloud seeding, but has done nothing about it. (1) State legislators, however, have reacted in varying degrees to weather control activities by enacting bills in thirty states during the 1950's (2) and 1960's. (3) The 1970's have seen a new wave of weather modification laws. Since 1970 thirteen state legislatures have enacted bills dealing with cloud seeding. Some of these enactments amend prior laws bringing about only slight changes, but most of them either effect complete restructuring of legal control over atmospheric management or are entirely new enactments passed in states which previously did not regulate weather modification.

Several trends can be identified in this avalanche of law making. First, there have been legislative manifestations of changing attitudes of legislators about cloud seeding. Second, as laws proliferate the institutional structure for legal control of weather modification has become more elaborate. Third, after years of ignoring private relationships legislators are now concerning themselves with questions such as the legal liabilities of weather managers and the right to use of waters generated by precipitation enhancement. Fourth, regulation is now being buttressed by new rationales and additional means and methods of control.

I. ATTITUDES

The 1953 South Dakota statute noted that "while weather modification is at present a reality, the ultimate extent to which it may be utilized is speculative." The uncertainty of the legislature shown by its use of the word "speculative" is no longer a part of its official attitude about cloud seeding. In 1971 the law makers substituted more positive language: "It is hereby declared that weather modification techniques for precipitation management should be used to augment precipitation and decrease hailfall damage in South Dakota." Colorado's 1972 law added to its twenty-one year old statute the statement that "the state of Colorado recognizes that economic benefits can be derived for the people of the state from weather modification." And the recently-enacted Illinois Weather Modification Control Act unequivocably declares that "properly conducted weather modification operations can improve water quality and quantity, reduce losses from weather hazards and provide economic benefits for the people of the State." Thus legislators have expressed their recognition that cloud seeding can be

effective. Norman Vincent Peale has replaced Doubting Thomas.

An awareness that science can alter the weather does not automatically carry with it a belief that the alteration will effect a net positive change. The New Mexico Weather Control and Cloud Modification Commission obviously believes that some consequences will result from cloud seeding. It is not, however, persuaded that the actual effects will be beneficial. In a position statement issued in April 1972 the commission declared that it would judge results only on the basis of a program continued over an extended period of time (perhaps five or more years) which obtained data from a dense raingauge network covering all areas likely to be affected. Even the new state laws refer to possible harmful consequences of cloud seeding. Illinois speaks of minimizing "possible adverse effects," and Colorado notes the need for "safeguards."

American lawmakers often express their attitudes by exercising their control over public monies. During the 1970's legislators in state capitals have loosened the purse strings more than in any comparable period. Roughly $2,000,000 was appropriated by the High Plains states for cloud seeding activities during fiscal year 1974. South Dakota, the most active of the states, increased its appropriations from $100,000 for fiscal year 1972 to $250,000 for 1973 to $643,000 for 1974. In Kansas the state Water Resources Board, which had a difficult time scrounging funds for its participation with the Bureau of Reclamation in Operation Kancup during the summer of 1972, was able to get a $100,000 for weather control work during 1973. The Texas legislature made $200,000 available to the Water Development Board for assessment of weather modification activities in that state during fiscal year 1974. These state funds have proven to be particularly useful during a period of cutbacks in federal funding.

Even when state weather control agencies do not conduct operational or experimental programs, it is important that they obtain adequate appropriations to support their regulatory activities. Containing the efforts of unpopular administrative agencies by starving them for funds is a long-standing legislative tradition, one as American as apple pie. Budget officers look askance at new programs which are either under-funded or not funded at all. In 1972 the New York legislature passed a bill which would have set up an interim weather modification agency, but the law makers did not appropriate it any money. For this reason the State Division of the Budget recommended that the governor veto the bill. He did. In contrast the Illinois law which was passed a year later was accompanied by an appropriation bill. The governor, who has made something of a career of vetoing bills, signed both the weather control act and the money bill.

Not only have state legislators been more willing to provide funds from state treasuries than heretofore, but also they have enacted statutory changes that have smoothed the way for acquisition of support from other sources. Iowa, a new state among the ranks of those with weather modification laws, has set up a procedure for creation of county weather modification boards and provided a means whereby they can have the county boards of supervisors levy and collect taxes on their behalf. In Oklahoma the 1972 statute was amended in 1973 to authorize local governmental entities to expend their

money on weather modification. The Montana law was altered in 1973 also: it now gives the advisory committee on cloud seeding the power to enter into cooperative agreements with the federal government, counties and cities, and to contract with both public and private entities. South Dakota, which has for a number of years operated multi-county weather modification districts, has now specifically authorized such arrangements under its 1973 law. County mill levies support cloud seeding within the districts.

Such enabling laws are not in themselves enough to bring about atmosperhic water resources development. The groups authorized to carry out the operations must actually use the power given them. Minnesota provides a classic example of one area in which authority granted to counties by the legislature to contract for weather alteration operations has not been used. In 1969 nine counties were given permission by the legislature to enter into contracts, up to $5,000 per year, with weather modification firms. Special legislation of this sort, according to Minnesota procedure, does not become effective until the local unit adopts a resolution approving it and files a copy of its certificate of approval with the state. Four counties did not file within the required period of time. One said that their "weather is great"; another claimed that there was "no need" to modify its weather; and a third refused to approve on the grounds that doing so would be a "waste of money." Of the five counties that filed, three let contracts in 1970 and only in 1970. A response from one of them said that there was not much effect. The Minnesota track record is one of truly negative thinking.

There is folklore to the effect that governmental regulation of industries has been imposed upon unwilling professions, recalcitrant businessmen and reactionary economic royalists. Studies indicate that this picture is quite inaccurate. Most industries and professions have been regulated at their own behest. Professional weather modifiers have followed this pattern by their keen interest in securing acceptable regulation of cloud seeders and of weather control activities. (4) The new laws to some extent show their influence. But a more important impetous to enactment of these statutes has been supplied by interested state governmental agencies. The Utah Division of Water Resources drafted that state's 1973 act; the Illinois State Water Survey sponsored preparation of a weather control act; the South Dakota Weather Control Commission has been an active proponent of legislative changes; and the Arizona Water Commission has expressed an interest in modernizing Arizona's inadequate law, but notes that "we know of no other group that is desirous of changing the current law."

Sometimes legislative attitudes can best be comprehended by looking at what kinds of bills have not been passed into law. There have been very strong anti-weather modification pressures brought to bear on the Colorado legislature. It has responded by passing laws in 1972 and 1973 which are far more restrictive of cloud seeders than was Colorado's original law; but the new enactments are not nearly as tough on the weather modification industry as many people would have preferred. The legislature could have been far more negative than it was. And in Maryland, a state which has three times passed short-term complete bans on all weather modification, the latest statutory bar quietly expired in 1971 and has not been replaced. Weathermen can truly say that "no news is good news."

II. ORGANIZATION

Political scientists, lawyers and legislators have an abiding interest in governmental organization; most other citizens do not. That is most people are content to let the bureaucracy bumble along as best it might, unless its boners become too noticeable or its activities directly affect them. Then people can and do become interested. Weather modification administrative agencies seem not to have done anything really bad that has raised the public up in arms about them demanding changes. And few state regulators, there are some exceptions, have managed to antagonize the bulk of reputable weather modifiers. So changes in the institutional structure of weather control agencies have for the most part gone un-noticed, except by legislators, lawyers and political scientists.

What has concerned legislators has been the effort to avoid proliferation of government bodies and to restructure and modernize existing agencies. A phenomenon in recent years has been that of the migratory weather modification control agency. In Arizona the authority was shifted from the Land Commission to the Water Commission. In Florida the independent weather modification agency was merged into the Water Resources Board which soon thereafter was moved into the Department of Natural Resources. Washington's independent board also got moved twice -- into the Department of Water Resources and then into the Department of Ecology. The South Dakota Weather Control Commission became the Weather Modification Commission and then was merged as the Division of Weather Modification into the Department of Natural Resources. As compared with state agencies like workmen's compensation boards, weather modification regulatory bodies have very little business and a much smaller staff. Efficiency can result from their merger into larger umbrella agencies. The trend is away from independent weather control bodies. For example, in Illinois regulatory power has been lodged in the state Department of Registration and Education, the body which has for years handled most professional licensing in the state. They have the machinery already set up to carry out regulation. Working through advisory boards from each of the professions the department can efficiently control them. The Illinois law establishes a Weather Modification Board within the department to perform the advisory role.

Lawyers, particularly since the days of the New Deal, have kept a wary eye out for rule making by administrative agencies. The old notion that the legislature makes the law, the executive enforces it and the courts interpret it has never been completely accurate. But in the 1930's it became less true than it had been prior to that time. Congress and the state legislatures delegated very broad law making powers to administrative agencies. Acting on behalf of clients whose views ran counter to those expressed in administrative rules and regulations, lawyers attacked such delegations as violative of the principle of separation of governmental powers. They lost and the administrative agencies prevailed. So long as the legislature provides an adequate standard by which agency rules can be judged, delegations of power will be upheld -- fulminations by the legal profession to the contrary notwithstanding.

The Illinois statute is a model modern law delegating power to make rules and regulations. The philosophy of that law can be seen from examination of the draftsman's commentary to the law.

> It is not the intent of this act to spell out in detail the weather modification control procedures and criteria for the state. Weather management technology is rapidly developing. It is not now possible to foresee all of the regulatory problems that will be associated with it. The necessary flexibility for control over the field can best be provided by setting forth the basic regulatory structure in the act and authorizing the Department of Registration and Education to fill in the gaps by use of its powers to make reasonable rules and regulations. Acting upon the advice of the board, the department can keep its regulations abreast of technological developments.

Or, put differently, it is easier to change administrative rules than it is to amend statutes. And the odds favor a group of experts knowledgeable in the field over a state legislature which is unlikely to have many members with a scientific, engineering or technological background. The administrators can make better rules.

More and more state agencies are being given wide rule making power and are using it. Weather control officials in Utah, Oklahoma, South Dakota and Colorado were among those who in 1973 made extensive use of their power to promulgate regulations. In the last names of those jurisdictions, Colorado, this rule making took place in spite of a state law which at present goes into absurd detail on such matters as qualifications for issuance of a license and conditions under which a permit may be granted.

Political scientists, at least in the view of some lawyers, seem to be power-oriented. They are want to examine governmental institutions and organizations to see where the real power is located. The trend toward statutory mechanisms for local financing of weather modification operations should interest them. The early laws passed in Nebraska, North Dakota and South Dakota made provisions for creation of weather control districts. Nebraska's effort failed; those in the Dakotas succeeded. But it has only been in the past few years that other states have joined in the effort to get local input into the decision making and money raising. Following the example of Texas, which in the late 1960's copied the northern high plains provisions, Oklahoma and Iowa have set up the procedure whereby weather control districts can be formed. South Dakota's present law approves the multi-county district arrangement established there; and the 1973 Utah regulations encourage formation of multi-county weather control districts in that jurisdiction.

III. RELATIONSHIP

Two areas of concern to legal scholars have not until recently been addressed in weather modification laws: civil liability of modifiers and property rights in supplemental precipitation and streamflow generated by cloud seeding. Enough new state statutes now do deal with liability for it to be accurate to state that there is a trend toward inclusion of such provisions in the laws of the 1970's. And one state in 1972 and another in 1973 tackled the more complex problem of allocation of the right to use water harvested by cloud seeding. There is no trend yet, but now there are those two precedents.

In 1966 Texas was the first state to look at liability. Its law stipulated that weather modification should not be deemed an ultrahazardous activity which would give rise to liability without fault. Under such a provision a complainant suing a cloud seeder would have to establish either that the modifier intended to injure the interests of the complainant or that the seeder carried on his project in a careless and negligent manner and thereby caused injury to the complainant. This Texas provision has now been copied elsewhere. Weather modification in Illinois is, by legislative fiat, neither an ultrahazardous activity nor an abnormally dangerous one.

The common law of liability has had some difficulty coping with rules about emission of small particles. Some appellate court cases consider such emissions as the basis for an action for a nuisance; others assert that trespass to real property is the proper theory under which a lawsuit should be brought. Whichever theory is used, there is some possibility under common law that the mere dissemination of seeding agents into the atmosphere over a person's property might give him a right to institute suit and prevail. To avoid this Colorado now states that the act of disseminating seeding materials is not in and of itself a trespass nor does it constitute a nuisance. Illinois says it is not a trespass. Utah states that there will be no presumption of either trespass or negligence. The Kansas bill, which was not enacted in 1973 but which is likely to pass in 1974, goes all the way and rules that the mere act of releasing seeding substances will not be the basis for a cause of action on any theory.

Colorado and Illinois have a provision that is intended to make it easier to obtain a recovery from someone who has carried out cloud seeding activities without compliance with the statutes and regulations of those states. Persons harmed by such unlawful operations will not have to prove either fault based on intent to harm them or based on carelessness. By law such conduct in violation of the statute constitutes negligence per se, that is negligence in and of itself. This concept is similar to the Pennsylvania and West Virginia notion that persons harmed merely need to prove that the modifier's seeding hurt their interests. The Pennsylvania and West Virginia provision is, however, much more inclusive than that of Colorado and Illinois; it applies to weather modifiers whose activities conform to law, as well as to those whose operations do not.

Oklahoma is one other state that has considered civil liability. It has taken a different approach from those taken in the state laws discussed above. The Oklahoma statute specifically says that it in no way affects either liability for tort (civil damages) or contract.

Persons attempting to recover damages from weather modifiers have been very unsuccessful. Problems in judicial procedure, at least in part, account for this. Lay jurors may not be qualified to cope with technical issues concerning the kind of care weather modifiers should take to avoid harm to others and issues dealing with connecting the harm the plaintiff asserts has befallen him and the conduct of the defendant weather engineer. Pennsylvania and West Virginia have taken damages cases out of the hands of the court system and have authorized the administrative agencies to handle such complaints. Colorado in 1972 took a shorter step away from the tradition of

letting the courts resolve claims for such losses. The advisory committee to the Department of Natural Resources or a departmental hearing officer will investigate any verified complaint of damages resulting from weather modification, make findings of fact (but not as to the amount of damages) and law, and make a record which with all documents shall be made available to any party in interest for use in any trial in a court of law for damages.

A recommended comprehensive water law for Florida in its chapter on weather modification has a provision dealing with the issue of what constitutes negligence. The administrative agency, under this unenacted proposal, would have the power by regulation to stipulate what standards of care should be adhered to by cloud seeders. A majority of both houses of the legislature could within a year revoke such standards. Failure to adhere to these administratively established standards which causes a loss would be a basis for a recovery of damages by the person harmed.

The Anglo-American legal tradition provides in many cases of actual or threatened harm to a person or to his property for injunctive relief in lieu of or in addition to a suit for damages. The power of a court to order a person to cease and desist from an activity is a very potent weapon in protection of property rights. The new breed of weather modification control acts grants such powers. In 1971 Texas plugged a loophole in its enforcement machinery. Prior to that time persistent violators who chose to ignore threats of criminal prosecution could thumb their noses at the Texas Water Development Board's efforts to shut them down. Under the 1971 amendment the board was given power to ask the state attorney general to seek a cease and desist order in court or could itself go to court to enjoin unlawful cloud seeding. Disobedience to a court order is contempt and persons in contempt can be jailed or fined forthwith. Illinois now authorizes the Department of Registration and Education to seek injunctive relief. And in Colorado (as well as under the Kansas proposal) the agency can itself issue an order commanding cessation of unlawful activities. It must, however, go to court to enforce such an order against someone who violates it. Although none of these laws gives a private citizen the right to get an injunction, common law principles, when a suit for damages would not give an adequate relief, permit a citizen harmed or threatened with harm to obtain a restraining order.

The other issue on which earlier statutes were silent, that of property rights, has now been addressed by the Utah and Colorado laws. These two states, which follow the prior appropriation doctrine of surface and ground water rights, have now added atmospheric water to the list of sources from which appropriation may be made. There are obviously serious problems of measurement involved in attempting to appropriate atmospheric waters. These may render the two new provisions not very useful. And the approach in those two appropriation states is not necessarily one which can be followed in jurisdictions which have adopted the riparian rights doctrine. That concept, which is the basis of the water law of the eastern states, views all land owners along a stream as having a common undivided interest in the waters of that stream. When water rights depend upon land ownership, rather than water harvesting, protecting the right of a sponsor of weather modification to water made available by the seeding would be difficult if he were not a land owner along the watercourse in which the supplemental water flowed. A

water rights provision was suggested for inclusion in the Illinois law, but sponsors of that act felt that the complications involved in the provision were not worth the effort and may have, by raising the atmospheric waters property rights issue, endangered adoption of the Illinois law.

IV. REGULATION

The heightened concern of state governments for protection of the environment has pushed its way into the list of reasons given in legislation for regulation of weather modification. Cloud seeding seeks to alter our atmospheric environment. If it is successful, there will be at least some impact on the ecological balance. The weather modification industry asserts that on the balance the environmental consequences of cloud seeding are positive. Some other persons assert the contrary. The states are now looking to see who is right, and newly enacted legal provisions are being employed as part of the means of arriving at some answers.

The National Environmental Policy Act of 1969 requires federal agencies conducting programs which significantly affect the quality of the human environment to file statements concerning the environmental consequences of those activities. This law is now an important factor in the planning and conduct of most federally-sponsored cloud seeding, as well as other federal programs. (5) Now the states are starting to get into the environmental act. For example, California and Washington have new laws which require state agencies to file environmental impact statements with the state when their programs significantly affect environmental quality. Other states may follow this approach.

Weather modification legislation enacted during the 1950's and 1960's nowhere makes mention of ecological or environmental concerns. The new laws do. Montana requires its regulatory agency to identify and evaluate ecological impacts of cloud seeding. Colorado's 1972 law demands that permit applicants supply a statement showing the expected effect of the proposed operation upon the environment. A year later a Colorado administrative regulation called for a detailed listing of potential risks from a project, an environmental impact statement from all permit applicants. The Illinois Weather Modification Control Act flatly states that weather modification affects the environment and requires permit applicants to set up emergency shut down procedures to be put into effect should ecological or other disasters threaten. Investigators of the Rapid City flood recommended that, to avoid unfounded allegations of contribution to a disaster by cloud seeding, all such projects have automatic stand down procedures. (6) Illinois gives force of law to that recommendation.

A variety of techniques is available for legal control over weather modification. In the Australian state of Victoria the Rain-making Control Act has been interpreted by the Department of Agriculture which administers it as permitting only the government to seed clouds. (7) Rather surprisingly Utah, a state normally regarded as a bastion of free and private enterprise, has gone the same route. The state Division of Water Resources was designated by the completely re-written Utah statute of 1973 as the only agency or person who could seed clouds. Governmental control is complete when only the

government can conduct operations.

Both in Victoria and in Utah the statutory monopoly has not been used to freeze out all non-governmental people from involvement in weather modification. Victoria contracts with private concerns for aircraft and pilots. Utah contracts with commercial weather modifiers. The Utah statute was modeled on earlier Utah laws which empowered the Division of Water Resources to construct small irrigation projects. It has contracted with persons interested in such projects and permitted them to do the actual construction.

When governments use their contracting power, particularly when the only way of doing business is with them, they are in a strong position to impose strict control over the activities of the contractor. The Utah Division of Water Resources has promulgated rules applicable to people who contract with them. By these rules persons conducting seeding must have a professional weather modifier's license issued by the division. The regulations also stipulate that an operational permit must be issued by the division covering projects proposed in Utah.

Utah is one among an increasing number of states which makes it clear that carrying out weather modification activities is illegal unless both a license and a permit have been issued. The comments to the Illinois section which imposes this requirement state:

> This section is the keystone of the statute. In order to protect the public from inept or unscrupulous cloud seeders and to assure that the most advanced scientific methods are employed for optimization of benefits from weather control operations, this provision requires that permits be issued authorizing weather modification activities and that persons in control of operations possess professional weather modification licenses. This dual requirement is designed to assure that both the personnel and the project are sound.

Other states, such as Oklahoma and South Dakota, have now made it clear that both a license and a permit must be obtained prior to any effort at artificial nucleation.

Another trend in the new laws is to provide for public participation in regulatory decision making. Massachusetts and Montana have heretofore been the only states with public hearing requirements in their laws. Massachusetts retains the compulsory hearing before permit issuance provision. Montana in 1973 changed from a compulsory hearing to a provision for pre-permit granting hearings which might be held at the option of the Department of Natural Resources. Colorado and Illinois have now joined the ranks of states with hearing provisions. In Illinois the state Weather Modification Board may, if it sees fit, hold a public hearing prior to granting an operating permit.

Colorado not only allows such hearings, but also has made use of a referendum in an area where a project was proposed. In the San Luis Valley of southern Colorado a precipitation enhancement project encountered fierce

resistance. The question was put to the public in connection with a general election, "Do you favor weather modification?" The majority voted no to this general proposition. When re-issuance of the operational permit was considered, the Department of Natural Resources hearing office admitted into evidence and relied upon the referendum, even though the question asked did not by its terms refer to the specific project in question. In August 1973 the Colorado district court to which the administrative decision was appealed upheld use of such evidence. That case, Atmospherics, Inc. v. Ten Eyck, marks the first time in weather modification litigation that the voice of the people has been accorded recognition. One such precedent, though, does not mark a trend toward that type of citizen participation in regulation.

There is, however, more evidence of a movement toward use of the ballot box to decide whether the taxing power should be used to raise money to fund weather management projects. Both Iowa and Oklahoma have enacted recent laws calling for a public vote on whether weather modification tax levies are to be imposed or not and when once imposed whether they are to be continued or not.

Finally, it is noteworthy that in the year the Watergate flooded, the federal government acted to help the states perform their regulatory task. An amendment to federal reporting rules was proposed in 1973 which was to take effect early in 1974. Among other things, it provides for public disclosure by the National Oceanic and Atmospheric Administration of information obtained by it from persons required to report their weather modification activities to it when there is an indication "that a proposed project may significantly depart from the practices or procedures generally employed in similar circumstances to avoid danger to persons, property, or the environment." The NOAA Administrator will notify state officials of such facts and "make recommendations where appropriate."

Regulation by adverse publicity can be devastating. (8) An official statement from NOAA containing information about unsafe practices of an operator and possibly including recommendations about such practices would be extremely persuasive in any state agency proceeding relating to an operating permit. Moreover persons with an interest in bringing about administrative, legislative or judicial decisions concerning cloud seeding could also make effective use of such information.

CONCLUSION

The trends in weather control legislation of the early 1970's have shifted from those which shaped the laws enacted during the first two decades of scientific weather modification. People concerned with the impact upon the practice of cloud seeding of this change and of acceleration in law making might well contemplate Charles Dickens' "Christmas Carol." Overnight Ebenezer Scrooge managed a massive change in his business practices. The reorganization process was a harrowing ordeal for Scrooge, but it was quick and lasting, and the happy ending doubtless gave him cause for later fond memories of that Night Before Christmas. Although speed and efficiency characterized Mr. Dickens' approach to alteration of the firm of Marley and

Scrooge, generally it is more useful to effect change in a somewhat more deliberate manner. The present flood tide of weather control legislation seems to have left few practitioners of the cloud seeding art suffering from a Scrooge-like "bad trip"; but members of the Weather Modification Association should redouble their legislative efforts. Otherwise they and legislators may not stand a "ghost of a chance" of working together productively.

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PRESENT-DAY STATE OF THE THEORETICAL INVESTIGATIONS ON THE HETEROGENEOUS ICE NUCLEATION

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The heterogeneous ice nucleation is the process of phase water transformations in the atmosphere which are made at the boundary between a foreign substrate on one hand and the vapor phase or supercooled water (liquid phase) on the other hand. That is why here the substrate peculiarities and properties (nature of the structural elements - atoms and molecules, the crystal symetry on the surface, the forces acting among the structural elements, surface defects of the grid, etc.) as well as the state of the vapors and the supercooled water play a role and should be taken into account. The specific surface energies between the different phases are of big significance. It is especially important to know the forces which act between the surface structural elements of the substrate (nucleus) and the water molecules from the vapor or the supercooled water situated on it.

These forces determine the initial connection of the water molecules with the structural elements of the substrate. Moreover the forces of the hydrogen connections which also influence the ice embryos formation act among the water molecules as well.

It is known that the presence of the ice phase in the atmosphere appears as a basic factor for the formation of the precipitation products in it. Under natural conditions the ice phase forms as a secondary product from the supercooled water drops freezing (1,2,3). The sublimation way of forming the ice phase appears as less probable. This fact has been proven long ago by Krastanov by solving the probability of the liquid and crystal embryos formation $\sim \ell - \frac{Ak}{kT}$ curves about condensation and sublimation are obtained:

$$\ell n p r_k - \ell n p_\infty = K_1 \frac{1}{T^{3/2}} \qquad K_1 = \sqrt{\frac{16\pi M^2 \sigma^3}{3KR^2 d^2 \left[\frac{Ak}{kT}\right]}} \qquad (1)$$

$$\ell n p' r_k - \ell n p'_\infty = K_2 \frac{1}{T^{3/2}} \qquad K_2 = \sqrt{\frac{\gamma_\omega M^2 \sigma^3}{3KR^2 d^2 \left[\frac{A'k}{kT}\right]}} \qquad (2)$$

represented in Figure 1.

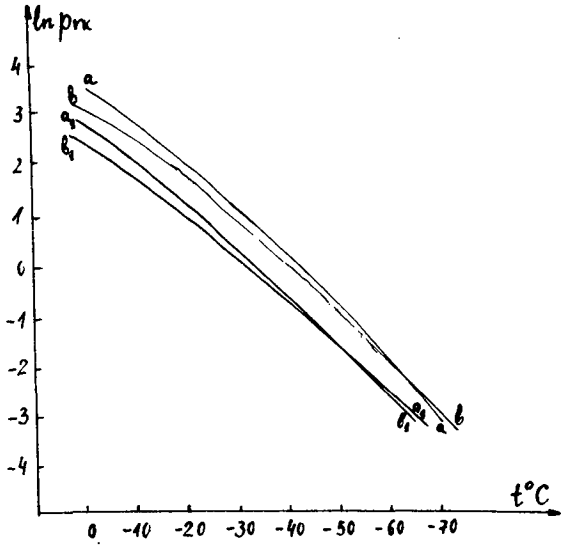


FIGURE 1

It is seen that the critical pressure for condensation pr_k is less than that of sublimation pr_k in the homogeneous case down to about -65°C, and in the presence of nuclei down to lower negative temperatures depending on the nucleus size. (4) Therefore first a water drop in the atmosphere is formed and then the ice crystal is formed by the freezing of the supercooled water drop. If we consider the same problem at adsorption of surfacely active substances (5,6) (substances which change the surface energy of the substrate as well as of the liquid) it is seen that the curves of condensation and sublimation cross at higher temperatures. For example, when changing the surface liquid energy with 20 percent ($\Delta\sigma/\sigma = 0.2$), the two curves cross at about -45°C, compared to when there is no adsorption, and they cross at -65C. In Figure 2 we have presented the change of the cross point depending on the adsorption. It turns our that the adsorption increases the temperature at which the formation of an ice crystal through sublimation is possible. This gives a possibility to change the conditions of the ice phase appearance in the atmosphere by means of the surface energy change with the help of surfacely active substances. The mechanism of this phenomenon should be probably sought in the investigations of Prof. Morachevski (7) who, with the help of a nucleus-magnetic resonance, shows that the energy of interaction between the hydrophilic part of the molecules of surfacely active substances and the water molecules increases with 15-20 per cent in comparison with the interaction among the water molecules thanks to the increase of the hydrogen connections number and strength.

The treatment of the thermodynamics of the heterogeneous formation of crystal embryos in supercooled drops was begun by Fletcher N.H. (8). The

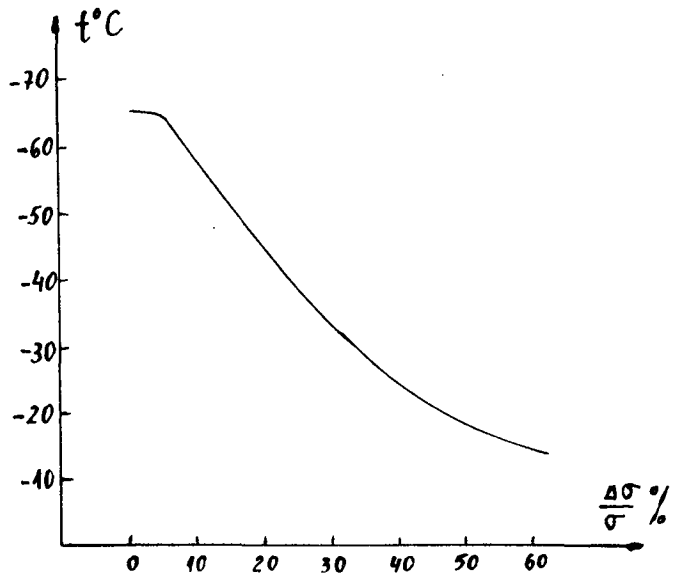


FIGURE 2

expressions about the work for the formation of ice embryos on incompletely and completely wettable nuclei, on a smooth substrate and in a homogeneous liquid were obtained:

$$\overline{A_k^*} = \frac{2}{3}\pi r_{23,0}^2\,\sigma_{23}'\left\{1+\left(\frac{1-XM_3}{g}\right)^3+3X^2M_3\left(\frac{X-M_3}{g}-1\right)+X^3\left[2-3\left(\frac{X-M_3}{g}\right)+\left(\frac{X-M_3}{g}\right)^3\right]\right\} \tag{3}$$

Where $X = r_0/r_{23,0}$; $M_3 = \cos\varphi_3$; $g = \sqrt{1+X^2-2XM_3}$

$$\overline{A_k^*} = \frac{4}{3}\pi r_{23,0}^2\,\sigma_{23}'\left(\frac{1}{2}-\frac{3}{4}M_3+\frac{1}{4}M_3^3\right) \tag{4}$$

$$A_k = \frac{4}{3}\pi r_{23,0}^2\,\sigma_{23}' - \frac{4}{3}\pi r_0^2\,\sigma_{23}'\left(3-2\frac{r_0}{r_{23,0}}\right) \tag{5}$$

$$A_k^o = \frac{4}{3}\pi r_{23,0}^2\,\sigma_{23}' \tag{6}$$

The expressions obtained are completely analogous to the expressions about the work of the formation of liquid embryos from the gas phase. The difference is that σ_{12} is replaced by σ_{23}, and the angle of wetting M is replaced by a new angle M_3 between the substrate and the crystal in the presence of the liquid phase. These cases refer to the formation of ice embryos in an infinitely big liquid phase. Later we consider the case of ice embryo formation in small drops comeasurable with the sizes of the crystal embryo. (9) In this case the crystal embryo is under a supplementary pressure because of the liquid drop curvature,

$$p_k = p_\infty + \frac{2\sigma_{12}}{r_{12}} + \frac{2\sigma_{23}'}{r_{23}'} \quad .$$

The equilibrium between the crystal embryo and the drop is given by the modified equation of Thomson-Gibbs, deduced by Kaishev (10).

$$\Delta\mu = \lambda \ell\mu \frac{T_\infty}{T} \cong \lambda \frac{T_\infty - T}{T} = \frac{2\sigma_{23}' Vk}{r_{23}'} - \frac{2\sigma_{12}\Delta V}{r_{12}} \quad , \quad \Delta\mu = \frac{2\sigma_{23}' Vk}{r_{23}'_0} \qquad (7)$$

where ΔV is the system specific volume. When the drop's radius $r_{12} \to \infty$, the equation of equilibrium of a crystal embryo in an infinitely big liquid phase is obtained. r_{23}' and $r_{23}'_0$ and radii of the embryos in a small droplet in an infinitely big liquid.

The expressions about the work for the formation of embryos in small droplets in the presence of incompletely and completely wettable nuclei, smooth substrate as well as in a homogeneous drop shown in Figure 3 are as follows:

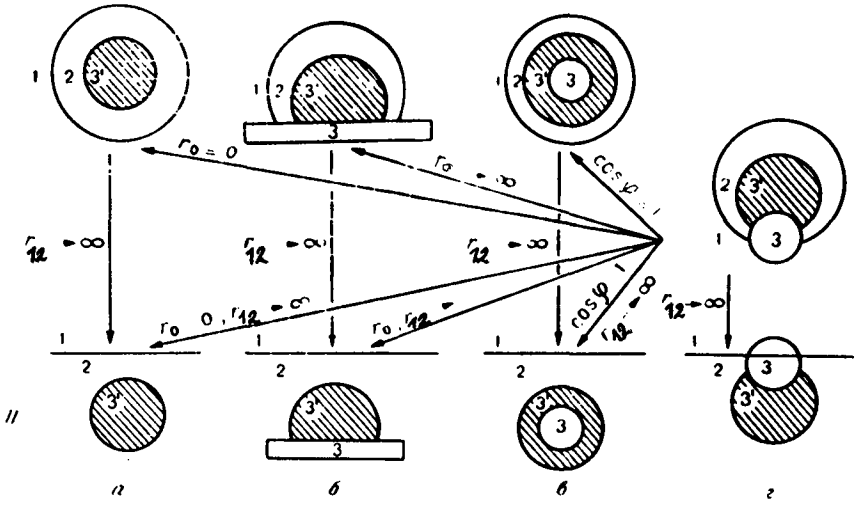


FIGURE 3

$$(\bar{A}_k^*)' = \frac{8}{3}\pi r_{23}^2\sigma_{23}'\left\{-\left[\frac{1}{2}+\frac{3}{4}\left(\frac{1-ZM_3}{g_3}\right)-\frac{1}{4}\left(\frac{1-ZM_3}{g_3}\right)^3\right]+\frac{0V}{Vk}\frac{r_{23}}{r_{12}}-\right.$$

$$\left[\left(\frac{1}{2}+\frac{3}{4}\frac{1-ZM_3}{g_3}\right)-\frac{1}{4}\left(\frac{1-ZM_3}{g_3}\right)\right]-Z^3\left[\frac{1}{2}-\frac{3}{4}\left(\frac{X-M}{g_1}\right)+\frac{1}{4}\left(\frac{X-M}{g_1}\right)^3\right]-$$

$$+\frac{\Delta V}{Vk}yZ^2\frac{\sigma_{12}}{\sigma_{23}}\left[\frac{1}{2}-\frac{3}{4}\left(\frac{X-M}{g_1}\right)+\frac{1}{4}\left(\frac{X-M}{g_1}\right)^3\right]-\frac{3}{4}Z^2\frac{(\sigma_{23}-\sigma_{3,3})}{\sigma_{23}'}-$$

$$\left(1-\frac{Z-M_3}{g_3}\right)+\frac{3}{4}\frac{r_{12}^2}{r_{23}^2}\frac{\sigma_{12}}{\sigma_{23}'}\left(1+\frac{\Lambda-yM_2}{g_2}\right)-\frac{3}{4}\frac{r_{12}^{12}}{r_{23}^2}\frac{\sigma_{12}}{\sigma_{23}'}\left(1+\frac{1-XM}{g_1}\right)-$$

$$\left.+\frac{3}{4}\left(1+\frac{1-ZM_3}{g_3}\right)\right\}. \qquad (8)$$

$$(Ak)' = \frac{4}{3}\pi r_{23}^2\,\sigma_{23}'\left\{1-3\frac{\sigma_{12}}{\sigma_{23}'}\left(\frac{r_{12}'^2}{r_{23}^2}-\frac{r_{12}^2}{r_{23}^2}\right)+2\frac{\Delta V}{V_k}\frac{\sigma_{12}}{\sigma_{23}'}\frac{r_{23}}{r_{12}}-3Z^2-\right.$$

$$\left.+2Z^3-2\frac{\Delta V}{Vk}\frac{\sigma_{12}}{\sigma_{23}'}yZ^2\right\} \qquad (9)$$

$$(\bar{A}_k^*)' = \frac{8}{3}\pi r_{k2}\sigma_{23}'\left\{-\left(\frac{1}{2}-\frac{3}{4}M_3+\frac{1}{4}M_3^3\right)+\frac{\Delta V}{V_k}\frac{r_{23}}{r_{12}}\frac{\sigma_{12}}{\sigma_{23}'}\left(\frac{1}{2}-\frac{3}{4}M_3-\right.\right.$$

$$\left.\left.+\frac{1}{4}M_3^3\right)-\frac{3}{8}(1-M_3^2)\frac{(\sigma_{23}-\sigma_3'{}_3)}{\sigma_{23}'}+\frac{3}{4}\frac{r_{12}^2}{r_{23}^2}\frac{\sigma_{12}}{\sigma_{23}'}(1-M_2)\right\} \qquad (10)$$

$$(A_k^0)' = \frac{4}{3}\pi r_{23}^2\sigma_{23}' - 4\pi\sigma_{12}(r_{12}'^2 - r_{12}^2) + \frac{8}{3}\pi\frac{\Delta V}{V_k}\frac{r_{23}^3}{r_{12}}\sigma_{12}\,, \qquad (11)$$

where $x = r_0/r_{12}'$; $y = r/r$; $z = r_0/r_{23}$; $M = \cos\varphi$;

$M_2 = \cos\varphi_2$; $M_3 = \cos\varphi_3$

$g_1 = \sqrt{1 + X^2 - 2XM}$; $g_2 = \sqrt{1 + y^2 - 2yM_2}$; $g_3 = \sqrt{1 + Z^2 - 2ZM_3}$

are the relations between the nucleus radius and the droplet radius, the radius of the droplet after the crystal embryo formation in it and the radius of the crystal embryo respectively. φ, φ_2 and φ_3 are respectively the angles of wettability between the surfaces of the liquid drop and the crystal embryo with the nucleus.

When the droplet radius tends to infinity $(r_{12} \to \infty)$, from the expressions above as private cases we obtain the expressions of Fletcher about the formation of embryos in an infinitely large liquid. From the expressions obtained about the work for the crystal embryo formation in small drops, we obtain the possibility to trace the change of the work depending on the radius of the supercooled drop (11) Figure 4.

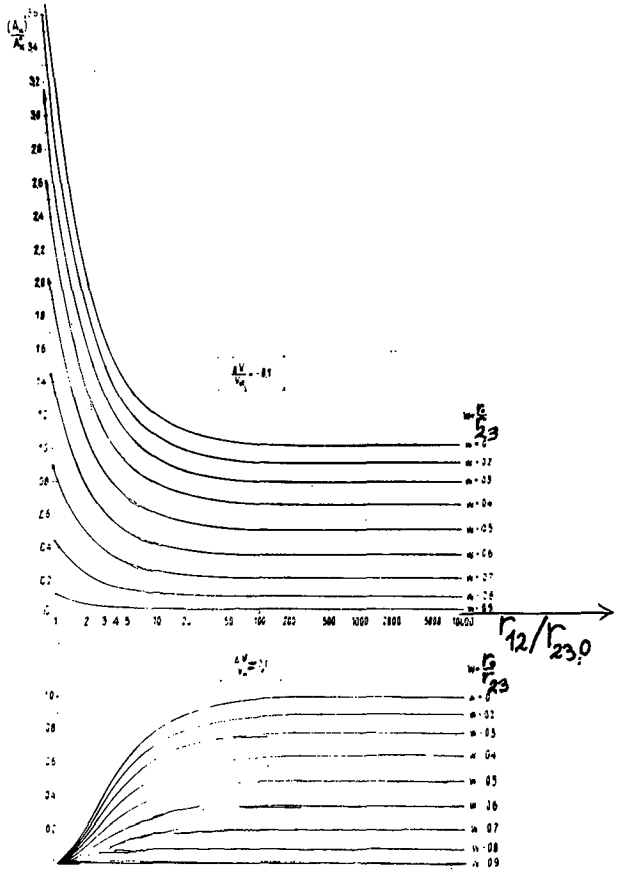


FIGURE 4

For example, concerning the homogeneous case (the crystal embryo formation in a homogeneous drop) it is established that the work diminishes with the increase of the drop size when there is an increase of the specific volume of the system at freezing $\Delta V/V_k = -0,1$. It is this very case in fact which refers to the water freezing. Concerning other liquids at whose freezing there is a decrease of the specific volume $\Delta V/V_k = 0,1$, the work for an embryo formation increases with the increase of the drop size.

The presence of completely wettable nuclei in the drop relieves the crystalization process at which the work for the crystal embryo formation decreases - more weakly or more strongly depending on the nucleus size. Thus, in a theoretical way through the amount of work for the embryo formation, we obtain a possibility to investigate the freezing influence of the condensation nuclei. The less the work is, the bigger the ice-forming activity of the nuclei and vice versa.

For all cases considered so far it is most important that the crystal embryos are wholly dipped into the liquid which means that the newly formed crystal phase is completely wettable by its initial liquid phase.

Most recently, however, it has been shown (12) in a very convincing manner that the ice crystal does not get completely wetted by the water, and its angle of wetting is $\Psi = 12^0 (m = 0,978)$.

It is clear then that the ice embryo will be formed on the surface of the liquid drop, Figure 5, and not inside it.

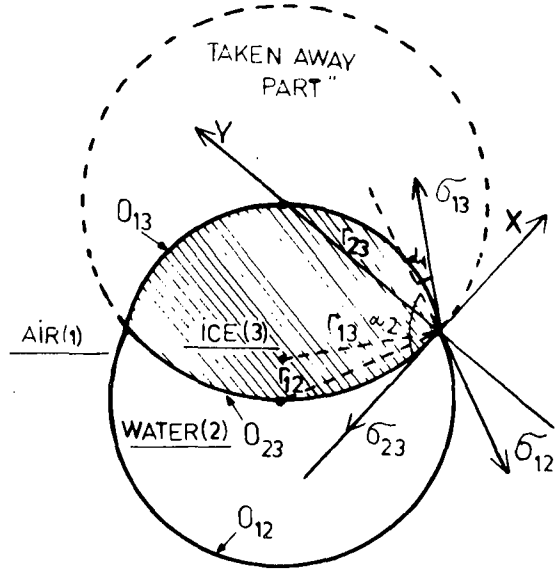


FIGURE 5

Therefore, all cases under consideration up to here, discussed by Fletcher and us, do not refer to the ice, but to the crystalization of

substances at which the crystal phase is completely wetted by its initial liquid phase.

Undoubtedly it is of interest to consider also the cases when the newly formed crystal embryo is not completely wetted by its initial liquid phase $(1 < M < -1)$. (13) This consideration will be most general and will refer to many substances - in particular to the ice crystal which does not get completely wetted by the water. Here we should have in mind the circumstance that the surface tensions have arbitrary directions because of which the condition of equilibrium among the three phases will be given by the vector equation

$$\vec{\sigma}_{12} + \vec{\sigma}_{13} + \vec{\sigma}_{23} = 0$$

whence

$$\frac{\sigma_{12}}{\sin(\vartheta_1 + \vartheta_2)} = \frac{\sigma_{13}}{\sin \vartheta_2} = \frac{\sigma_{23}}{\sin \vartheta_1} \qquad (12)$$

Moreover by means of projecting $\vec{\sigma}_{12}$, $\vec{\sigma}_{13}$, and $\vec{\sigma}_{23}$ on suitably chosen coordinates axes x and y, it becomes possible to express the unknown angles and σ_{23} can be replaced by the known connection

$$\sigma_{23} = \sigma_{13} - \sigma_{12} \cos \varphi \qquad (13)$$

where φ is the actual angle of wetting of the crystal phase by its initial liquid phase in the presence of a gas phase. Here we should bear in mind also the relation which exists among the capillary pressures, namely

$$\frac{\sigma_{13}}{r_{13}} = \frac{\sigma_{12}}{r_{12}} \pm \frac{\sigma_{23}}{r_{23}} \qquad (14)$$

which is easily proved by the model.

The work for the embryo formation will be

$$\Delta G = - n_k \Delta\mu + O_{13}\sigma_{13} + O_{23}\sigma_{23} + O_{12}\sigma_{12} - 4\pi r'^2_{12} \sigma_{12} \qquad (15)$$

where n_k is the number of molecules of the crystal embryo, $\Delta\mu$ the supercooling at which the crystal embryo in the small drop is in equilibrium, $\Delta V = V_f - V_k$ - the difference in the volumes which fall to the molecules in the liquid and crystal phases, r_{12} and r'_{12} - the radius of the drop before and after the formation of a crystal embryo in it. In such a way we take into account the actual angle of wetting, the change of the system volume and the influence of the small drop curvature.

In the case of a complete wetting when the specific volume of the system increases $\Delta V/V_k = -0, 1$ (Figure 6), the work for the embryo formation increases with the decrease of the drop size (this is the previous case which we have considered).

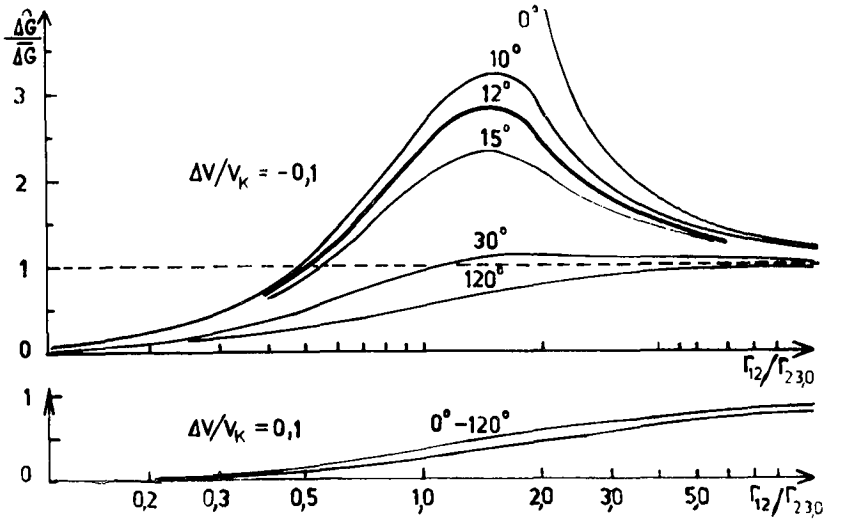


FIGURE 6

At incomplete wetting of the crystal embryo by the liquid, diminishing of work is observed with the decrease of the drop size after its passing through a maximum. The less the wetting of the crystal embryo by its initial liquid phase, the stronger the decrease of the work. Therefore, small water droplets exist with suitable radii which freeze more easily than the big drops. This effect of the small drops explains a series of phenomena of the phase transitions in the atmosphere and gives a new mechanism for treating the crystalization processes in the clouds and fogs. This model with which we consider the crystalization processes is the most plausible one since it reflects most fully (with most parameters) the physical essence of the process and also the most general as it unifies all cases of crystalization (in small phases and in infinitely big liquid at incomplete and complete wetting of the crystal phase by its initial liquid phase). Indeed, at complete wetting we obtain as private cases all our considerations, and when $r_{12} \to \infty$, as the cases of Fletcher. (8)

In Figure 7 we have considered specially the change of work for the ice embryo formation ($\Psi \simeq 12^0$) at a different supercooling. (14) Hence, for each supercooling we have determined the sizes of drops when they freeze more easily than the "infinitely big liquid phase". Thus, for example, for 1^0 supercooling this size is $3{,}3.10^{-6}$cm, for 2^0 - $1{,}6.10^{-6}$ cm, for 3^0 - $1{,}1.10^{-6}$ cm, for 5^0 - $0{,}64.10^{-6}$ cm, for 10^0 -$0{,}32.10^{-6}$ cm, etc.

The considerations hitherto are made about homogeneous drops. The presence of nuclei will enhance this effect of the small drops still more.

In the light of the last results stated above, we think that the ice embryo-formation must be considered under the following conditions:

a) The process of the ice embryo formation must be considered on the surface of the liquid phase after proving that the ice does not get

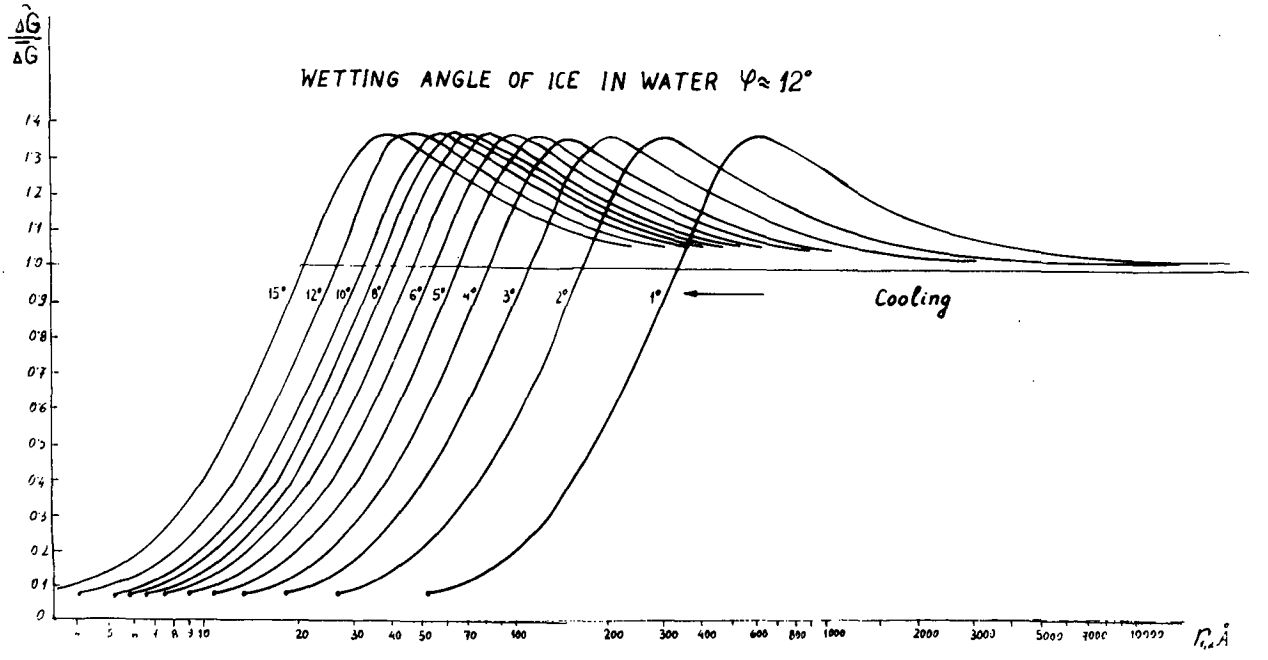


FIGURE 7

fully wetted by the water. This allows to introduce the actual angle of ice wetting by the water. The works which discuss the crystal embryo formation inside the liquid refer to the crystalization of other substances whose crystal phase is completely wetted by its initial liquid phase and not to the ice crystalization which is not completely wettable by the water.

b) We think that in the process of the ice embryo formation, the influence of the small drop curvature should be taken into account. The curvature significantly reflects on the work of embryo formation in the drops. This supplies us with an additional opportunity to consider the change of the system specific volume which at the small drops is essential.

c) In the theory of embryo-formation, besides the surface energies which are taken into account, the edge (peripheral) energy, which is treated in the work of Evans and Lane (15), as well as the peak energy may be introduced. In addition, the latter energies are considered many times in the molecule-kinetic theory of Stranski-Kaishev (16,17) who show that the above energies' influence is of secondary importance. In such a way the introduction of the edge energy, and eventually of the peak energy in the processes of embryo-formation, does not contradict the theory of phase

transitions. Their introduction may have sense only as a supplementary specification of this theory, which in some cases may play a certain role.

d) There are a number of phenomena which cannot be satisfactorily explained with the thermodynamic theory. For example, the formation of ice nuclei on an ice crystal and the problems connected with this concerning the ice crystal form and transformation in the clouds depending on the temperature and supersaturation, the formation of ice embryos on substrates with a definite crystal structure and the problems in this relation concerning the ice-forming activity of the crystalographic walls of the various substances, the mechanism of crystal embryo formation on isomorphic and non-isomorphic nuclei (toward the ice), the processes of the oriented crystalization (epitaxy) on infinitely large substrates and on nuclei, etc.

All these problems must be considered on a molecule level by means of a method which will give the individual arranging of the molecules on the basis of the forces which act between the building elements in the crystal grid. The molecule-kinetic theory of Stranski-Kaishev appears as such a method. (16,17)

The considerations stated refer to the works of Evans and Lane (15) and their scientific argument with Knight (18).

The molecule-kinetic theory of Stranski-Kaishev finds the equilibrium form of the crystals and calculation of the work of embryo formation on the basis of the work of separation of the crystal building elements. The equilibrium form is characterized by the equation of the so-called mean work of separation (mean thermodynamic potentials) of all crystal walls $\bar{\varphi}_1 = \bar{\varphi}_2 = \cdot \cdot \cdot = \bar{\varphi}_i$; at that, the work of separation of each building element on the crystal surface should be equal or bigger than the mean work of separation so that the embryo is stable. The equilibrium between the crystal embryo and its vapors is given by the equation:

$$kT\ell\mu \frac{p}{p_\infty} = \varphi_{1/2} - \bar{\varphi}_1 = \varphi_{1/2} - \bar{\varphi}_2 = \ldots = \varphi_{1/2} - \bar{\varphi}_i \qquad (16)$$

where p and p_∞ are the crystal embryo pressures in the gas phase over the crystal embryo and the infinitely large crystal; $\varphi_{1/2}$ - the work of separation from a position of "half a crystal". This work is the boundary towards which $\bar{\varphi}$ tends, when the linear measurements of the crystal tend to infinity. The work for the embryo formation is given with the expression:

$$A_k = \sum_1^N (\bar{\varphi} - \varphi_i) = N\bar{\varphi} - \sum_1^N \varphi_i \qquad (17)$$

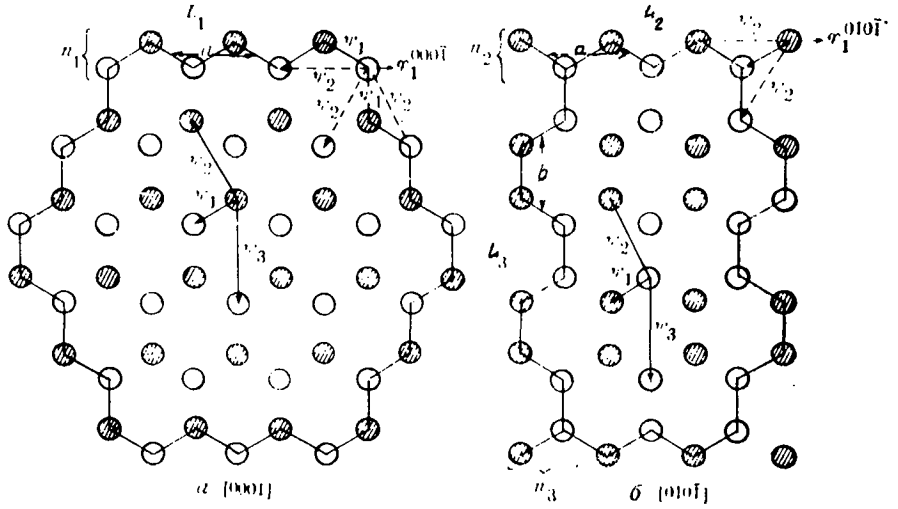
where φ_i is the work of separation of the i-th crystal building element, therefore $\sum_1^N \varphi_i$ represents the energy of connection (the thermodynamic potential) of the crystal composed by N building elements. From the above formulas when knowing the forces which act among the crystal building elements, the equilibrium form, vapor pressure and work for the formation of embryos at a given supersaturation are found.

On the basis of this method we have considered the problem of ice nucleation on an ice crystal (19, 20) with which one of the basic problems in physics of the atmosphere is investigated - the problem of the form of the ice crystals and their transformation in the clouds depending on the temperature and supersaturation of the water vapors. When forming ice on the surface of an ice monocrystal it should be taken into account that the equilibrium form of the ice monocrystal is surrounded by three kinds of walls: base, prysmatic and pyramidal ones which have different surface structures.

Therefore, the work for the formation of an ice two-dimensional embryo on each wall is different under equal other conditions - temperature and supersaturation. In order to find this work, it is necessary to specify the equilibrium form of the initial two-dimensional ice embryo on each wall. According to the theory of Stranski-Kaishev, a stable equilibrium form of the two-dimensional embryos is that one whose work of separation of their particles is equal or bigger than the work of separation in the position of "half a crystal".

$$\Upsilon_{1/2} = 2\,\psi_1 + 6\,\psi_2 = \varphi_1^{0001} = \varphi_1^{0101} \qquad (18)$$

In such a way we determine that on the base and prysmatic walls the two-dimensional embryos are correspondingly a hexagon and a rectangle.



Фиг. 1

FIGURE 8

where ψ_1 and ψ_2 are respectively the work of separation of the first and second neighbors in the crystal grid. The expressions about the work for the formation of the two-dimensional embryos are respectively:

$$A_{0001} = \frac{3\psi_1^2 + 18\psi_1\psi_2 + 24\psi_2^2}{4kT\ell\mu \frac{P}{P_{0\infty}}}, \quad A_{01\bar{0}\bar{1}} = \frac{2\psi_1^2 + 15\psi_1\psi_2 + 28\psi_2^2}{4kT\ell\mu \frac{P}{P_{0\infty}}} \tag{19}$$

$$A_{0001} = \frac{3}{4} \frac{(\psi_1+2\psi_2)(\psi_1+4\psi_2)}{2\psi_1+6\psi_2+kT(\ell\mu p-2.5\ell\mu T+1.88}, \tag{20}$$

$$A_{01\bar{0}\bar{1}} = \frac{1}{4} \frac{(\psi_1+4\psi_2)(2\psi_1+7\psi_2)}{2\psi_1+6\psi_2+kT(\ell\mu p-2.5\ell\mu T+1.88)}$$

where P and $P_{0\infty}$ are the gas phase pressure with respect to the two-dimensional embryos and the infinitely big three-dimensional crystals.

It is established that the work for the formation of the two-dimensional embryo on the prismatic wall is less than that on the base wall at small and big supersaturations. Therefore, under equal other conditions (t^0 and supersaturation) the prismatic wall is more active and the form of increase of the ice crystal appears to be a hexagonal plate which the experiment confirms too. We are considering the formation of two-dimensional embryos of the ice on an ice crystal, but, of course, this method and these considerations may be referred as well to the formation of ice embryos on foreign substrates near in its structure to that of the ice, as, for example, AgI and PbI_2. For them we may also accept that for small and big supersaturations their prismatic walls appear to be more active. If we know the forces which act between the water molecules and substrate we can exactly determine the values of work about the embryo formation on the different walls. Fletcher (21), calculating the change of the entropy at the ice embryo formation on substrates of AgI, explains the distinction in the activity of the base and prismatic wall with the existence of differently charged ions of the prismatic wall and obtains the same result for its bigger activity.

On the basis of the molecule-kinetic theory of Stranski-Kaishev, the mechanism of formation from the gas phase of crystal embryos with a definite crystal grid on incompletely wettable isomorphic nuclei is considered (22,23). For simplicity we consider the formation of cubic embryos at the most general configuration of the nucleus and embryo shown in Figure 9a.

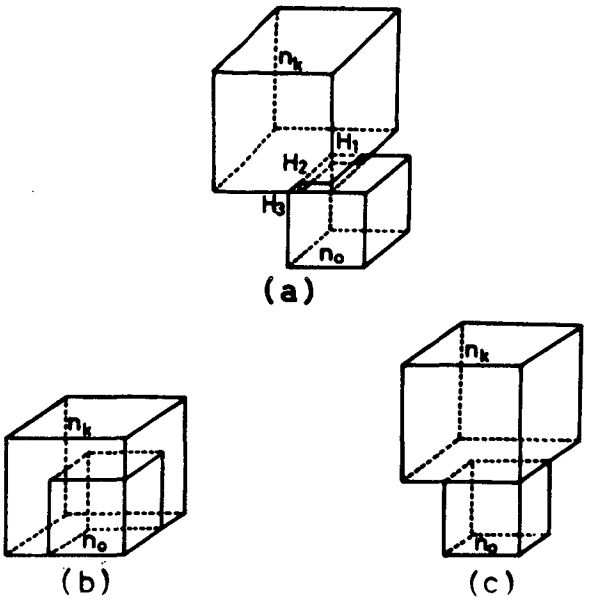


FIGURE 9

The nucleus wettability by the crystal embryo is defined. In this case it is proved that the crystal embryo does not wholly include the nucleus. The work for the formation of such an embryo by the method of the mean work of separation is given with the expression:

$$A^{(a)} = n_k^2\psi + 2\,\frac{H_1H_2H_3}{n_k}\,\psi - H_1H_3\psi^1 - H_2H_3\psi^1 - H_1H_2\psi^1 \qquad (21)$$

where ψ and ψ^1 are respectively the work of separation of the connections between neighboring atoms in the grid of the forming crystal and between an atom of the forming crystal and atom of the isomorphic nucleus. By means of annulling the private products of the work $A^{(a)}$ by H_1, H_2 and H_3, we obtain the condition

$$H_1 = H_2 = H_3 = n_0 \qquad (22)$$

i.e., that part of the nucleus which sinks in the embryo always appears as a cube, and

$$\frac{n_0}{n_k} = \frac{\psi^1}{\psi} \qquad (23)$$

which represents the value of n_0, i.e., of "sinking" of the nucleus in the embryo for which the work is minimal.

If $n_0/n_k \lesseqgtr \psi^1/\psi$, i.e., if the nucleus is smaller or bigger than that defined with condition (23) corresponding configurations (b) and (c) in Figure 9 are obtained, whose expressions for work are:

$$A^{(b)} = n_k^2\psi \left(1-3 \frac{n_0^2}{n_k^2} \frac{\psi^1}{\psi} + 2 \frac{n_0^3}{n_k^3} \right) \qquad (24)$$

$$A^{(c)} = n_k^2\psi \left(1 - \frac{n_0^2}{n_k^2} \frac{\psi^1}{\psi} \right) \qquad (25)$$

Therefore, for smaller nuclei than those defined by condition (23), the configuration (b) in Figure 9 appears as more probable at which there is a "sucking in" of the nucleus by the crystal embryo. While for bigger nuclei than those defined with condition (23), configuration (c) in Figure 9 appears as more probable where a "pushing out" of the nucleus from the embryo is observed the nucleus being stuck to one of the crystal embryo walls. From the expressions thus obtained as private cases of them under respective boundary conditions ($\psi^1 = \psi$, $n_0 = n_k$, $n_0 = 0$) we obtain the expressions about the work for the crystal embryo formation on completely wettable nuclei, on an infinitely big substrate and in homogeneous water vapors

$$A_k = n_k^2\psi \left(1 - 3 \frac{n_0^2}{n_k^2} + 2 \frac{n_0^3}{n_k^3}\right); \quad \overline{A}_k = n_k^2\psi \left(1-\frac{\psi^1}{\psi}\right) ; \quad A_k^0 = n_k^2\psi$$

In Figure 10 we have represented the work change $A^{(b)(c)}/A^0_k$ in a function of the nucleus size n_0/n_k for different wettability ψ^1/ψ of the embryo by the crystal.

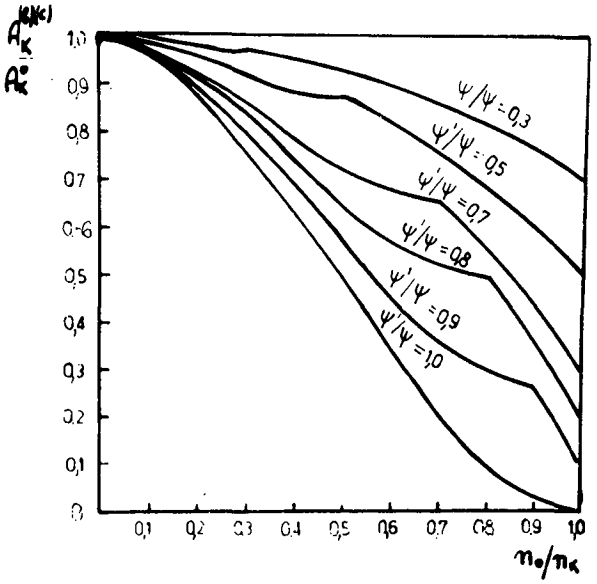


FIGURE 10

We have also considered the adsorption influence of foreign substances (substances which change the surface energy) on the equilibrium form of the embryo and the work for its formation. The adsorption influence is taken into account with the help of the value W which represents the mean work of adsorption on an area answering one building element of the i-th crystal wall.

Here the two configurations between the nucleus and embryo (Figure 9(b) and (c)) are also in force, the value W already figuring in the new expressions about the work.

$$A_{ads}^{(b)} = n_k^2\psi \left(1-2\frac{W}{\psi}\right) - 3\frac{n_0^2}{n_k^2}\left(\frac{\psi^1}{\psi} - \frac{W}{\psi}\right) + 2\frac{n_0^3}{n_k^3}\left(1-2\frac{W}{\psi}\right) \tag{26}$$

$$A_{ads}^{(c)} = n_k^2\psi \left(1-2\frac{W}{\psi}\right) - \frac{n_0^2}{n_k^2}\left(\frac{\psi^1}{\psi} - \frac{W}{\psi}\right) \tag{27}$$

The nucleus size which differentiates the two configurations in this case has the form

$$\frac{n_0}{n_k} = \frac{\psi^1 - W}{\psi^1 - 2W} \tag{28}$$

Here now we can take the relationship of the two crystal walls as a criterion of the adsorption influence:

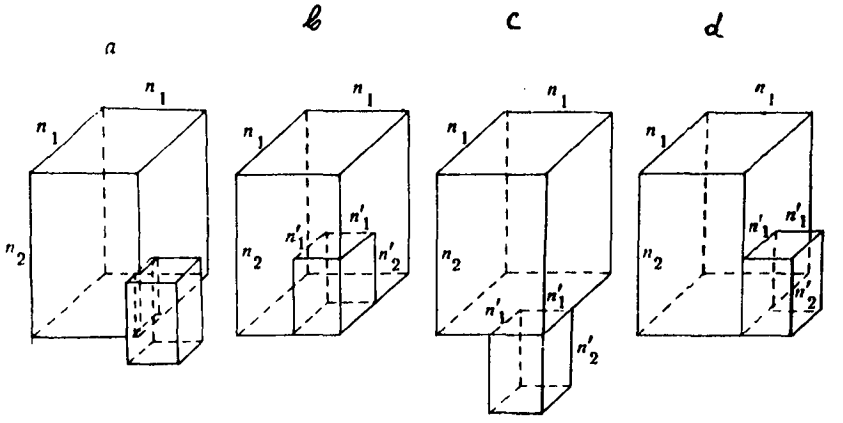
$$\frac{n_k - n_0}{n_0} = 1 - \frac{\psi^1 - W}{\psi - 2W} \tag{29}$$

or the difference of these relationships at adsorption and lack of adsorption

$$\Delta\left(\frac{n_k-n_0}{n_0}\right) = \left(\frac{n_k-n_0}{n_0}\right)_{ads} - \left(\frac{n_k-n_0}{n_0}\right) = \frac{W(\psi-2\psi)}{\psi(\psi-2W)} \tag{30}$$

From the expression above it may be seen when the equilibrium form remains unchangeable or one of the walls disappears as it is not difficult to establish also the conditions of the appearance of a new wall, for example (111).

This new model of the crystal embryo formation on isomorphic nuclei may be applied also to other crystal grids. Thus, for instance, we have also considered the formation of embryos with a rectangular and tetragonal grid on nuclei (24). The equilibrium forms and work of the real configurations formation shown in Figure 11 are found.



Фиг. 2

FIGURE 11

where there is also "sucking in" and "pushing out" of the nucleus by sticking to one of the other embryo walls. The expressions about the work and conditions of their realization are respectively:

$$A^{(b)} = n_1\psi_2 + n'_1 n'_2 \frac{\psi_1}{n_1} - n'_1\psi'_2 - n'_2\psi'_1$$

$$A^{(c)} = n_1\psi_2 \left(1 - \frac{n'_1}{n_1}\frac{\psi'_2}{\psi_2}\right)$$

$$A^{(d)} = n_1\psi_2 \left(1 - \frac{n'_2}{n_1}\frac{\psi'_1}{\psi_2}\right) \qquad (31)$$

$$\frac{n'_1}{n_1} \gtrless \frac{\psi'_1}{\psi_1} \quad , \quad \frac{n'_2}{n_1} \lessgtr \frac{\psi'_2}{\psi_1} \qquad (32)$$

The case when there is adsorption of foreign substances and its influence on the work and the equilibrium form of the crystal embryos with rectangular and tetragonal grid (25) is considered.

By means of this problem we made a full generalization of all existing cases about the crystal embryo formation in homogeneous water vapors, on a smooth substrate and completely wettable nuclei, under natural conditions and at adsorption.

The results which are obtained for the formation of crystal embryos on isomorphic nuclei give an opportunity to consider also the processes of the oriented crystalization (epitaxy) on nuclei (26). Up to the present moment these processes have been considered only on an infinitely big substrate. The small sizes of the nuclei lead to important changes in the conditions of the oriented crystalization. A basic moment here is the determination of the maximally assumed difference $\Delta a_{max.}$ in the sizes

of the coalescing elementary complexes of two crystals for which the epitaxy is realized. The condition of the oriented crystalization is given by the expression

$$A^D = A + E^D \leq A^{(b)(c)} \quad \text{or} \quad E^D \leq A^{(b)(c)} \tag{33}$$

where $A \ll A^{(b)(c)}$ is the work for the formation of a two-dimensional non-deformed embryo, E^D - the work necessary for its deformation, and $A^{(b)(c)}$ - the work for the formation of the three-dimensional embryo. By replacing the two expressions (24) and (25) in the condition about the oriented crystalization we obtain the criteria of epitaxy on the nuclei, i.e., the expressions about the maximum assumed difference Δa_{max} in the sizes of the elementary coalescing complexes.

$$\Delta a_{max}^{(b)} = \left(\frac{2a\,\sigma}{C_{11}+C_{12}}\right)\left(1-3\,\frac{n_0^2}{n_k^2}\,\frac{\psi'}{\psi}+2\,\frac{n_0^3}{n_k^3}\right)^{1/2}\left(1+\frac{\psi'-\psi-\varepsilon}{kT\ell\mu\dfrac{P}{P_\infty}}\right)\cdot 2 \tag{34}$$

$$\Delta a_{max}^{(c)} = \left(\frac{2a\,\sigma}{C_{11}+C_{12}}\right)\left(1-\frac{n_0^2}{n_k^2}\,\frac{\psi'}{\psi}\right)^{1/2}\left(1+\frac{\psi'-\psi-\varepsilon}{kT\ell\mu\,\dfrac{P}{P_\infty}}\right)\cdot 2 \tag{35}$$

where the nucleus sizes n_0 are already figuring. Besides,

C_{11}, C_{12} - are the crystal elastic coefficients

a - the grid constant

σ - the specific surface energy

ε - the work about the deformation of a particle of the two-dimensional crystal

T - temperature

$S = \ell\mu\dfrac{P}{P_\infty}$ - supersaturation

In Figure 12 we have built the change of Δa_{max} in a function of the factor of wettability ψ'/ψ for different sizes of the nuclei. The first curve is about the case when there is epitaxy on an infinitely big substrate $n_0/n_k = 1$. The remaining curves are about different sizes of the nuclei (n_0/n_k = 0,g; 0,f; 0,5 ....0,1.)

While the infinitely big substrate assumes a difference within the sizes of the coalescing complexes in the presence of nuclei, this difference increases with the decrease of their size. Therefore, on the nuclei the processes of epitaxy are realized at bigger differences in the sizes of the elementary coalescing complexes. This result is especially essential since it explains the fact that so different structures with so big differences

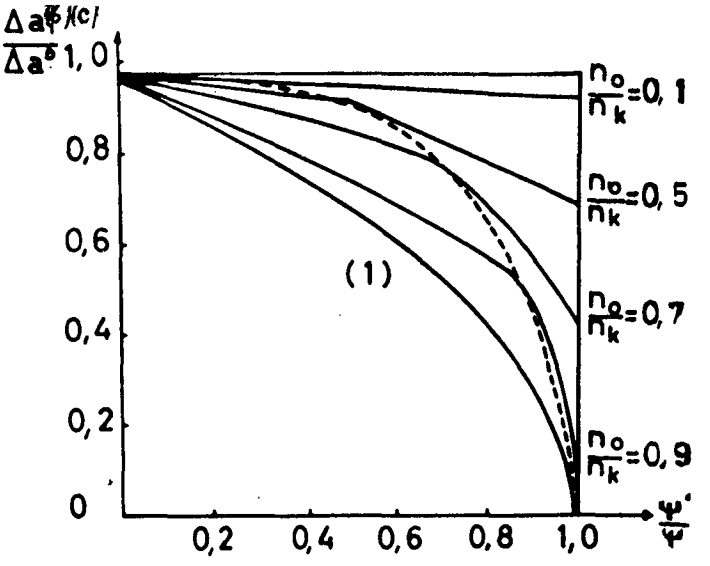


FIGURE 12

between their grid constants and those of the ice act as crystalization nuclei.

If in the condition of epitaxy we replace the expressions about the work for the formation of crystal embryos on nuclei at adsorption, we obtain the criteria of epitaxy from which we can evaluate the influence of the surface-active substances on the oriented crystalization

$$\Delta a_{max}^{(b)ads} = \left\{\left(\frac{2a\sigma}{C_{11}+C_{12}}\right)\left(1-\frac{2W}{\psi}\right)\left[1-3\,\frac{n_0^2}{n_k^2}\left(\frac{\psi'-W}{\psi-2W}\right)+2\,\frac{n_0^3}{n_k^3}\right]\right\}^{1/2} - \cdot\left(1+\frac{\psi'-\psi+W-\varepsilon}{kTS}\right)\cdot 2 \qquad (36)$$

$$a_{max}^{(c)ads} = \left\{\left(\frac{2a\,\sigma}{C_{11}+C_{12}}\right)\left(1-\frac{2W}{\psi}\right)\left[1-\frac{n_0^2}{n_k^2}\left(\frac{\psi'-W}{\psi-2W}\right)\right]\right\}^{1/2} - \qquad (37)$$

$$\cdot\left(1+\frac{\psi'-\psi+W-\varepsilon}{kTS}\right)\cdot 2$$

Finally we wish to deal with a possible mechanism with which the strong ice-forming activity of some inorganic compositions is explained and recently suggested by Krastanov (27). These are the compositions of the elements of Ib and IIb groups with the elements of VIb and VIIb groups of the periodic system. The molecules of these compositions are strongly

polar thanks to the polarizing ability of the elements of Ib and IIb groups and the strong ability of being polarized of the elements of VIb and VIIb groups. This polarization is best expressed on the surface of the crystal where it is occupied by strongly polarizing anions. On the other hand, the molecules of the water are also strongly polar; they come into interaction with the polarized molecules of the inorganic compositions indicated. This interaction is determined by the hydrogen connection in the case of the hydrogen molecules with the anions from the crystal surface which interaction appears to be dipole-orienting. When there is an interaction among water molecules (formation of an ice embryo on an ice crystal) the interaction is realized through the hydrogen connections. It should be noted that the role of such interactions is not well studied yet. A quantitative investigation in this region will introduce a bigger clarity in the treatment of the crystalization processes, especially for the formation of the first ice layer on foreign substrates.

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SNOWFALL ENHANCEMENT

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The problem of snowfall enhancement is closely related to the more general problem of precipitation enhancement or rainmaking. We know that the proof for effective precipitation enhancement is for most projects based on statistical evidence. This evidence while often convincing to mathematicians as often fails to convince physicists. However, only in the past years has evidence become available which permits a physical assessment. It is particularly the insight into the interrelationship between several parameters -- some of them are microscale, some are mesoscale -- in nature which has brought the understanding of the snow process into sharper focus. The most important mesoscale parameter is the rate of condensation which determines the amount of moisture released for precipitation. The most important microphysical parameter is the concentration of snow crystals furnished by nature.

1. Concentration of snow crystals

Apparently this parameter depends on two factors: 1) the concentration of freezing nuclei and 2) the rate of upward flux of freezing nuclei. When the rate of updraft doubles from say 5 cm/sec to 10 cm/sec at a certain atmospheric level, characterized by the threshold termperature of freezing nuclei, twice as many nuclei will become active and twice as many crystals will form. As the rate of condensation also depends on the updraft velocity, one has here an interesting self-regulating mechanism: the more precipitable water is liberated by the rate of condensation which is related to the large scale cyclonic mechanism, the more crystals form to snow-out the water. Since the rate of condensation and the rate of precipitation are related, it is not surprising that -- in general -- proportionality exists between the latter and the snow crystal flux. This important relationship follows from the research of Gunn (1). He studied the number of individual snow crystals by carefully separating those which were aggregated in a snowflake, then he melted them and determined from the size of the resulting droplets an average mass $\overline{m}$ of an individual crystal. At the same time he determined the rate of precipitation R and was able to compute the flux of snow crystals $R/\overline{m}$ per cm^2 and sec as a function of R.

$$R/\overline{m}\ (m^{-2}\ sec^{-1}) = 1.5R^{1.0}$$

Figure 1 shows the results of 6 storms and 84 individual measurements. If we assume an average fall velocity of the snow crystals of 1 m/sec, then the figure says that at a rate of precipitation of 1 mm/hr, an average concentration of about 20 crystals per liter exists with a variation from 6 to 40; the concentration increases to about 50/1 for a rate of precipitation of 3 mm/hr. Gunn

points out that in individual snowfalls the variability of the particle flux may vary within a factor of 4. The graph clearly indicates the proportionality between snow crystal concentration and rate of precipitation. Looking at the graphs of the individual snowfalls, however, which are given by the author, a marked inverse proportionality between snow crystal concentration and the average mass for a snow crystal is apparent also. In two cases the compensation is practically complete: While the rate of precipitation remains essentially constant, variations of the particle flux are compensated by inverse variations of the average particle mass. This permits the important conclusion that nature compensates for the small scale variability of nuclei concentrations by adjusting the crystal size. This observation makes it highly plausible that, in general, nature does a pretty good job in stratiform snow producing systems to snow out very effectively the water which is furnished by the rate of condensation. Unprecipitated water is stored in the cloud as liquid water, and it is well known from measurements in the USSR as well as in the USA that this amount is small indeed and hardly worth the effort of artificially inducing its precipitation.

We were able to confirm Gunn's basic numbers of particle flux by a somewhat different approach. We based our studies on the Bergeron (2) concept of the mechanism of plentiful precipitation. Bergeron defines a "releaser" or "seeder" cloud and a "spender" or "feeder" cloud. The former produces the ice crystals which subsequently snow out the latter. The releaser cloud is usually a Cirro or Altostratus in which the particle grow by diffusion while the spender cloud is a low level Stratus where growth proceeds by diffusion, riming and aggregation. Both cloud systems occur independently as well. The releaser cloud crystals are typically prism bundles which deform in the spender cloud through growth of endplates and branches as well as additional irregularities through riming. These crystals easily aggregate, and it requires Gunn's tedious procedure to separate them. If, however, the spender cloud does not exist, they fall as single crystals and can easily be counted. In such cases we found concentrations of 5 to 40 per liter in good agreement with Gunn's values (Weickmann (3) and Jiusto and Weickmann (4).

It appears that these concentrations are perfectly capable of supporting considerable rates of stratiform precipitation. Figure 1 indicates that a flux of 3-5 cm^{-2} sec^{-1} supports a rate of precipitation of 4 mm/hr, which can be easily anything from a 4 to 8 cm snowfall per hour.

The concentration of crystals, the rate of condensation and the temperature at which crystals form determine other important parameters, such as: the growth habit, regular or irregular, affecting the rate of diffusional growth; the fall attitude, oscillating, rotating, tumbling affecting the ventilation factor in the diffusional growth equation; the riming efficiency depending on crystal habit, fall velocity and attitude and affecting in various ways the rate of crystal growth; and finally the aggregation of crystals into flakes depending on crystal concentration and attachment factors, and affecting the riming efficiency.

It is not yet possible to assess all of these parameters in their relationship and importance to precipitation efficiency, but we would like to mention a few examples. In cases where the crystal concentration is lacking,

special growth habits are developed which appear to compensate the deficiencies. We would like to quote one typical case from our log on snowfalls. On November 2, 1969 a convective Stratocumulus layer about 2500 m thick with tops at -25C precipitated rimed flakes made up of rimed spatial plate crystals. Suddenly, the snowfall changed to very large flakes. These large flakes consisted of rimed large spatial dendrites of about the same concentration as the small spatial plate crystals before. Apparently, a sudden abundance of the water supply or an increase of the rate of condensation has caused a habit change from rimed spatial plate crystals to rimed large spatial dendrites thus increasing effectively the scavenging ability of the precipitation particles. Likewise, if riming occurs in the temperature range between about -5C and the freezing level, the collected droplets tend to crystallize into fast growing needles which in turn increase the collection efficiency of the crystal ensemble.

It appears that overabundance of freezing nuclei and consequently of ice crystals does not lead to overseeding and loss of precipitation, but to much increased efficiency in aggregation of the crystals to large snowflakes. This follows clearly from our seeding experiment near Buffalo on 21 November 1969 (Weickman (3). On this day multiple cloud lines formed over Lake Erie in a NW-SE direction and produced snowshowers over the southern shores of the Lake. The cloud base was at 600 m and -10C while the tops were at 2400 m and -18C. The structure of the cloud system was convective, consisting of Cumulus clouds which were topped by a Stratocumulus layer, penetrated on isolated locations by the Cumulus clouds. The precipitation consequently was of shower character. From 11.57 to 12.23 local time, seeding was carried out at 800 m with pyrotechnic flares releasing a total amount of 2400 g AgI. After one hour a cloud volume of about 2000 km^2 had become modified and was made visible from the aircraft flying above the cloud tops by an intensive undersun forming downwind of the seeding track over a cloud area of 28 x 40 km. The seeding rate at homogeneous distribution of the nuclei throughout the cloud system would have produced a crystal concentration of about 50 to 60/ℓ. Homogeneous distribution, however, seldom occurs; therefore, some areas will have received more and others less. From 13.30 to 13.54 a mobile ground observer unit observed the composition of a heavy snowshower which apparently had received an abundance of nuclei (Figure 2). The normal precipitation consisted of a broad distribution of particle sizes made up of mixed dendrites and graupel. This particle characteristic changed to great numbers of tiny crystal forms most of which were unrecognizable, the others consisted of plates, stars, needles and columns. They were aggregated in great numbers to large flakes. Some flakes contained from 100 to 1000 individual crystals according to the observer's log. Qualitatively it appeared that the shower became intensified during the snowflake stage. Figure 3 shows on the right the natural particle characteristics and on the left the flakes made up of the many tiny crystals. This important observation which was made repeatedly points strongly to the fact that overseeding is not the problem in snow enhancement; the problem is underseeding. Any seeding project should always tend to produce at least as many crystals as the natural process does, or at least 10 to 50 crystals/ℓ.

2. Rate of condensation and cloud thickness

We mentioned above that precipitable water in a cloud appears in two forms: 1) as liquid water stored in the cloud and 2) as water released by the

rate of updraft in the condensation process, shortly by the rate of condensation. The water storage in stratiform clouds is with few exceptions very small, mostly less than .3g/m^3. The total precipitable water in a cloud 1000 m thick is therefore only of the order of 0.3 mm -- hardly enough to reach the ground and produces only one shower, then the cloud has to be reformed. Contrary to this storage, the rate of condensation is a process which may proceed over many hours and produces little precipitable water per hour but much over the entire time. The amount of water R_w liberated in mm/hour by an updraft of 1 m/sec is given by the relationship:

$$R_w = \frac{780}{T} \frac{de_w}{dT} \gamma_w - 2665 \frac{e_w}{T^2}$$

where e_w is saturation vapor pressure over water (mb)

T is temperature (^oK)

γ_w is saturated pseudo adiabatic lapse rate (^oC/100 gpm)

For a 1000 m thick layer, seeding from roughly 950 mb to 850 mb and a range of base and top temperatures, Table 1 gives R_w in mm/hour for various updraft velocities:

Table 1.

Base & Top Temp.	0 to -10C	-5 to -15C	-10 to -20C	-15 to -25C
Updraft				
1 m/sec	1.45 mm/hr	1.18 mm/hr	.93 mm/hr	.70 mm/hr
.5 m/sec	.73 mm/hr	.59 mm/hr	.47 mm/hr	.35 mm/hr
.1 m/sec	.15 mm/hr	.12 mm/hr	.09 mm/hr	.07 mm/hr

Precipitable water R_w in mm/hr released in a cloud 1000 m thick as a function of updraft velocity and base and top temperature.

Table 1 shows clearly that 1000 m is indeed a minimum thickness for which cloud seeding should be attempted as only for updraft velocities larger than .5 m/sec and top temperatures warmer than -20C are noteworthy amounts of precipitable water being released. Of course, at a top temperature of -20C the natural release of precipitation is already quite effective; furthermore, it may be possible that the snow-out efficiency is less than 100%. Effective snowfall enhancement under such conditions requires either a thicker cloud deck or a higher updraft velocity.

3. Snowfall enhancement opportunities

The previous discussion indicates that snowfall enhancement opportunities may present themselves through the microscale mechanism of snow formation as well as through the mesoscale flux parameters of cloud systems. Chappell (5) in studying natural and artificial snowfall in unpolluted air from orographic winter clouds over the Rocky Mountains derives somewhat schematized physical conditions for snowfall enhancement opportunities. Observation indicated that in these orographic snowfalls most snow crystals had grown by diffusion only and not through riming or aggregation. For this to occur model considerations of the air flow over the mountains suggested an uprdraft velocity of 11.0 cm/sec. It was assumed that the cloud tops were at about the 500 mb level; then, the observational data permitted construction of a diagram (Fig. 4) which has as abscissa the 500 mb level temperature from -35 to -10C, and as ordinate the water equivalent per precipitation day. In the diagram two parameters are plotted: the average rate of condensation (solid curve) and the average diffusional growth rate of ice crystals for a 460 mb cloud top and the natural ice nuclei spectrum (dashed curve). The author also plots values of observed precipitation averaged over the number of observational days. While for temperatures below -20C these values follow the curve for the average rate of condensation, for temperatures warmer than -20C the precipitation no longer is proportional to the rate of condensation but follows the diffusional growth rate -- thus exhibiting a precipitation deficiency. Of course, then water storage should occur in the cloud and why is it not that nature invokes other growth processes for compensation, such as riming and the formation of secondary dendritic branches, etc? Figure 5 which is self-explanatory shows how seeding was able to bring the rate of precipitation back to agree with the rate of condensation. Seeding in this experiment was carried out by surface generators. This somewhat idealized definition of existing seeding opportunities for temperatures of the (assumed) cloud tops warmer than -20C postulates that no releaser or seeder cloud exists or that for temperatures colder than -20C no spender or feeder cloud exists -- which of course is an obvious condition when the target area is already at about the 700 mb level and the entire cloud thickness is not more than 200 mb. Indeed, such cloud layers exist also in the flatlands more frequently than generally assumed.

4. Winter cloud systems with seeding potential

4.1 The convective Stratocumulus systems.

Shallow convective Stratocumulus systems with top temperatures warmer than -20C have been observed and described for the Pacific NW territories in the USA (Hall (6) in the Great Lakes region of the USA (Lavoie (7); they furnish the snowfall in Hokkaido, Japan (Magono (8); satellite observations show them over the Caspian Sea (Bugaev (9); they are known to occur in the Mediterranean and we believe that they are the cloud systems which furnish water for the effective rain making experiments in Israel. All these systems have one thing in common: they are related to relatively shallow layers of cold air within the planetary boundary layer moving over warm bodies of water -- be it the Gulf of Alaska and its southern regions, the Great Lakes, the Japan Sea, the Mediterranean Sea, or the Black or Caspian Seas. These cloud systems are highly convective and may locally also have high water con-

tents of the order 1 g/m^3. Updraft velocities have been measured by means of a doppler radar (McVehil, et al. (10) which would reach several meters, thus producing an effective rate of condensation. Snow crystals falling from them have been described by Magono (8), Jiusto and Holroyd (11), Weickmann (3); they are typically dendrites, rimed and in flakes. A useful numerical model for these cloud systems has been developed by Lavoie (12).

4.2 The Upslope Stratocumulus Systems.

Figure 6 shows a satellite picture of the western USA (note the Pacific coast line) with a cloud system in the center. Denver, Colorado, is located at about the cross mark in the center of the picture. This system was caused by an Anticyclone located north of Denver which moved the air to ascend more than 1000 m, so that condensation is eventually reached. The Denver Radiosonde shows the thickness of the cloud system and a temperature-humidity profile which was highly favorable for artificial precipitation having a cloud top temperature of only -10C. Slope and wind component perpendicular to the slope determine the rate of condensation which is in most cases near 10 cm/sec. A climatological study of the frequency of such systems in the High Plains over the past ten years (Whiteman- 13) has shown that per year about one dozen seedable cases occur (Figure 7). Such cloud systems also occur frequently over the Bavarian High Plains in Germany. The special feature of these cloud systems is that precipitation can be released over a large area and not just from single Cumulus clouds.

Typical shallow cloud systems also occur within the large winter anticyclone over the USSR, but it appears that these layers are usually shallow (about 300 m thick) and formed due to radiation processes which makes for a low rate of condensation. They have, therefore, a poor artificial precipitation potential (Leskov - 14); (Kondratova - 15).

4.3 Cyclonic shallow cloud systems

Shallow cloud systems also occur in connection with warm fronts and may constitute a true and so far unexploited seeding potential (Grunow-16); (Weickmann-17, 3).

5. Geometry of precipitation zone (target area determination)

The geometry of the precipitation zone or the determination of the target area has been the subject of studies by Elliott (18), Grant (19), and more thoroughly by Soviet scientists (e.g. Leskov - 20). Elliott discusses the movement of the seeding agent which was dispersed from a single ground generator and which affected atmospheric layers subjected to wind shear. He moves the plume first with the low level wind vectors and then with the upper level vectors. Grant (19) studies the effect of orography and finds preferred propagation along mountain passes. Soviet scientists (Leskov - 20) eliminate one-half of this difficult problem by seeding from aircraft and so do we (Weickmann - 3). The problem is presented in Figures 8a-f. Figure 8a is taken from Leskov (21) and shows the difference of target location if an average wind vector from the surface to cloud top is used, compared to taking

into special consideration the wind below the cloud layer separate from an average wind in the cloud layer. Airborne seeding takes place along line A-B. Leskov could explain why in two special cases the target area with the Leonov method was incorrectly forecast to be inside the network area (dashed line parallelograms) while his method would have given the correct forecast (solid line parallelograms). The correctness of his argument is reflected in Fig. 8b which shows how the true precipitation is located within the area forecast by his method. Note, however, that the shear in this case is only in speed not in direction. The conditions for shear in direction are discussed by Leskov (21) by means of Figure 8c. Leskov suggests consideration of the low level and upper level drifts of the seeding line. Of course, since there will always be a transition zone between these two vectors, the entire area AA_1B_1 A_2B_2B will be affected by the seeding agent. This follows clearly from our experiment on Dec. 3, 1969 (Fig. 8d-f). On this day we seeded a cloud line with AgI over the south shore of Lake Erie. A considerable shear in speed and direction existed within the convective Stratocumulus layer, base temperature at 900 m (2700 feet) was -4C, top temperature -18C at 2750 m (8300 feet). The seeding level was at 1000 m, wind was NNW 15 kts while at the top of the layer it was WNW 30 kts. Fig. 8d shows the aircraft flight path during seeding and thereafter as well as low level streamlines while Fig. 8e shows the same information with the addition of the upper level streamlines. The shaded area gives boundaries of the cloud volume into which the AgI will have diffused if an effective vertical exchange exists within the cloud layer. Fig. 8f confirms this circumstance by indicating the analysis flight path during which the concentration of the ice nuclei was measured. In the entire area diamond dust was observed and regions of high nuclei concentration. Of particular interest is the series of high counts in the western half of the flight path. They were measured at a flight level of 1200 m (4000 ft) and it is clear that they could have arrived there only by means of the upper level winds. Especially high counts of ice nuclei are marked along the flight path by large dots or emphasis of the line. During summer in convective atmospheric conditions airborne seeding near the cloud bases as was done in Whitetop may result in different target areas, as diffusion throughout a deep atmospheric layer reaching from the surface to some level above the flight level needs to be taken into account. Whitetop used two different diffusion plumes: the so-called "Chicago plume" which took into account the most divergent winds between flight level and 4200 m (16,000 ft), and the "Missouri plume" defined by the winds at seeding level (Braham - 22). We feel that both approaches are incorrect as the 4200 m top level is quite arbitrarily selected and as the plume has not been extended to the ground surface.

6. Seeding technique

During airborne seeding operations the experimenter has a number of options, such as: one-dimensional line seeding at cloud base or cloud tops and two-dimensional "curtain" seeding from the cloud tops. Fig. 9 shows the effect in one and the same cloud deck of line seeding with an aircraft AgI generator at cloud base, and of Dry Ice "curtain" seeding from the cloud tops (Weickmann-3). Curtain seeding was accomplished by a seeding rate of 10 lbs/mile

using pea to walnut sized Dry Ice particles. In both cases strong seeding effects developed in the cloud deck which were observed by radar (Figure 10a,b). The echo areas were carefully planimetered and the growth of the affected area plotted in Figure 9. While the Dry Ice grows linearly from the beginning, the AgI area requires about 20 minutes delay before its spreading rate parallels that of Dry Ice. It shall be mentioned in this connection that the nuclei concentration in the Dry Ice area was a factor of about 3 larger than in the AgI area. Corresponding data are obtained when the rate of linear spreading perpendicular to the seeded line is plotted. The irregularity of the diffusion mechanism causes the rate of lateral spreading to scatter considerably, but Figure 11 shows that the Dry Ice effect spreads out twice as fast as the AgI effect. Again, however, Dry Ice produced more nuclei than AgI by about a factor of 10. This is an entire order of magnitude and could cause internal eddies in the cloud deck. In this case, both agents were introduced about 150 m beneath the cloud tops; the rate of spreading was measured by repeatedly passing over the seeded areas. The absolute numbers of nuclei produced in these cases were as follows: left side of Figure 11--Dry Ice 3.5×10^{14} nuclei/mile, AgI + NaI 0.32×10^{14} nuclei/mile. Right side of Figure 11: line 1: 4×10^{13} nuclei/mile; line 2: 2×10^{13} nuclei/mile; line 3: 12×10^{13} nuclei/mile. From this work it follows that the lateral spreading of the seeding effect throughout the cloud layer depends on the seeding intensity and the seeding mode. Curtain seeding will apparently enhance the spreading velocity by roughly a factor of two. The results are in good agreement with earlier data (Weickmann (23), Figure 12. These data are based on curtain seeding with Dry Ice only. On the average the line did spread within about 30 minutes 1 1/2 miles to either side, or a total of about 5 km. If consequently parallel lines are seeded 3 miles (5 km.) apart, then after 30 minutes they should have joined. This brings us to the problem of the most advantageous seeding pattern for modification of large areas.

SEEDING PATTERN

In most cases of snowfall enhancement from Stratus clouds, it is desirable to affect the entire deck downwind of the seeding track. There exists an infinity of seeding patterns, depending on cloud conditions, seeding technique, size of seeding pattern, aircraft speed and wind speed. It is always assumed that seeding proceeds perpendicular to the wind direction. Subsequently, we would like to call attention to some basic features of importance. Experience says that it takes about 1/2 hour to develop precipitation in a Stratus deck and it takes also about 1/2 hour for the seeding effect to spread to a total width of 3 miles (5 km) or 1 1/2 miles to either side (2 1/2 km), if seeding is done with Dry Ice in the "curtain mode" from the cloud tops. The seeding pattern shall then be such that it combines to one large modified area about at a distance of 1/2 hour wind translation. It is assumed that the seeding pattern is flown as a race track or a flat pattern eight, fixed to the earth surface and such that the distance between two flight legs does not exceed 3 miles or 5 km. Figure 13 shows three patterns for a windspeed (or drift velocity of the cloud deck) of 10, 20, and 30 m/sec and a flight velocity of 4 km/minute; the flight pattern itself is a racetrack pattern 10 km long and 2.5 km wide. The figure shows that the pattern will no longer close in 30 minutes on one end even before the wind velocity reaches 20 m/sec. The flat

pattern "8" however, if the turns are made against the wind is good to almost 30 m/sec. (Figure 14). Depending on the purpose of the seeding project there exists a great variety of seeding patterns which are designed to make optimum use of the source of water in the cloud layer. Some may be flown in a Lagrangian mode, upwind or downwind; for some two or more aircraft are needed. Of course, it needs to be said, that also here wind shear needs to be considered. Use of the proper pattern will enable the experimenter to manipulate the areal development of the precipitating snow clouds. We observed during a seeding experiment in November 1971 that a seeding pattern as in Figure 15 for a wind speed of 20 m/sec caused the cloud deck to become arranged in parallel lines of increased dynamic development. The convective development with a strong undersun in the foreground is seen on 15. There can be no doubt that we are only in the beginning of understanding the areal and downwind development of seeded areas under conditions of a convective cloud deck.

7. Results of show enhancement projects

The reliable measurement of snowfall is one of the most difficult measurements in meteorology; this should always be kept in mind. Table 2 points to some results after seeding of convective Stratocumulus layers, from which artificial snowshowers precipitated (Weickmann (24). One such shower, that of November 25, 1968, is shown in Figure 16. The time between seeding end and precipitation onset was determined a few times to be between 26 and 36 minutes from clouds which were about 1500 m thick. Leskov (25) reports precipitation increases after aerial seeding for a period of 2 to 3 hours downwind with an intensity varying between 0.30 and 0.40 mm/hr. He remarks that increases between 50% and 200% occur, but it was particularly interesting that he emphasizes (Leskov (26) "...frontal clouds cannot be considered reservoirs of possible additional moisture; they are really generators of natural precipitation." He cannot find redistribution of the available precipitable water; i.e., a decrease downwind, but he remarks that the network was too small, since it did not permit study of the development of precipitation to at least 5 hours after seeding. He is somewhat at variance with Litvinov and Ruzheinikovz (27) who state that "directly beyond the zone of increased amount of precipitation a zone of decreased amount of precipitation occurs so that the overall effect of the increase due to modification is equal to zero." It is interesting to note that in the USA reports to the contrary gain momentum, namely that further increases of precipitation occur at distances between 100 and 200 miles (Grant (19), Elliott (18). A definition of clouds for systematic modification in the Volga Basin is given by Kondratova (15). This author finds essentially three groups: Group A. These are clouds 400 to 500 m thick, water content 0.16 to 0.20 g/m^3. Group B. Clouds with a thickness of 500 to 600 m, but the thickness can vary between 300 and 1000 m depending on location. Liquid water content nearly as in Group A. Group C. This cloud group is most efficient in the production of artificial precipitation, yet their thickness is similar as in Group B. A general assessment of the seeding potential of winter time clouds from so-called "dry-fronts" is given by B. N. Leskov, et. al. (14). These authors estimate that the precipitation of the cold period could be increased by not more than 3 to 5%.

TABLE 2

Initiation of Precipitation

Date	Convective layer				Stratiform layer				Seeding	
	Base		Top		Base		Top		Type	Result*
	m	°C	m	°C	m	°C	m	°C		
13 Nov 68	900	-7	2000	- 9					650 lb dry ice racetrack	$\overset{*}{\nabla}$ 35 min. A.S.
25 Nov 68	900	-2	1800	- 9.5	2100	-10	2400	-10.8	250 lb dry ice circle	$\overset{*}{\nabla}^{1}$ 26 min. A.S.
29 Nov 68	700	-2	1800	-10.8					450 lb dry ice 3 legs	$\overset{*}{\nabla}^{1}$ 1/3"/hr
2 Dec 68	300	+1	2400	-11					550 lb dry ice	$\dot{\nabla}$ over lake
3 Dec 68	1000	+1.5	2600	- 8	2700	-11.3	2900	-12.3	2400g AgI fusees	$\dot{\nabla}$ over lake
6 Dec 68	300	-6.5	1500	-12.0	1800		2100	-14.5	2400g AgI fusees 700 lb dry ice	$\dot{\nabla}^{1-2}$ over lake $\dot{\nabla}^{1-2}$ 36 min A.S.

*Legend: $\overset{*}{\nabla}$ snow shower; $\dot{\nabla}$ rain shower; A.S. after seeding; and exponent ^{1} or ^{2} indicates intensity: ^{1}moderate, and ^{2}heavy.

Figure Legends

Figure 1 Snow cyrstal flux R/m ($m^{-2}sec^{-1}$) versus rate of precipitation R(mmw hr^{-1}) according to Gunn (1).

Figure 2 Size distributions of snow crystals collected at S. Dayton on 21 Nov. 1969.

Figure 3 Photographic pictures of snow crystals collected at S. Dayton on 21 Nov. 1969.

Figure 4 Distribution of non-seeded precipitation at High Altitude Observatory as a function of 500 mb temperature compared to a theoretical distribution computed using the mean diffusional model. Precipitation data are from Climax 1 sample (251) and values are a running mean over a two-degree temperature interval.

Figure 5 Distributions of seeded and non-seeded precipitation at High Altitude Observatory as a function of 500 mb temperature compared to a theoretical distribution computed using the mean diffusional model. Precipitation data are from Climax 1 sample (251) and values are a running mean over a two-degree temperature interval.

Figure 6 Satellite picture of western USA with large upslope cloud system flowing from east to west against Rocky Mountains. (Note: location of counter crossmark is approximately the location of Denver.) Left side of picture shows Denver Radiosonde and the atmospheric profile of the cloud layer.

Figure 7 Number of upslope seedable situations in 10 years during winter over the US High Plains area.

Figure 8a Definition of target area according to Leoniv and Leskov.

Figure 8b Target area as defined by Leskov and isohyets of precipitation in target area.

Figure 8c Additional sophistication of target area definition according to Leskov.

Figures 8d-f Case of December 3, 1969, and target area definition in conditions of wind shear in speed and direction.

Figure 8d Flight path during seeding and analysis phase on 3 December 1969. Picture illustrated low level wind field as streamlines.

Figure 8e Same as Figure 8d but high level streamlines have been added.

Figure 8f Shaded area defines target area affected by the seeding, freezing nuclei observations along analysis flight path, diamond dust was observed along flight path.

Figure 9 Development of seeded areas after seeding with Dry Ice and AgI on 6 Dec. 1968.

Figures 10a, b — Seeding effects in cloud layer on 6 December 1968.

Figure 11 — Rate of linear spreading of seeded line in Stratocumulus depending on time after seeding and seeding agent. Data from 21 February 1971, cloud base 1500m at -6°C, cloud tops 2100m at -7.5°C. Data for right side of Figure from 24 Feb. 1971, cloud base 1500m at -8.5°C, tops 2100m at -10.8°C.

Figure 12 — Lateral spread of a seeded line.

Figure 13 — Development of race track seeding track in Stratucumulus layer for various wind speeds.

Figure 14 — Development of figure eight seeding track in Stratocumulus layer for various wind speeds.

Figure 15 — Intensive development of seeded area in a convective Stratocumulus deck, apparently caused through combination of two race track seeding lines as in Figure 13.

Figure 16 — Artificial snow shower on 25 Nov. 1968 over south shore of Lake Erie, NY. Note sunshine behind shower as sign of effective show-out.

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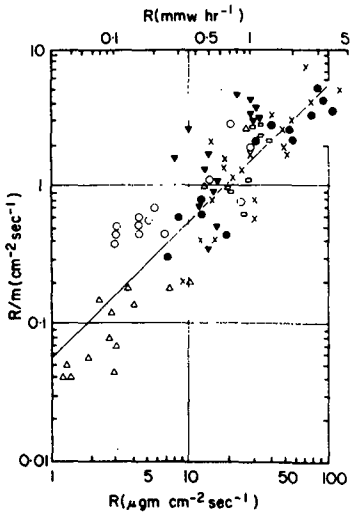


Figure 1

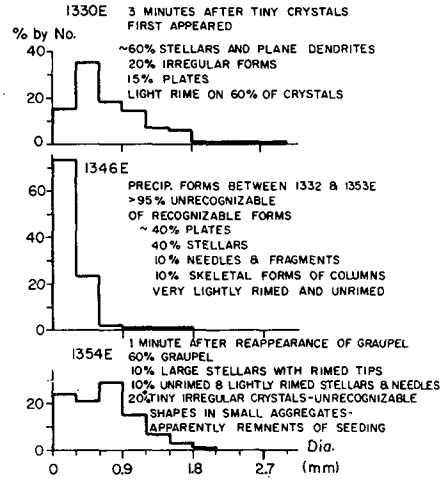


Figure 2

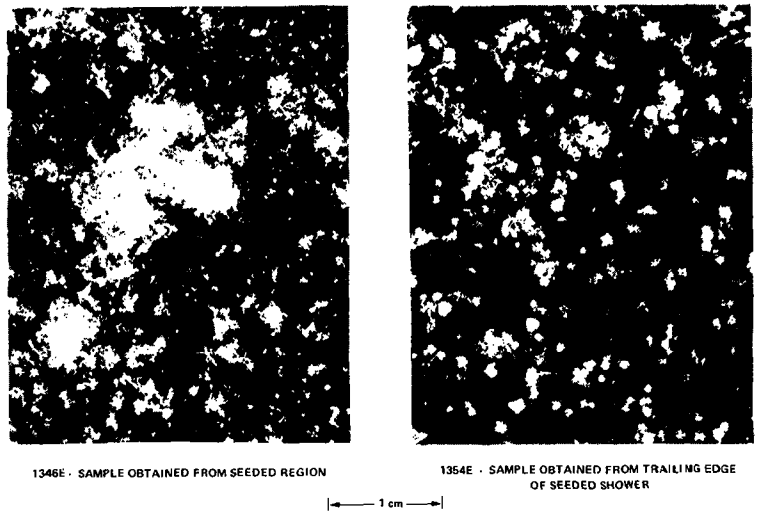


Figure 3

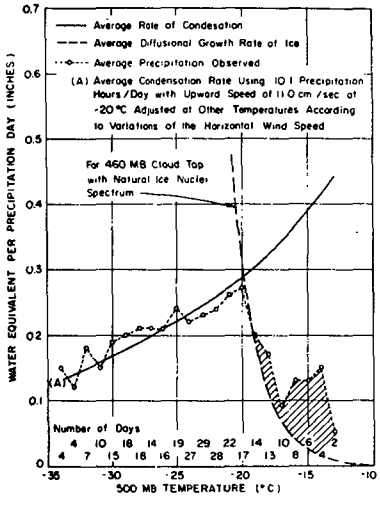


Figure 4

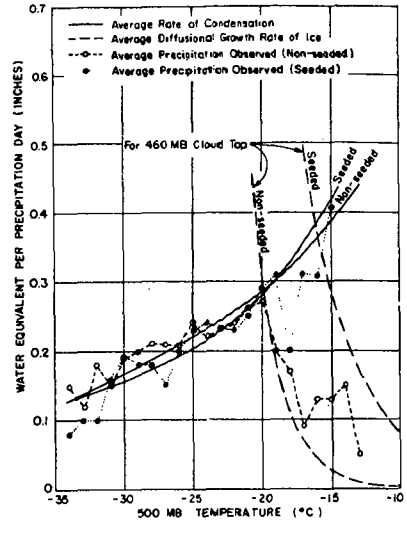


Figure 5

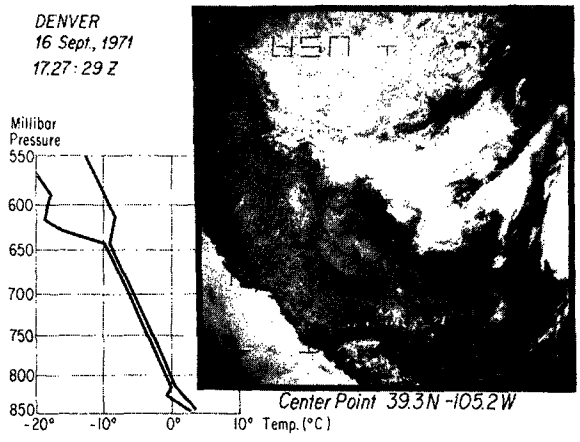


Figure 6

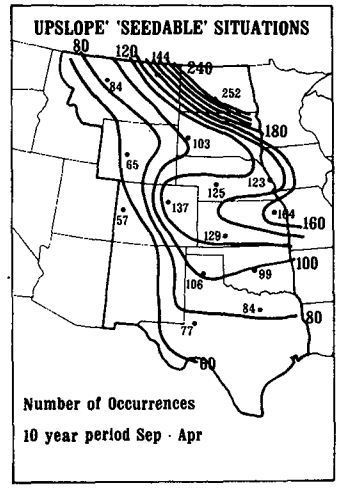
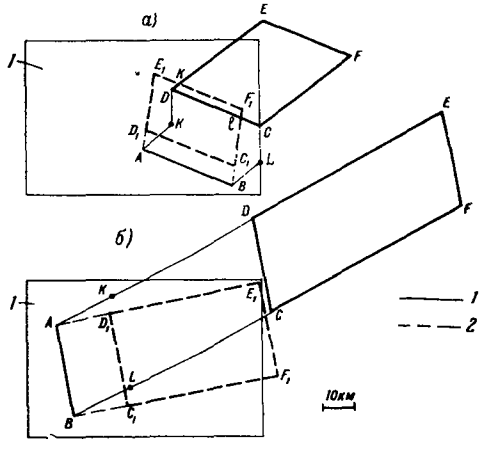
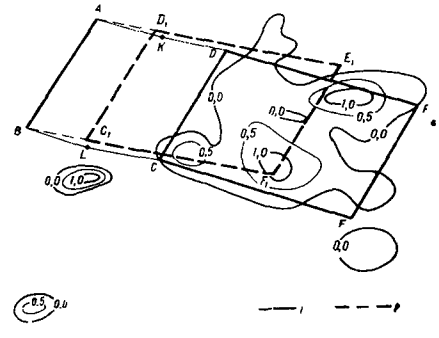


Figure 7



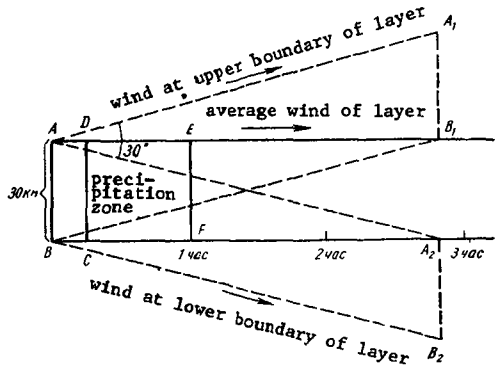
Comparison of results of isolated zones of increased precipitation using the Leskov (1) and Leonov (2) methods. (Leakov 1969)

Figure 8a



Actual zone of increased precipitation in comparison with the Leskov (1) and Leonov (2) method of determination. (Leskov 1969)

Figure 8b



Definition of modification zone due to shift of wind direction in the layer to be seeded (Leskov 1970).

Figure 8c

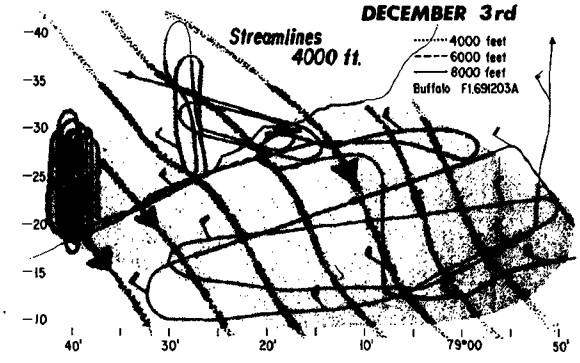


Figure 8d

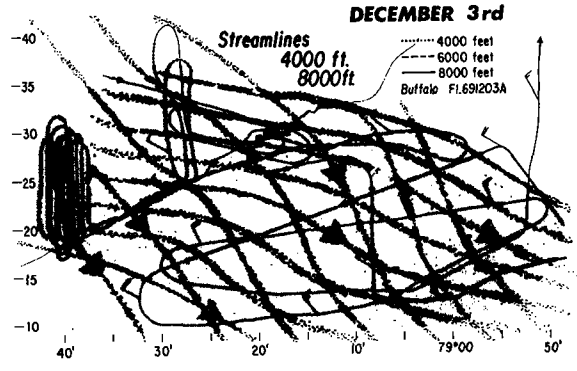


Figure 8e

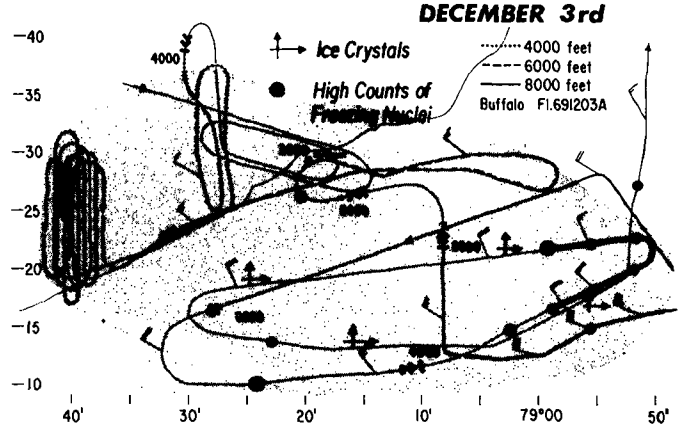
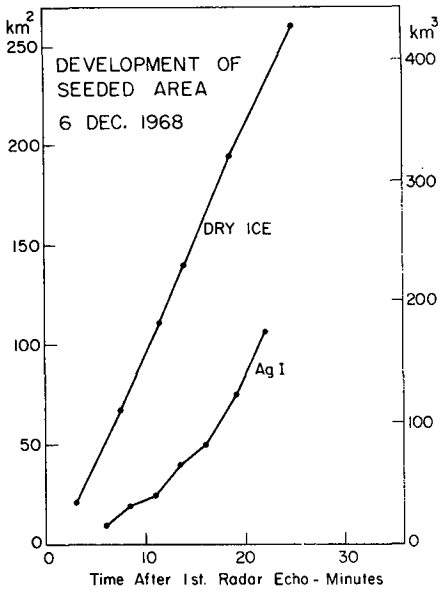


Figure 8f



Areal spreading of AgI and dry ice seeding.

Figure 9

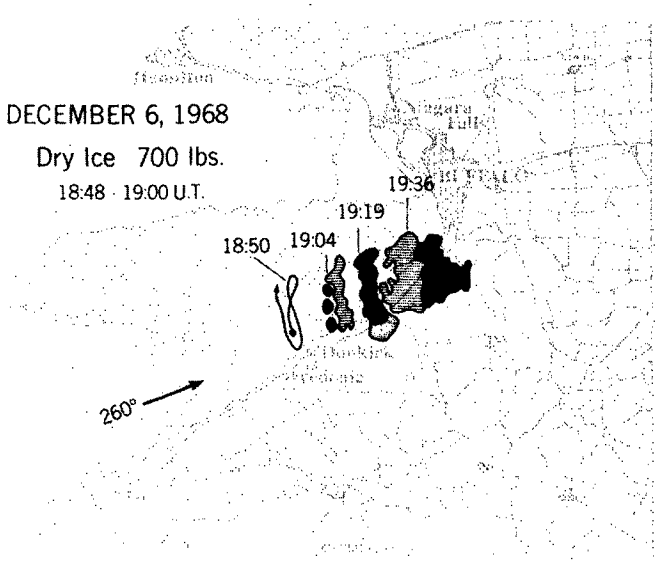


Figure 10a

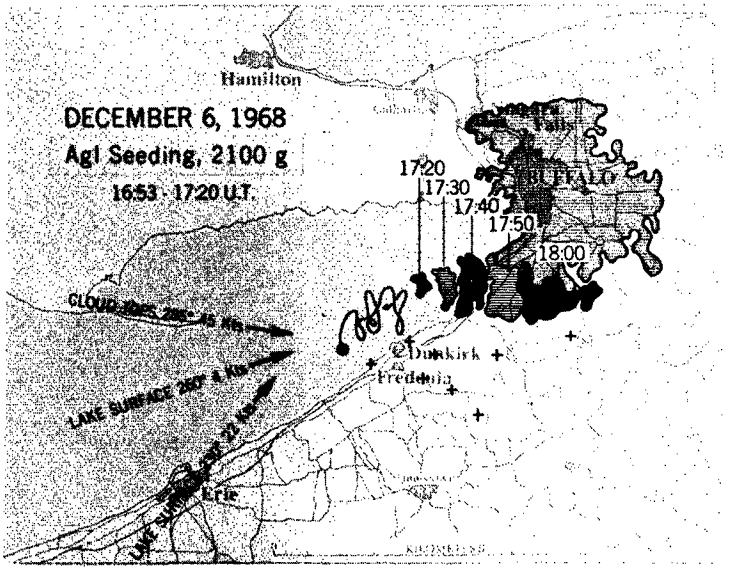


Figure 10b

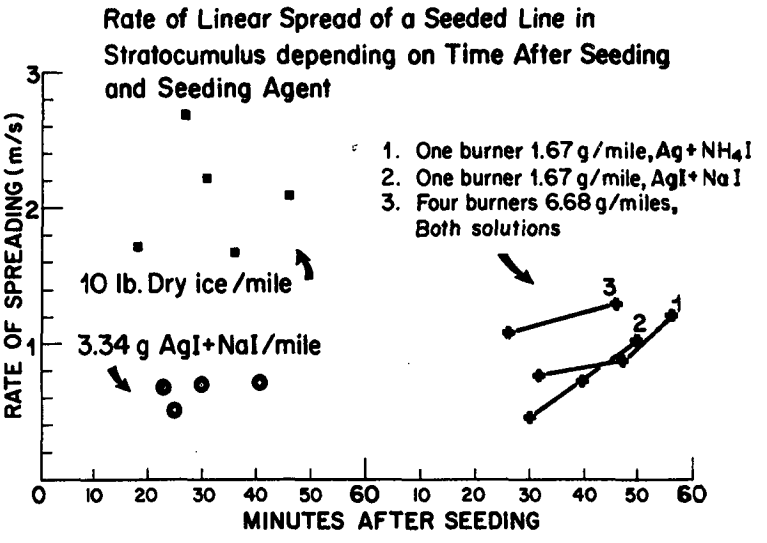


Figure 11

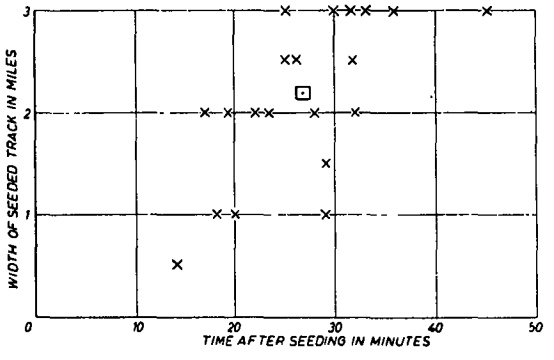


Figure 12

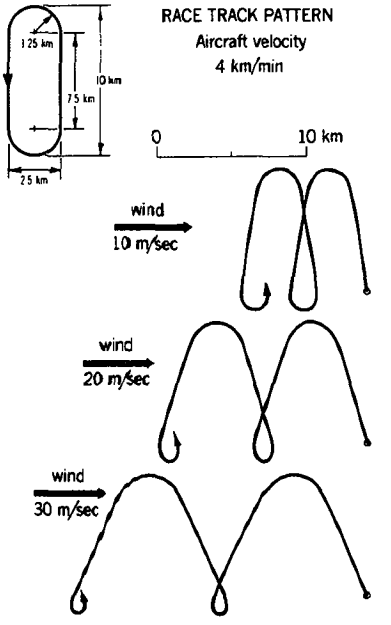


Figure 13

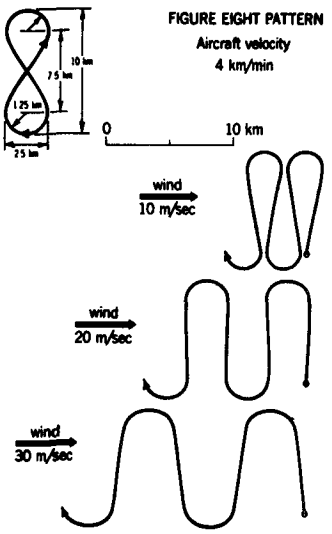


Figure 14

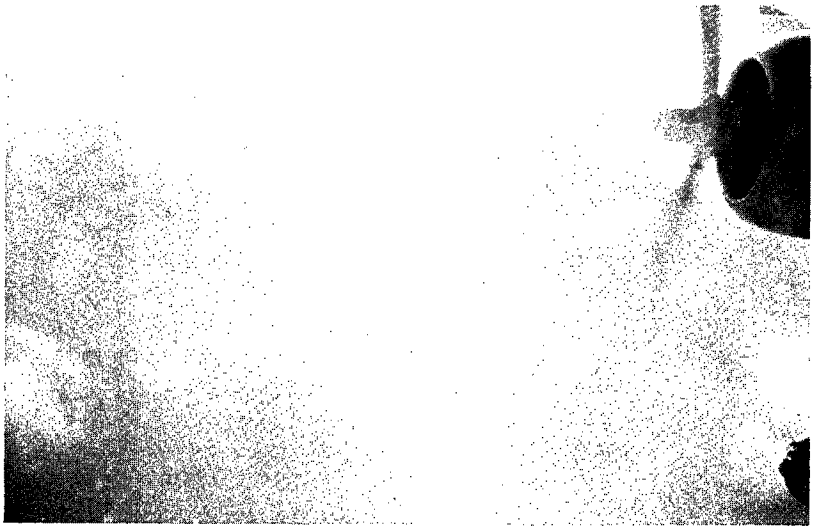


Figure 15

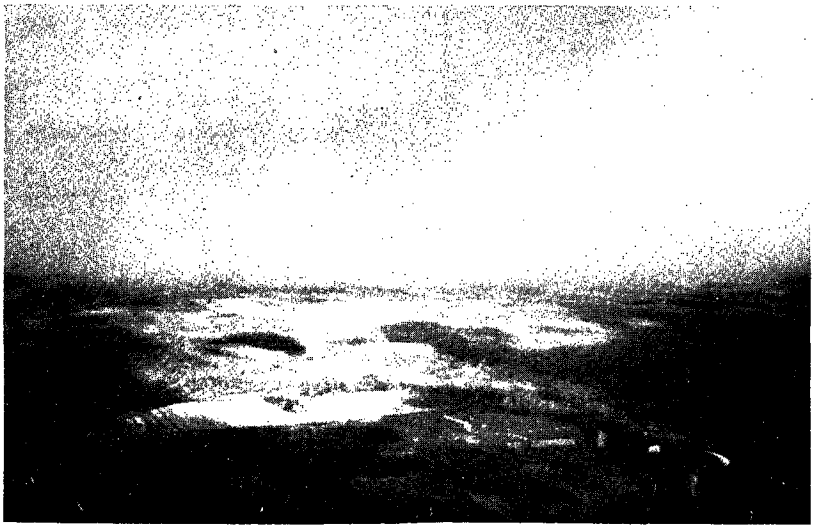


Figure 16

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ICE NUCLEI GENERATOR TECHNOLOGY*

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ABSTRACT

Problem areas of artificial ice nuclei used in weather modification are surveyed. Roles played by the nuclei in seeded clouds and optimization of effects are discussed. Recommendations are made for directions of future research and engineering in ice nuclei generator technology.

INTRODUCTION

Operation of ice phase weather modification begins, as is well known, with the seeding of ice-forming nuclei into a supercooled cloud or system of clouds. The nature of the ice-forming nuclei largely controls the results of seeding, although the ultimate optimization of the operation involves delicate consideration of the method of nuclei introduction, the behavior of the cloud system, and the purpose of the modification. It is therefore important to understand the nature of artificial ice nuclei and their behavior within the system of clouds. However, this aspect of cloud seeding technology has received relatively little, or at the most, scattered attention.

The scientific aspect of weather modification must first deal with this area and it is, therefore, the purpose of this paper to discuss problems related to ice nuclei generation technique, their characteristics, and usage within the reacting cloud system. Since we already discussed some aspects of this problem with respect to organic ice nuclei (Fukuta, 1972a) we shall consider different aspects with emphasis on the seeding effect in clouds.

ENGINEERING PROBLEMS OF SMOKE GENERATOR

The nucleants currently used or being developed, or those which were at least once considered for practical applications, may be placed into three categories.

(i) Inorganic crystals (non-ice solid); AgI, PbI_2, CuS. Ice nucleation mechanism is heterogeneous.

(ii) Coolants; dry ice, liquid propane, liquid N_2, Freons, adiabatic-

*Presented at the WMO/IAMAP International Conference on Weather Modification, Tashkent, 1-7 October 1973.

ally expanding gas. Ice nucleation mechanism is homogeneous.

(iii) Organic crystals; 1,5-dihydroxynaphthalene, metaldehyde, phloroglucinol, phenazine and urea (Fukuta, 1972a). Ice nucleating mechanism is heterogeneous. Phenazine and urea are not suitable as cloud seeding nuclei. The former is toxic and too expensive (Garten and Head, 1965, and the latter does not produce a large enough number of active nuclei. The number of urea particles reported (Knollenberg, 1966) is simply the numbers of particles produced and not the measured number of ice crystals formed.

Nuclei Particle Generation

There are two methods of particle generation, i.e., the dispersion and condensation methods. Experimental and theoretical studies of ice-forming nuclei indicate that the optimum size for cloud seeding is around 0.1 μm in radius or slightly less. The best method of submicron particle production is that of condensation (Fukuta, 1972a; Green and Lane, 1964). There has been no practical dispersion method developed which produces particles of sizes comparable to or smaller than those obtained by condensation. Nuclei materials which are nonvolatile at elevated temperatures without decomposition will therefore meet a severe restriction in their practical application.

In the condensation process, the maximum supersaturation that the vapor experiences, in response to cooling or quenching, controls the number of particles formed. It has been experimentally verified that for coolant nucleants, the number of ice crystals produced per gram, regardless of the material used, cannot exceed 10^{12} to 10^{13} (Fukuta, 1965 and 1972a). This is probably because the same chemical species is involved in the nucleation, i.e., water, and it could very well be reflection of the nature of the small ice crystals created. However, for other chemical species, this limitation will be at different levels.

AgI is an inorganic compound with a reasonably high melting point, but it is still volatile at the temperature of flame or pyrotechnical reaction. The vapor of AgI experiences automatically large cooling or quenching from such an elevated temperature, and this is partly why AgI smokes generated by a condensation method are featured with large numbers of active nuclei per gram compound dispersed. Because of the rather efficient condensation method employed in the current AgI smoke generators, application of the supersonic expansion method (Fukuta, 1972a; Paik et al., 1972) to the compound is not likely to give a significantly better result. Moreover, corrosion of the container and nozzle by AgI vapor adds another problem, and even if one can improve the number to some extent by successful application of the supersonic nozzle, the already existing size effect in the smokes from the present generators, due to the large density (5.7 gm cm^{-3}) and small particle sizes, will be enhanced. The best chance of improvement using the supersonic expansion method exists for nuclei such as organics whose particle production efficiency is still low (coarse smoke particles) provided that the nuclei compounds satisfy other requirements.

The techniques for handling nucleant materials for smoke generation

present an important problem area. In most cases, continuous generation of smoke, advantageous for subsequent nuclei plume diffusion, is desired. Two main different methods of continuous handling of AgI can be seen among current AgI smoke generators: continuous burning of a spray of AgI-alkaline iodide-acetone solutions, and burning of pyrotechnical formuation in solid form. For coolant nuclei, there are two different continuous methods currently used, viz., continuous dispensing of pellets (dry ice, sometimes kept in cages without dispensing) and spraying or blowing of liquid coolants or compressed air out of nozzles (Fukuta, et al., 1970). For organic nucleants, the only condensation method of particle dispersion hitherto applied to a cloud scale experiment is one that employed continuous transport of Cab·O·Sil-fluidized metaldehyde powder into the exhaust stack of an aircraft engine, where rapid evaporation and recondensation of the resulting fine metaldehyde smoke particles occurred (Fukuta, 1967).

The control of nucleant particle size is probably the most important problem for seeding generator development. Coarse smoke particle formation leads to the use of larger amounts of material, which results in a weight problem in the case of airborne seeding, low cost efficiency, natural resource problems, air pollution, ecological disputes, etc. On the other hand, too finely divided particles will suffer an activity drop due to the size effect (Fletcher, 1958).

It is a plausible idea in general to enhance the ice nucleability of a nucleant by doping. In practice, however, this is difficult to achieve, particularly for the smoke particles prepared by condensation methods. During the condensation process, which is the only possible time for doping, the nuclei particles are hot and the distance to the surface from the interior of the particles is extremely small. Any exotic materials leading to distortion of the nuclei crystal lattice are easily excluded, leaving an undisturbed small crystal of the pure compound (probably a single crystal). The rapid exclusion of dislocations near the crystal edges is well studied in metallurgy and other fields.

Features of Nuclei Smokes Generated and the Activation During the Seeding Operation

The nuclei particles generated are subject to deactivation. Coagulation is also important during the process of smoke generation. Metaldehyde shows an unusually high rate of coagulation (Fukuta, 1972a). Evaporation of nuclei particles, due to the Kelvin effect and temperature fluctuations, should be taken into account during the smoke formation process. Some organic nuclei are liable to slowly evaporate under a finely dispersed condition even at room temperature. Photolytic decay is a well-known deactivation process for AgI smoke particles although, initially, activation occurs instead (Garvey, 1973).

Small ice crystals formed by seeding of coolants disappear when they experience temperatures higher than $0^{o}C$. The difference between the coolant ice nucleators and solid heterogeneous nuclei (at room temperature) originates here. In order to gain efficient nuclei diffusion into a large cloud volume, nuclei often have to be generated in a warm temperature or a dry zone

a long distance away from the cloud. In such a case, ice crystals formed by a coolant will not survive. Another important difference between these two categories of nucleants are the larger number of ice crystals produced per gram of the latter nucleant. At temperatures where ice crystal growth is rapid, the latter nucleants may produce up to 10^3 times more ice crystals.

Other Requirements for Practical Nuclei Generation

There are requirements to be considered other than those mentioned above. Toxicity of nuclei compounds to the human body and to the ecological system during handling, while in air and when settled on the ground should probably be considered first. This is a complex subject. Acute toxic effects are of common concern and this is usually taken into account. The hidden, and therefore more dangerous, toxicities are chronic ones due to slow accumulation. DDT accumulation through the biological food chain is a well-know example. Heavy metal ions are another example, and since AgI contains a heavy metal, it presents a serious problem. For the same reason and because of their inferior nucleabilities compared with AgI, PbI_2 and CuS are not worth developing. Many of the silver compounds have low solubilities in water, and this is advantageous in view of the toxic effect. However, the chemical binding force among silver compounds is weak, and they tend to decompose under the excitation of the ultraviolet light existing in our environment (Fukuta, 1972a). The low solubilities of silver compounds thus cannot guarantee their safe use in the biosphere. However, with the present rate of their use, and for some time in the future, widespread serious effects may not be a problem, except in localized areas such as generator sites. The direct effect of Ag ions from AgI seeds in rain water to the human body is probably negligible (Standler and Vonnegut, 1972).

The ecological effect of Ag ions should be considered from a couple of other viewpoints. The goal of present weather modification studies is to enable future control of weather on a large scale and for a long time. Therefore, the problem is not simply for the next decade on a confined scale. Since there is no ecological cycle for Ag ions, the accumulation tendency is strong. Unless the capacity of the system is large enough, as in rivers or oceans, the irreversible process of accumulation will proceed at a slow but significant rate, thereby causing a problem in the environment which will be very difficult to solve later.

It appears necessary to develop ecophile seeding agents which satisfy all other requirements, and to use them in place of AgI, at least to some extent before it is too late, so that the possibility of upsetting the ecology no longer reamins in the area of AgI use. A possible approach to this problem is to use biodegradable nucleant compounds, such as organics (Fukuta, 1972a). Cost of seeding material reflects the natural resource problem, and to it and that of material dispersion, a proper consideration should be given.

Outdoor Tests of Seeding Generators

Nucleability of seeding material often becomes controversial. Comparative tests of smoke generators are desirable in a real cloud or in a fog whose condition closely resembles that of clouds, such as the fog in

Yellowstone Park in winter.

ACTIVATION MECHANISM OF ICE NUCLEI

The ice nuclei activation problem may be analyzed in two different angles: micromechanisms, were detailed interactions of water molecules and surfaces of nucleus crystals are involved, and macromechanisms, where only macroscale quantities such as supersaturation and supercooling are the variables. Strictly speaking the former cannot be separated from the latter. For normal weather modification purposes, however, the direct need is for data in the latter category, provided that the former problems do not create uncontrollable fluctuations in data. In other words, even if one does not understand how water molecules interact to form ice germs on the nucleus crystal surface, as long as he knowsthe supersaturation, supercooling and other important macroscopic conditions for the onset of the ice formation, on a particular nucleus, he can make use of this knowledge in weather modification.

The major subjects in this category are contact nucleation, freezing by partly or totally submerged nucleus particles, ice nucleation in air (undersaturated with respect to water but supersaturated with respect to ice), and the dependence of ice nucleability on particle size. What is most needed for weather modification is clear quantitative data on these subjects under seeding conditions which must take account of changing cloud conditions.

ROLE OF ICE NUCLEI IN CLOUD SEEDING

Temperature Spectrum of Ice Nuclei Activity and Ice Crystal Growth Rate

The effect of seeding depends on the amount of water whose phase is changed. The heat generation rate, therefore, involves two terms, i.e., the ice crystal growth and the water droplet evaporation, as

$$\frac{dQ}{dt} = L_d \int_o^\infty f_S(m)\left(\frac{dm_S}{dt}\right)dm + L_c \int_o^\infty f_L(m)\left(\frac{dm_L}{dt}\right)dm$$

where L_d and L_c are the latent heat of deposition and of condensation, $f_S(m)$ and $f_L(m)$ are the numbers of ice crystals and of water droplets whose masses lie between m and m + dm, dm_S/dt and dm_L/dt are the growth rate of ice crystals and the evaporation rate of supercooled water droplets, respectively. When the ice crystals are sufficiently large but have not reached the coalescence growth stage,

$$\frac{dm_S}{dt} \propto C(S-1),$$

where C is the capacitance of an ice crystal and (S-1) is the supersaturation. For a sperical ice crystal, C = r, where r is the radius. That is, the size of the ice crystals has to be large in order to have a rapid growth rate.

The ice crystal growth rate by diffusion, at a given time after nucleation, shows two maxima with respect to temperature, at -6.5 and -18C (Fukuta, 1969).

For effective seeding, it is desirable for the cloud parcel to maintain upward motion so that the ice crystal growth continues. Under such a condition and without mutual competition for the moisture, a maximum mass of ice crystals may be obtained by making use of the two growth rate maxima. In order to make use of the advantage effectively, the ice crystals must be made reasonably large by the time they reach the advantageous temperature zone. For this purpose, it is desirable to have the nucleation completed at warmer temperatures. This is an important role played by nuclei with a high threshold temperature. However, as the temperature approaches to 0^{o}C from below, the growth rate becomes so small that it can no longer affect the cloud to a significant extent if a large number of ice crystals is nucleated. For analysis of these combined effects in the cloud system, computer modeling is highly advantageous.

Fig. 1 shows an example of computer modeling for idealized seeding in an orographic cloud formed around the top of a gentle mountain, 1 km high, with a half width at half height of 10 km. T_o is the air temperature on the ground; the temperature difference between the ground and the top of the cloud (2.2 km high) is 15.8C. A dry stable layer extends above the mountain ridge. A seeding generator is located on the ground 20 km upwind of the mountain peak and the ice nuclei plume diffuses from there under the influence of a uniform eddy diffusivity of 100 m^2/sec. Fig. 2 shows the temperature spectra of ice nucleability of three ice nuclei selected, AgI-high output, AgI-low output and 1,5-dihydroxynaphthalene (DN). The smoke of DN shows a flat activity spectrum and the number of active nuclei per gram compound is the highest between -7 and -10C. In Fig. 1, the broken lines with shorter dashes, representing DN, give the highest precipitation efficiency. From the results, it is apparent that the number advantage of DN nuclei in the warm temperature range is furthered by the growth rate peak at -6.5C.

In addition to the effects stated above, it is important to consider where and in what mode the ice crystals fall. If they fall through an ascending cloud, they act as a filter of moisture. On the other hand, if they fall through a descending cloud, the moisture filtration effect switches into a moisture releasing effect at the point where the moisture level drops to ice saturation.

Supersaturation in Clouds and Ice Nuclei Activation

When a cloud forms, the cloud condensation nuclei (CCN) activate according to the supersaturation created. At the beginning of the CCN activation, the number of nuclei and the size of cloud droplets are small so

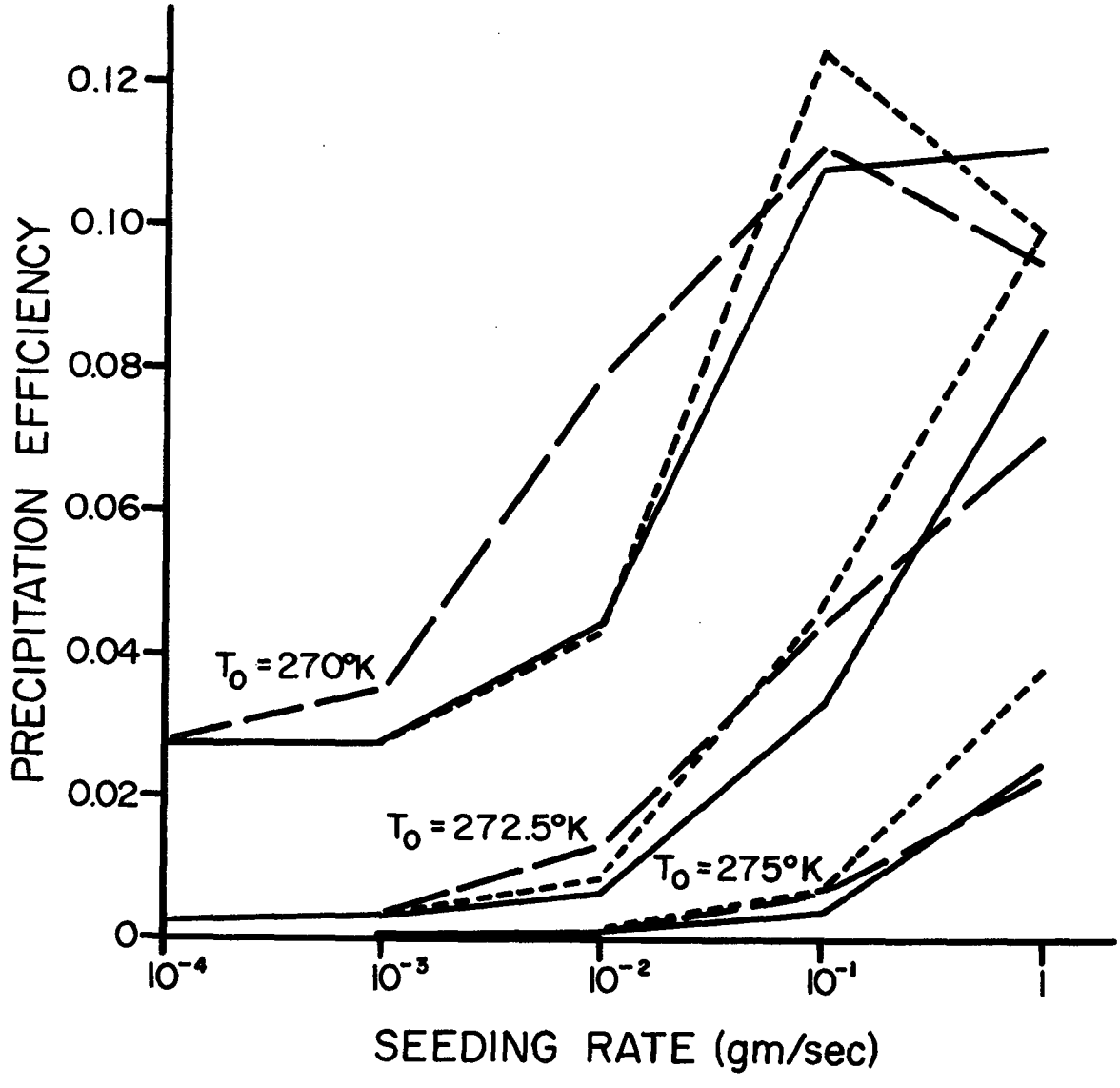


Fig. 1. Precipitation efficiencies vs. seeding rate for idealized test cases. Nucleant curves identified as in Fig. 2.

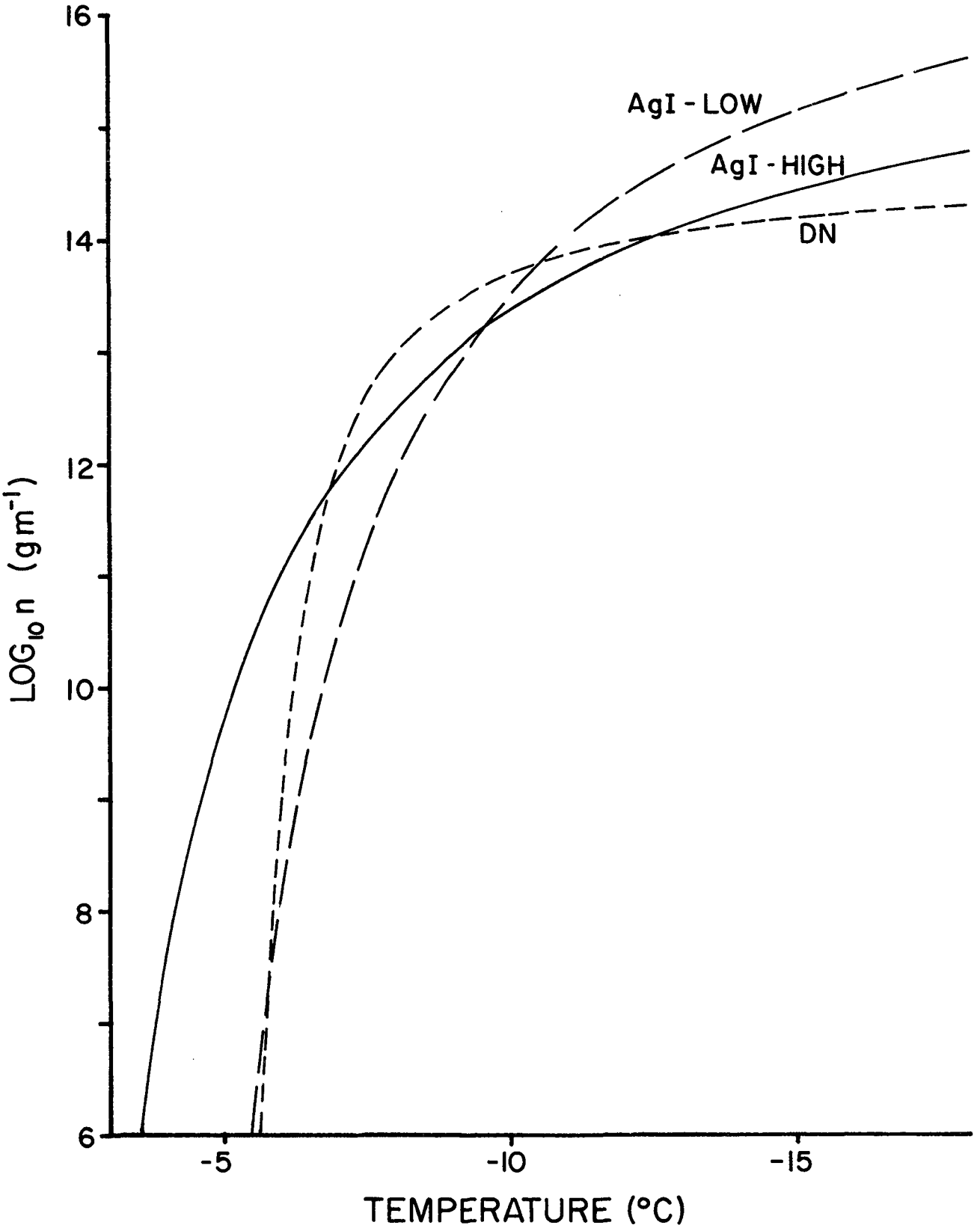


Fig. 2. Artificial ice nuclei activity vs temperature. AgI-high: typical high-output AgI nuclei generator (pyrotechnics); AgI-low: low-output generator (acetone burner); DN: 1,5-dihydroxynaphthalene from DU supersonic nozzle generator

that the supersaturation reduction rate due to droplet growth is slower than the generation rate in the cloud environment. As a result, the supersaturation rises and nucleation continues. However, the increasing number and size of droplets provide an increasing supersaturation reduction rate and eventually catch up to the generation rate in the environment, thereby giving the maximum supersaturation. This process has recently been treated analytically in our laboratory and the result is becoming available.

Some of the ice nucleation mechanisms are known to depend on the supersaturation, such as condensation-freezing and sublimation. It appears that these mechanisms become dominant at relatively low temperatures compared with that of contact freezing.

Since the supersaturation in clouds is thus predictable, it is desirable to understand the nucleation behavior of artificial ice nuclei under precisely controlled but different supersaturations. This approach will help estimate the number of ice particles nucleated by the two mechanisms in cloud.

Behavior of Growing Ice Crystal Plume in Eddy Diffusion Field

When in-cloud seeding is performed, a plume of ice crystals or nuclei, normally in the line shape, starts diffusing into the cloud according to the eddy diffusion field existing there. Shortly after seeding, there appears a zone around the center of this diffusing plume where supercooled cloud droplets are completely missing. It consists of ice crystals with or without unactivated ice nuclei. Growth of ice crystals by vapor diffusion in this zone has virtually ceased. In this completely glaciated zone, the heating and buoyancy increase in the plume can be described thermodynamically (Fukuta, 1973).

Outside this zone, ice crystals are mixed with supercooled droplets and ice crystals grow without interfering with each other.

A complex interaction takes place at the front of this glaciated zone. If the moisture abstraction rate due to growth of ice crystals there is larger than the supply rate of supercooled droplets by eddy diffusion, the front advances,and vice versa. Falling of ice crystals makes the problem still more complicated.

This is a very important problem which must be solved in order to assess the time dependent effects of seeding. Analytic solutions have been recently obtained in our laboratory on this subject under simplified conditions.

Shapes of Nuclei Plumes and the Diffusion Volume

In relation with the preceding section, it is important to understand possible initial shapes of ice nuclei plumes and their subsequent diffusion as well as interactions with the cloud, because the seeding effect depends on the volume of cloud into which the nuclei have diffused, and the diffusion must take place during a rather short time. For instance, because dry ice

is a solid, the pellets can fall thousands of feet and produce a curtain of ice crystals if the seeding is done continuously from an airplane. Such a curtain is advantageous for subsequent diffusion of the ice crystal plume thus formed.

Dynamic Effects

By now it is well known that heating by seeding due to the phase change contributes to buoyancy. Overseeding is desirable to obtain the maximum dynamic effect (Fukuta, 1973). However, as the present author pointed out, when the ice crystals descend, a thermal center separation takes place (Fukuta, 1972b). As ice crystals cross the 0°C isotherm, they begin to melt and create a dynamic effect which is completely opposite, i.e., decreasing the buoyancy. This will act against the updraft or for the downdraft. These processes can be controlled by properly engineering the ice nuclei.

DISCUSSION AND CONCLUSION

It is clear that the results of seeding experiments are dependent upon the particular nuclei compound used, the method of smoke generation and the manner of introduction employed, and the cloud or meteorological conditions. Conclusions drawn from seeding with AgI nuclei are basically inherent to this nucleant (Smith, 1970). The results of seeding with a particular kind of nuclei, such as AgI, represents merely a part of all the possibilities existing in weather modification.

It is important to realize that an advantageous feature of a particular nucleant under one condition can often become a drawback in another. For example, because dry ice is solid and can fall a considerable distance without aerodynamic disruption compared with drops, it can create a deep vertical curtain of ice crystals. However, because pellets have to fall a large distance through the supercooled zone, the seeding aircraft has to climb to a high altitude. This is costly. Although the number of ice crystals produced is largest near 0°C, this is not necessarily advantageous, because the ice crystal growth rate there is low. In the lower temperature zones, where ice crystals can grow at significant rates, other nucleants can produce a larger number of ice crystals for the same weight of the nuclei compound. In this regard, it can be said that no single seeding agent will serve all the different purposes for modification of complex clouds and cloud systems.

The best approach appears to develop several different kinds of nucleants, each having advantageous features in its own area. Then, by knowing their features in nucleation, understanding their interactions in cloud processes, and by making use of computer modeling, optimum use of the seeding material may be sought out.

ACKNOWLDEGEMENT

This research was supported under Grant GI-39849 as a part of the research on Organic Cloud Seeding Generator Development Study, sponsored by the Weather Modification Program, RANN, National Science Foundation.

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IDENTIFICATION OF QUICK LIME AS ICE NUCLEANT

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ABSTRACT

In an attempt to investigate into the cause for the observed ice nucleating activity of Portland cement, the authors have conducted drop-freezing experiments on the suspensions of CaO and AgI. The study has revealed that CaO is a highly efficient ice nucleant.

INTRODUCTION

Portland cement, which is used as a seeding agent in weather modification work in USSR (Gaivoronskii, et. al., 1968; Battan, 1969; 1970), has been identified as a good ice nucleant (Ramachandra Murty and Ramana Murty, 1972). The present authors have since undertaken a study to investigate into the cause for the observed ice nucleating activity of Portland cement. In the course of this study, which is in progress, they have examined the nucleating behaviour of certain selected substances which are nearly similar to cement in their affinity for water. The substance CaO (quick lime) is found to possess ice nucleating activity up to the same level as AgI. But the activity of CaO, at the level of that of AgI, is limited to the first half-an-hour after its introduction into water. The results of these new findings are reported here.

EQUIPMENT AND EXPERIMENT

The technique used in the study is drop-freezing, which is essential, is similar to that used by Vali (1971). The equipment and the method of experiment are briefly as follows. Drops of 2.2 mm diameter, produced from aqueous suspensions of CaO and AgI (both BDH make and LR-grade), aged for the same time periods, are placed in equal numbers (30 each) in two identical metal dishes (Figure 1), the inside bottoms of which have been coated with Dow Corning silicone lubricant. The dishes are sealed with glass covers and subjected to identical rates of cooling by transferring them simultaneously to a cold stage which is pre-cooled to -10C by a suitable refrigerator system. The number of drops freezing, as shown by opacity, are noted with naked eye at successive 1-minute intervals until all the drops taken in the dishes have frozen. The temperature attained by the pair of dishes at successive intervals of time is measured by a thermocouple arrangement. With the temperature of the cold stage initially at -10C the dishes attain, in the quasi-equilibrium condition, a temperature of -9.8C, which is maintained by the dishes over a

period of more than one hour. The suspensions are of concentration 10 gm per litre prepared with double distilled water. The drops in the batches of 30, referred to above, are produced from these suspensions after allowing them to age for different time periods ranging from 10 minutes to 24 hours.

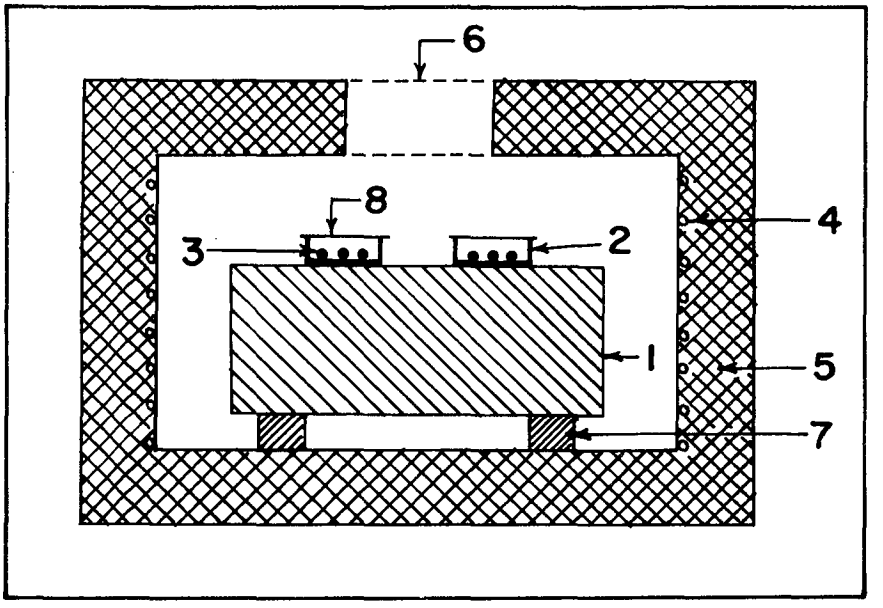


FIGURE 1

NUCLEATING ACTIVITIES OF CaO AND AgI

The fraction of drops frozen, on the mean (each experiment conducted was repeated 3 times), at successive intervals of time is given in Figure 2. For clarity, the value of the temperature at which the first freezing event occurred and the total time taken for all the drops to freeze, in each case, which may be considered as an index of the ice nucleating activity of the material in suspension, are given in table 1. The dish temperatures indicated are given in the figure at successive 5-minute intervals.

The nucleating activity of the drops produced from the AgI suspension, aged for different time periods, did not show any measurable change. The activity deteriorated very fast in the case of CaO suspension with longer periods of ageing. But when this suspension is aged only for 10 minutes (this is the minimum time required to commence the experiment after the preparation of the suspension), the drops produced from such suspension exhibited, over a period of more than 15 minutes, as much nucleating activity as the drops from the AgI suspension (see curve for CaO - 10 min.). This feature points out that, CaO, for a period of up to about half-an-hour after its introduction into water, behaves in a similar manner as AgI in so far as its ice nucleating activity is concerned. The threshold temperature of nucleation for CaO, as

for AgI, is -4.2C. The drops produced from the CaO suspensions, aged for 4-hours and beyond, have shown no activity at all, at the lowest temperature reached in the present series of experiments, namely, -9.8C.

TABLE 1

Freezing behavior of drops of AgI and CaO suspensions aged for different time periods

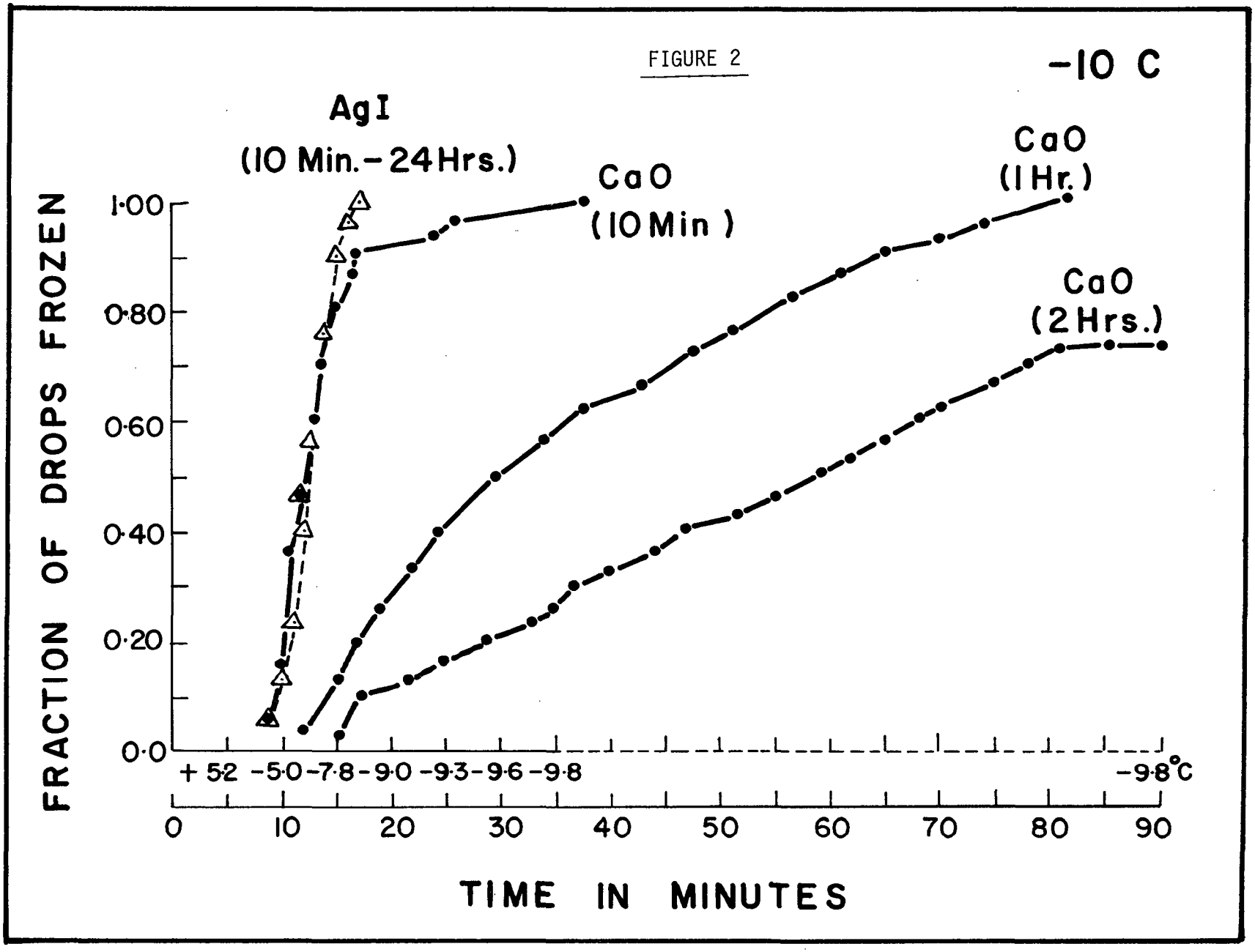
Time of ageing	Temperature at which first freezing event was noticed (C)	Total time taken for all drops to freeze (min)
	AgI suspension	
10 minutes	-4.2	17
1 hour	"	18
2 hours	"	19
4 hours	"	20
24 hours	"	19
	CaO suspension	
10 minutes	-4.2	40
1 hour	-6.5	82
2 hours	-8.1	*
4 hours	No freezing	-
24 hours	No freezing	-

*only 73 per cent of the drops froze even after 80 minutes.

NUCLEATING ACTIVITY OF PREHEATED CaO

The above series of experiments on CaO were conducted with samples of the substance taken as it was from a sealed tin supplied by the manufacturer. Keeping in view that CaO is a highly hydrating substance, an experiment was conducted with one such sample after heating it. The sample was heated for a period of 1 hour at 120C in a closed oven. The experiment was conducted with the CaO suspension aged for 10 minutes. As before, AgI was used for comparison. The results obtained are presented in figure 3. The activity of the preheated CaO sample is found to be nearly the same as that of the AgI in the entire course of the experiment unlike in the case of the unheated CaO sample.

FIGURE 2


-10 C
AgI
(10 Min.-24Hrs.)
CaO
(10Min)
CaO
(1Hr.)
CaO
(2Hrs.)
FRACTION OF DROPS FROZEN
1·00
0·80
0·60
0·40
0·20
0·0
+52 -5·0 -7·8 -9·0 -9·3 -9·6 -9·8 -9·8°C
0 10 20 30 40 50 60 70 80 90
TIME IN MINUTES

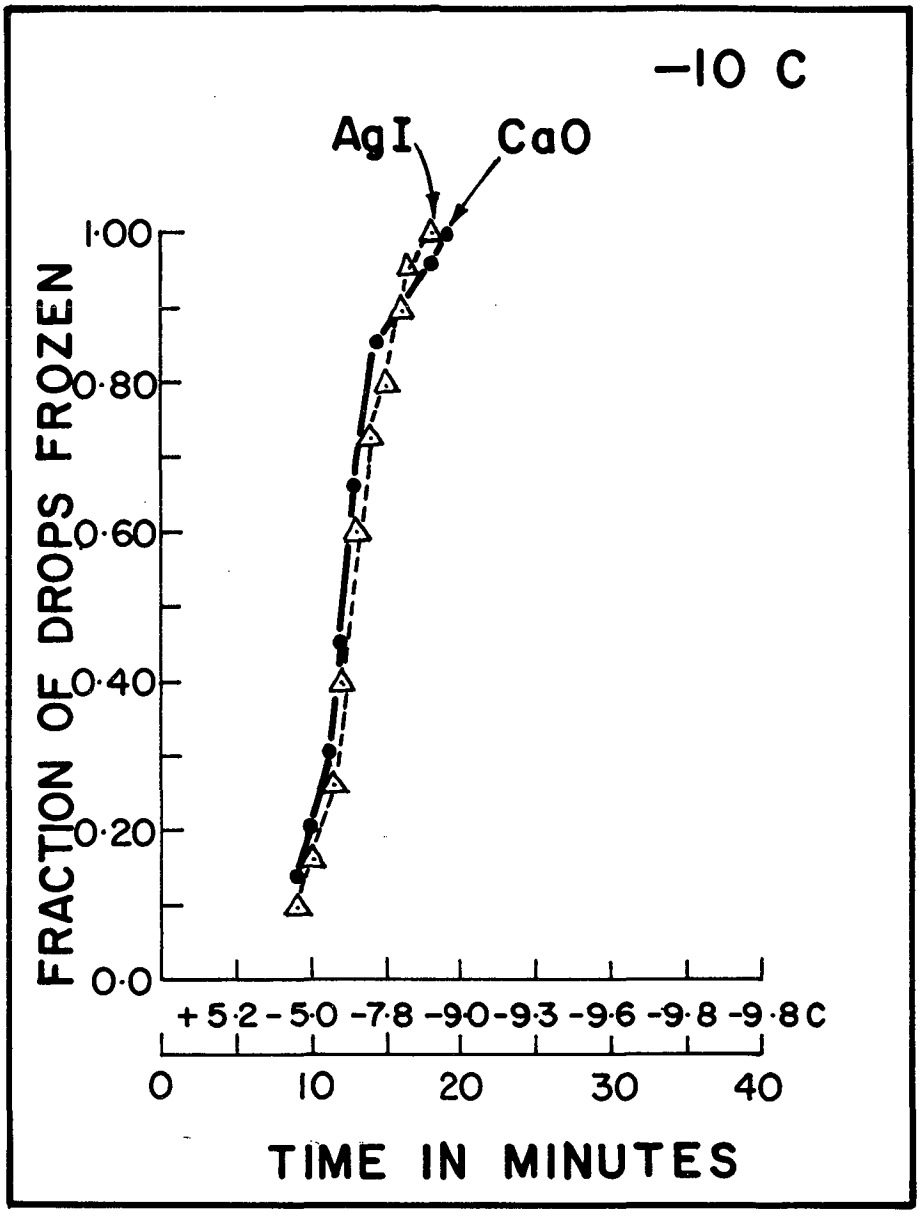
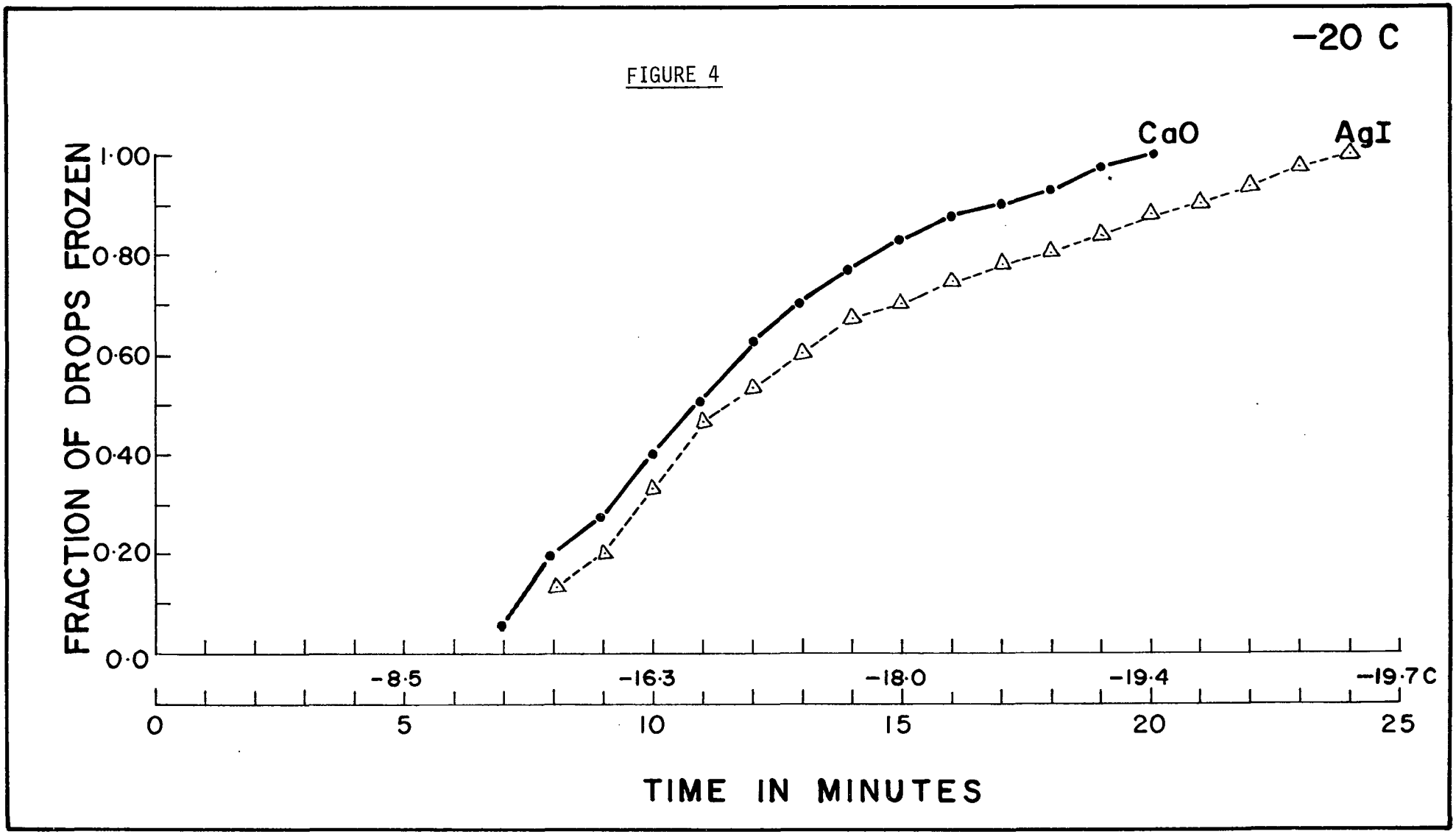


FIGURE 3

NUCLEI YIELD PER UNIT MASS

The application value of an ice nucleant is dependent upon the effective nuclei yield per unit mass at a given temperature. The drop freezing technique used in the study could be made use of for comparing different substances in this regard. An attempt has, therefore, been made to obtain such comparison between CaO and AgI. For this purpose, a new series of experiments have been conducted with these two substances as before, but with the corresponding suspensions diluted 10^{11} times (10^{-10} gm per litre), in convenient steps, and with the cold stage set at -20C. Only preheated samples of CaO have been used in this series of

FIGURE 4


-20 C
CaO
AgI
FRACTION OF DROPS FROZEN
1·00
0·80
0·60
0·40
0·20
0·0
-8·5
-16·3
-18·0
-19·4
-19·7 C
0
5
10
15
20
25
TIME IN MINUTES

experiments. The fractions of drops frozen at successive intervals of time are shown in Figure 4, only for the maximum dilution tested. The numbers denoting the effective nuclei per gram of the substance have been estimated after Vali and Finnegan (1970) for -15 and -18C from the curves given in Figure 4.

The values so obtained are given in table 2, which point out that the nuclei yields from CaO are no less than those from AgI.

TABLE 2

Estimated nuclei yields (number per gram) for CaO and AgI at the given temperatures

Substance	Nuclei Yield	
	-15C	-18C
CaO	1.1×10^{13}	1.3×10^{13}
AgI	0.9×10^{13}	1.1×10^{13}

CONCLUSIONS

The substance CaO, commonly known as quick lime, is found to possess marked ice nucleating activity. But the activity noticed suffers conspicuous decrease with longer periods of the substance remaining in suspension.

The factors governing the ice nucleating activity of CaO should be different from those of AgI. The hydration process, which sets in when CaO comes into contact with water, may have a role in the nucleating activity exhibited by this substance. Also, substances similar to CaO in their behavior with water, may, in turn, happen to be good ice nucleants. These aspects are under study.

ACKNOWLEDGEMENTS

We express our grateful thanks to Professor S. K. K. Jatkar, retired professor of Poona University, for the helpful suggestions received in the course of the study.

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LEGEND

Figure 1: Cold chamber: (1) cold stage, (2) metal dish, (3) suspension drops, (4) cooling coils, (5) glasswool insulation, (6) perspex window, (7) metal stand, and (8) glass cover.

Figure 2: Freezing behavior of drops of AgI and CaO suspensions. The ageing periods of the suspensions are given in brackets.

Figure 3: Freezing behavior of suspension drops of preheated CaO and AgI.

Figure 4: Ice nucleating activities of the suspensions of CaO and AgI of concentration 10^{-10} gm per litre.

THE MECHANISM OF MULTIPLICATION PROCESS OF GLACIATION IN THE ATMOSPHERE*

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It has been reported that high concentrations of ice crystals in cumulus clouds in the order of 10 to 100ℓ^{-1} are measured. These concentrations are 10^2 to 10^4 times higher than those of the ice nuclei present. Also several mechanisms with capability of production of secondary ice crystals are suggested (Ref. 1 and 2) to explain this discrepancy.

Most of the field studies show that multiplication process in clouds which contain large water drops at the start of glaciation. Results of Cheng's observations (3 and 4) on water drop experiments reveal three stages of massive fragmentation of hydrometeors during their phase transitions:

1. Microdroplets are generated from a freezing supercooled water drop.
2. Ice fragments are produced by sublimation from the frosty surface of a growing frozen particle, such as an ice pellet, hail or graupel.
3. Microdroplets are ejected by the bursting of air bubbles released from a melting ice particle. It is noted that fragments of hydrometeor in the forms of ice are observed only in the growing period of frozen ice particles. Few ice splinters are observed occasionally from a freezing supercooled water drop in an environment of high concentration of Carbon Dioxide (CO_2). (5)

Based on early observations by Schaefer (6 & 7), microscopical investigation reveals that numerous miniature ice structures are formed on the surface of a frozen water drop immediately after completion of its phase transition in a moist environment. (8) The ice particle rapidly grows until dendritic growths appear, the dendritic trees twisting and turning as they respond to the moisture flow and growth environment. At times the entire dendrite would suddenly shoot off and then disintegrate into myriads of fragments as they literally exploded. (Figure 1) Depending on the temperature profile existing between a precipitated ice particle and its warmer environment, the shape of the developing frost crystal would follow Nakaya's classical growth pattern. (9)

Time-lapse photomicrography revealed the tenuous attachments which bind frost crystals grown from water vapor and accreted frozen cloud droplets. These attachments often have diameters of only a few micrometers, and they readily sublimate (Fig. 2 & 3) even when the large outer portions are growing because of the difference in vapor pressure between

these slender columnar attachments and the more massive ice structures nearby.

Careful examination of the ejected fragments revealed that both ice crystal fragments with various structures and crusty, rimed, frozen water droplets were generated from the frosty surface of the growing ice particle (Fig. 4). This indicates two types of growth of ice particles, by the diffusion of water vapor and by the accretion of cloud droplets.

Photomicrography also shows that the ejected ice fragments or frozen droplets can be grown to produce perfect ice crystals.

High concentrations of ice fragments are measured by a NCAR Ice Nucleus Counter (10) near two temperature zones: -5C and -15C with crystal structure of needles or columns and dendrites, respectively. More than 50 ice fragments per minute is recorded from a frosty ice pellet of a diameter of 2 mm.

The observation of the ejection of ice fragments from the frosty frozen drop during the growing period suggests a mechanism of rapid glaciation phenomena of ice multiplication process in the atmosphere.

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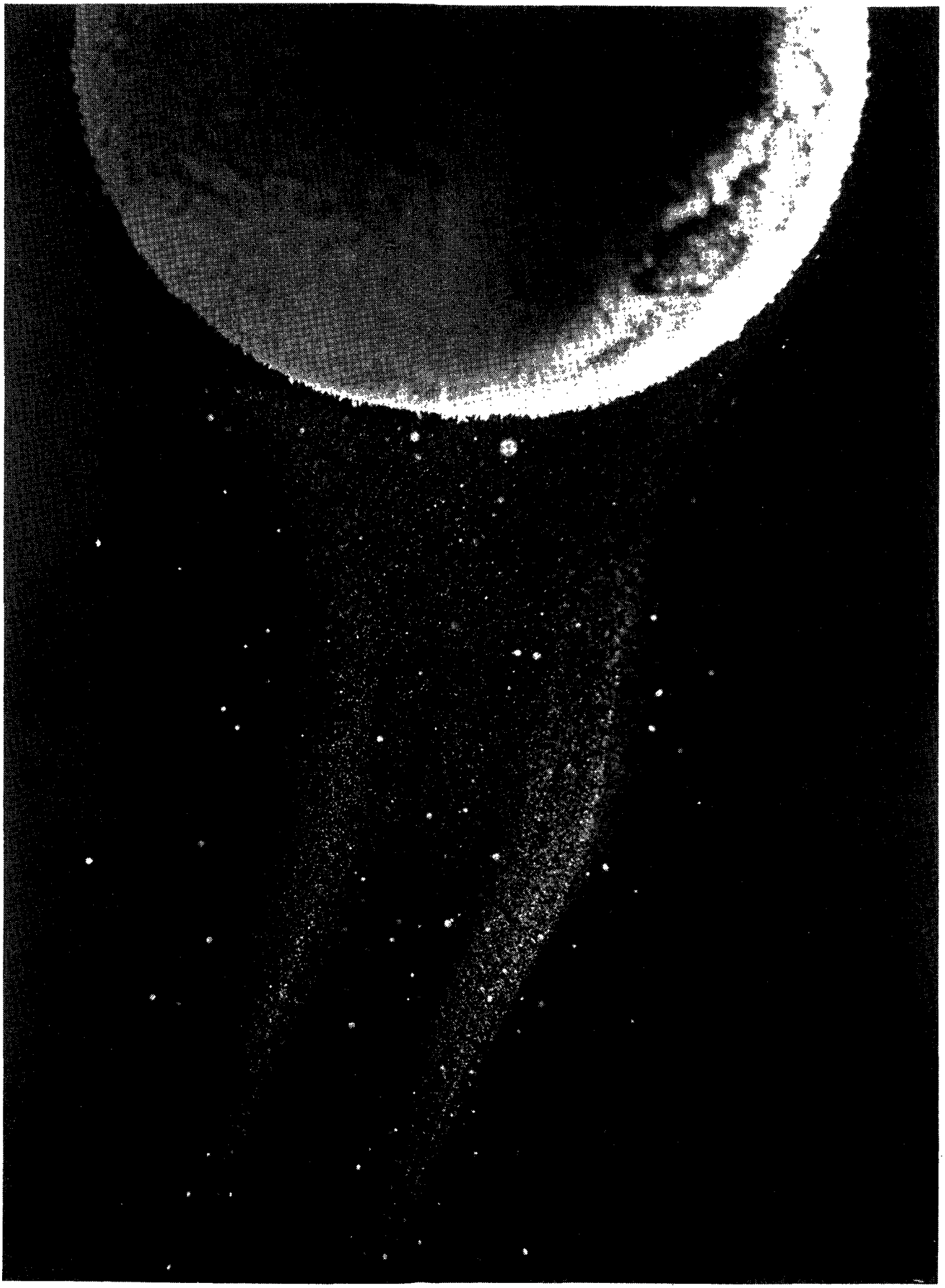


FIGURE 1

FIGURE 2



FIGURE 3



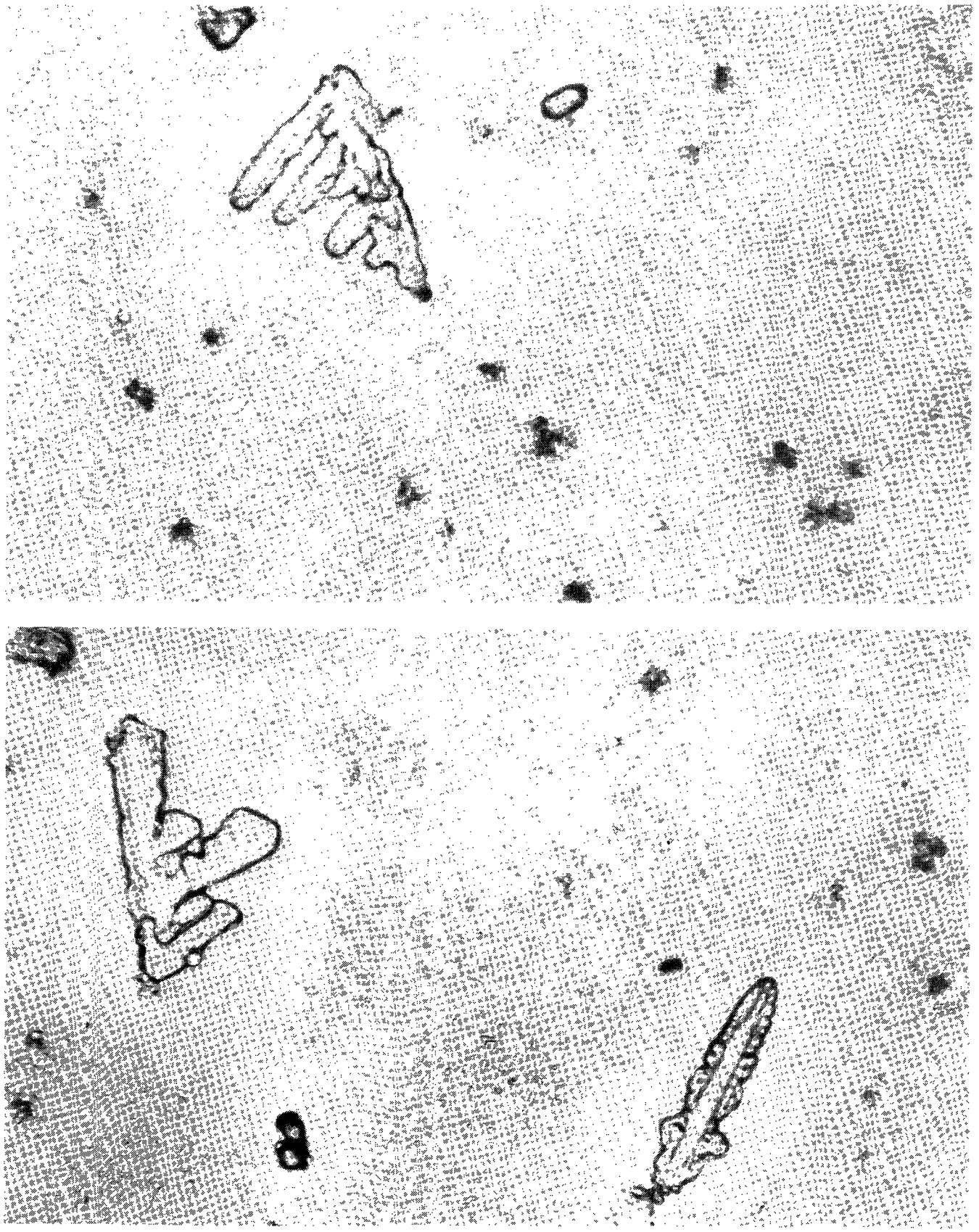


FIGURE 4

CLIMATOLOGICAL ASSESSMENT OF EXTRA-AREA SEEDING EFFECTS

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ABSTRACT

Two climatic investigations concerning detection of alterations of precipitation beyond a target area were pursued. In the first investigation, monthly and seasonal precipitation data were used to study the natural distribution of highs and lows in precipitation patterns over a 325,000 mi^2 area centered on southern Illinois during the period 1950-69. The highs were studied in regard to their location, spacing, frequency and persistence. Overall, the most frequent distance between highs is in the range of 40-60 miles. However, on 1-yr and 5-yr patterns the mean distance is in the range 75-95 miles and when the mean distance is determined in a directional sense (downwind), the mean distance is 100-117 miles. The mean distance between persistence areas and preferred locations of highs is approximately 60 miles. The implications of the natural distribution study are two-fold: 1) the mean and median distances between natural occurring precipitation highs in the Midwest are in the range of downwind highs reported as caused by seeding in other areas; 2) the broadness of the correlation pattern between points in a pattern indicates that one must be very cautious when postulating extra-area effects out to distances as great as 300 miles from the target in weather modification experiments.

The second investigation concerned the monthly and seasonal precipitation patterns (1950-69) in and downwind of large midwestern cities having urban-induced increases in precipitation. Overall the results indicated that the urban rain effect is limited to within 50 miles of the city, and that no downwind effect occurs beyond 50 miles. There was also some indication that rainfall deficits tend to occur in the neighborhood of excesses. In addition, the individual storm patterns in and downwind of St. Louis were investigated in most detail using 1972 METROMEX data. The analysis indicated that the major effect occurs within 0-25 miles with a smaller increase in the area 25-50 miles of the city. However, the storm analysis was based on a 1-yr sample only, and additional data and analyses are required to confirm the storm results.

I. INTRODUCTION

A major problem for rain enhancement projects, both in the scientific interpretation of effects and in interactions with the users and the public, concerns whether an enhancement or depletion in the target area is causing a depletion or enhancement of rainfall in off-target areas. It has been postulated by some investigators that an enhancement of rainfall in the target

area would likely cause a depletion of rainfall in the off-target area. Others have postulated that an enhancement of rainfall in the target area would lead to an enhancement of rainfall in the off-target area, and still others have postulated that a depletion of rainfall would lead to enhancement of rainfall.

One example of the confusion in evaluating downwind results is Project Whitetop in Missouri. Lovasich, et al. (1971) implied that the loss of rainfall was 21% in an area up to 180 miles from the target center and in all directions. Schickedanz and Huff (1970) reported that the evidence for a downwind decrease in rainfall in the Whitetop experiment was very weak. Flueck (1971) also reported that there is little evidence to support an overall seeding effect in the control areas outside of the Whitetop Research Area. From an analysis of an Arizona experiment, Neyman, et al. (1973) reported apparent decreases of 45% and 34% in downwind localities 90-180 miles away from the target.

In contrast, Adderley (1968) indicated increases up to 200 miles from the target area in Australia. Brown and Elliott (1968) indicate increases at 100 miles and up to 250 miles downwind of a target in the western United States. Grant (1971) reported evidence of increases 90-120 miles downwind in Colorado. Mielke (1971) indicated increases downwind of the Park Range project in Colorado. In some cases, it has been indicated that the increases of precipitation in the downwind areas are often greater than those in the target area. Thus, evidence exists for both an enhancement of rainfall and depletion in the downwind areas.

The conflicting results point to the difficulty of physical or statistical evaluations of extra-area effects. Statistical analyses of the subject are complex because of 1) the difficulty and yet necessity of defining the extended area, 2) the posterior nature of the analysis, 3) the extended area being outside the area in which the experiment was designed, 4) the natural variability of precipitation and 5) the possibility of a "good" or "bad" draw caused by the failure of randomization to balance out the uncontrolled background factors.

Because of the conflicting results and the difficulty of evaluating extra-area seeding effects, two climatic investigations concerning detection of alterations of precipitation beyond a target area were pursued (Schickedanz, 1973b). These investigations were largely a part of a recent effort aimed at developing a Precipitation Enhancement Program (PEP) in Illinois (Changnon, 1973b). This effort included aircraft sampling, ecological, social and cloud modeling studies in addition to the extra-area study described herein. The investigation concerning urban areas was also a part of a project investigating urban effects on rainfall (Changnon, 1973a).

The goals of the analysis were to 1) study the natural distribution of highs and lows in monthly and seasonal patterns in regard to space and time, 2) investigate the monthly and seasonal patterns in and downwind of cities with urban-induced increases in precipitation (treated), 3) study the monthly and seasonal patterns in and downwind of control cities (non-treated),and 4) investigate storm rainfall patterns in and downwind of St. Louis.

II. DATA

The choice of data to be used in the study was based on several requirements placed on the analysis. These requirements included 1) a data sample from a reasonably long period of records (20 years), 2) the existence of "treated" targets, 3) a data sample from a large geographic area so that the natural distribution of highs and lows could be defined, and 4) location of the study area in and surrounding a proposed experimental seeding site in Illinois (Changnon, 1973b). Requirements 1 and 3 eliminated the consideration of daily, storm or hourly data except on a limited scale because the cost of obtaining and analyzing the required amount of data was prohibitive in relation to the funds available for the project. Thus, the primary source of data was monthly data for the summer months of June, July and August, and the winter months of December, January, and February of 1950-69. These data came from 1171 cooperative reporting stations of the National Weather Service located within the area shown on Fig. 1. In addition, storm rainfall data for the summer of 1972 from the extended METROMEX network (Changnon, 1973a) was used.

III. ANALYTICAL TECHNIQUES

a. Natural Patterns

In order to provide versatility and flexibility in the various analyses, all station data were gridded on a 20 mi x 20 mi grid and the data from each grid intersection entered on punch cards. Thus, each month had a set of punch cards which contained the gridded monthly patterns. This procedure permitted certain computer analyses of the data that would not otherwise have been possible. For the summer months, the data were plotted on base maps and the data were gridded by visual interpolation. For the winter months, the data were gridded directly with the computer (Schickedanz, 1973b). The gridded data were then subjected to trend surface analysis (Schickedanz, 1973a, 1973b) which was the basic tool used throughout the study. This technique for the analysis of residuals from 2-dimensional regression surfaces was chosen because it can 1) provide a method in which the data can be transformed into a form which is easily programmed for production of pattern maps directly from the computer, and 2) provide significant factors for highs and lows in the rainfall pattern.

The basic residual is the difference between the actual precipitation at a particular location within the map coordinate system and the precipitation estimated from the first order trend of the precipitation over the area. The collection of these point residuals in space can be used to describe highs and lows in the rainfall pattern. An example of the application of trend surface analysis in the delineation of precipitation highs from a complex precipitation pattern is shown on Fig. 1. The basic residuals greater than specified values are portrayed in sequence to demonstrate the type of pattern clarification that can be obtained. For most analysis, the residuals would be standardized by dividing by the standard error of estimate of the trend surface and only those greater than 1.64 (10% significance level) or those greater than 1.96 (5% significance level) would be retained on the map. These would be considered to be the significant highs and lows of the pattern. For

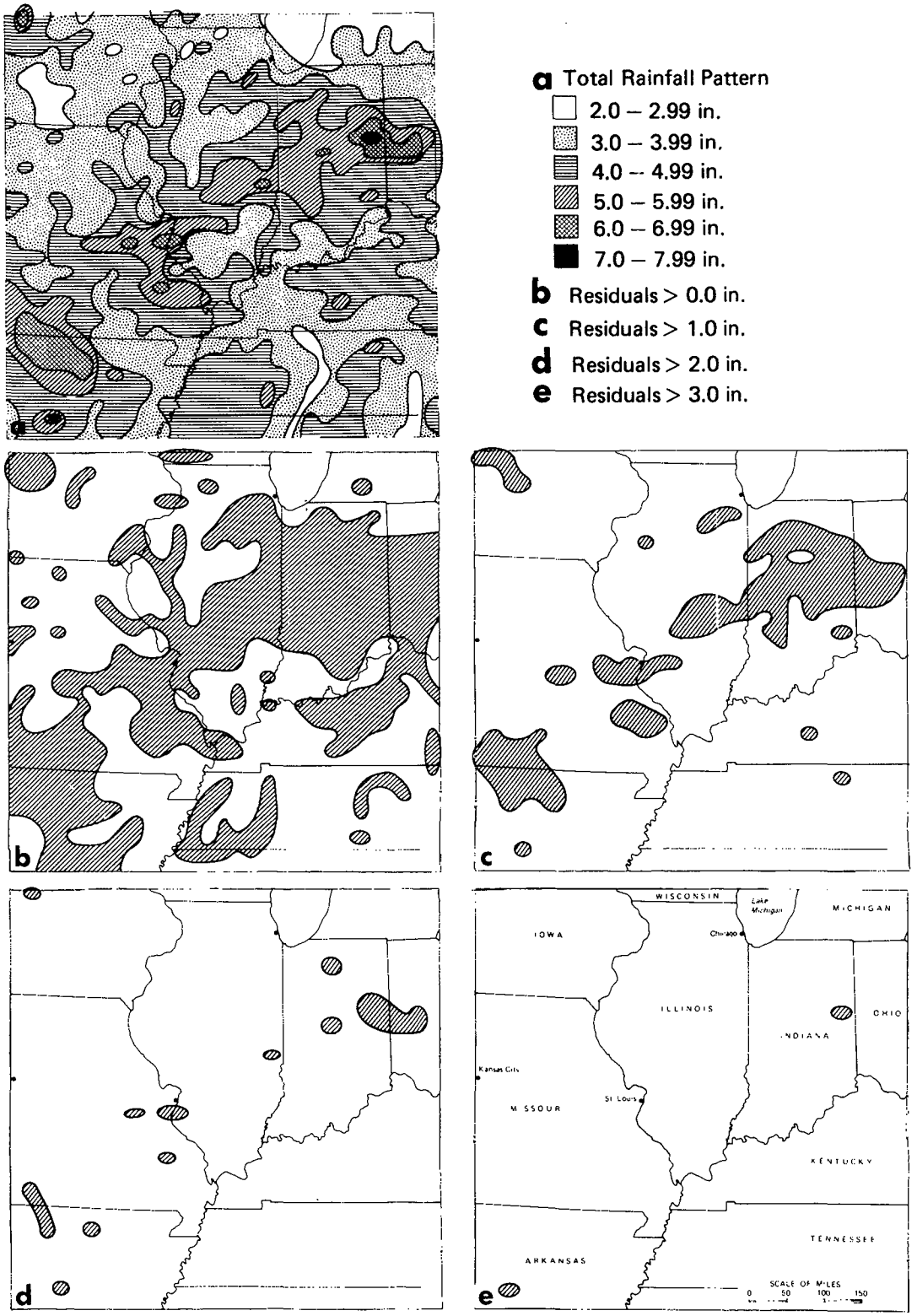


Figure 1.

The application of trend surface analysis in the delineation of precipitation highs from a complex rainfall pattern (June, 1955-59).

example, the standard error of estimate is .845 for the data in Fig. 1 so that basic residuals greater than 2.00 in (Fig. 1d) would have standardized values greater than 2.47 and would be significant at the 5% level of significance. Throughout the remainder of this paper, the term *standardized residuals* refers to the collection of the point residuals in space to form pattern highs and lows.

Near-neighbor analysis (Schickedanz, 1973a, 1973b) was then used to indicate the spacing between highs and lows and whether the highs and lows in a particular pattern were aggregate, random or systematic. This technique provides an objective method for describing the nature of highs and lows which can produce universal generalizations which are comparable from map to map. Near-neighbor analysis is applied by measuring the distance between the center of each high and the center of the high nearest to it in space. The probability distribution of the near-neighbor distances is useful in that statements concerning the probability of a high being within a specified number of miles can be made. The ratio of the actual mean of distances and the expected value of distances is the near-neighbor statistic and is used as a measure of the randomness (or lack of randomness) of highs (or lows) in the rainfall pattern. For additional details concerning trend surface analysis of precipitation patterns, and the description of highs and lows using the near-neighbor analysis, the reader is referred to Schickedanz (1973a, 1973b).

In order to further describe the patterns, lag correlation analyses over time at each grid point were used to describe the persistence of the pattern from year to year and the inter-correlation analysis between grid points was used to describe the persistence of the pattern in space.

b. Rainfall Patterns In and Downwind of Cities

Trend surface analysis was again used, but in a different manner than with the analysis of natural patterns. Instead of performing the trend surface analysis over the entirety of the area, it was performed individually for each city and its surrounding area. The resulting 5 and 10% residuals are shown on Fig. 2. In this manner, the importance of a high is judged in relation to the variability over the local sphere of interest. Such a comparison was necessary because some highs are significant in relation to a relatively small area, but are not significant in regard to a very large multi-state area.

The size of the sampling areas for each city was based on the sampling area used by Huff and Changnon (1972). In their climatological study of the precipitation at St. Louis, Huff and Changnon concluded that there was strong circumstantial evidence for the presence of an urban effect on summer precipitation. Since the size of their sampling area provided meaningful analysis of the urban high, a similar area was chosen for use in delineating effect and non-effect cities in the present study. Trend surface analysis was applied to the 120 x 90 mile areas, and the resulting highs and lows (residuals) could be evaluated in relation to the variability of data over these sampling areas.

These sampling areas were used with each city in the multi-state study

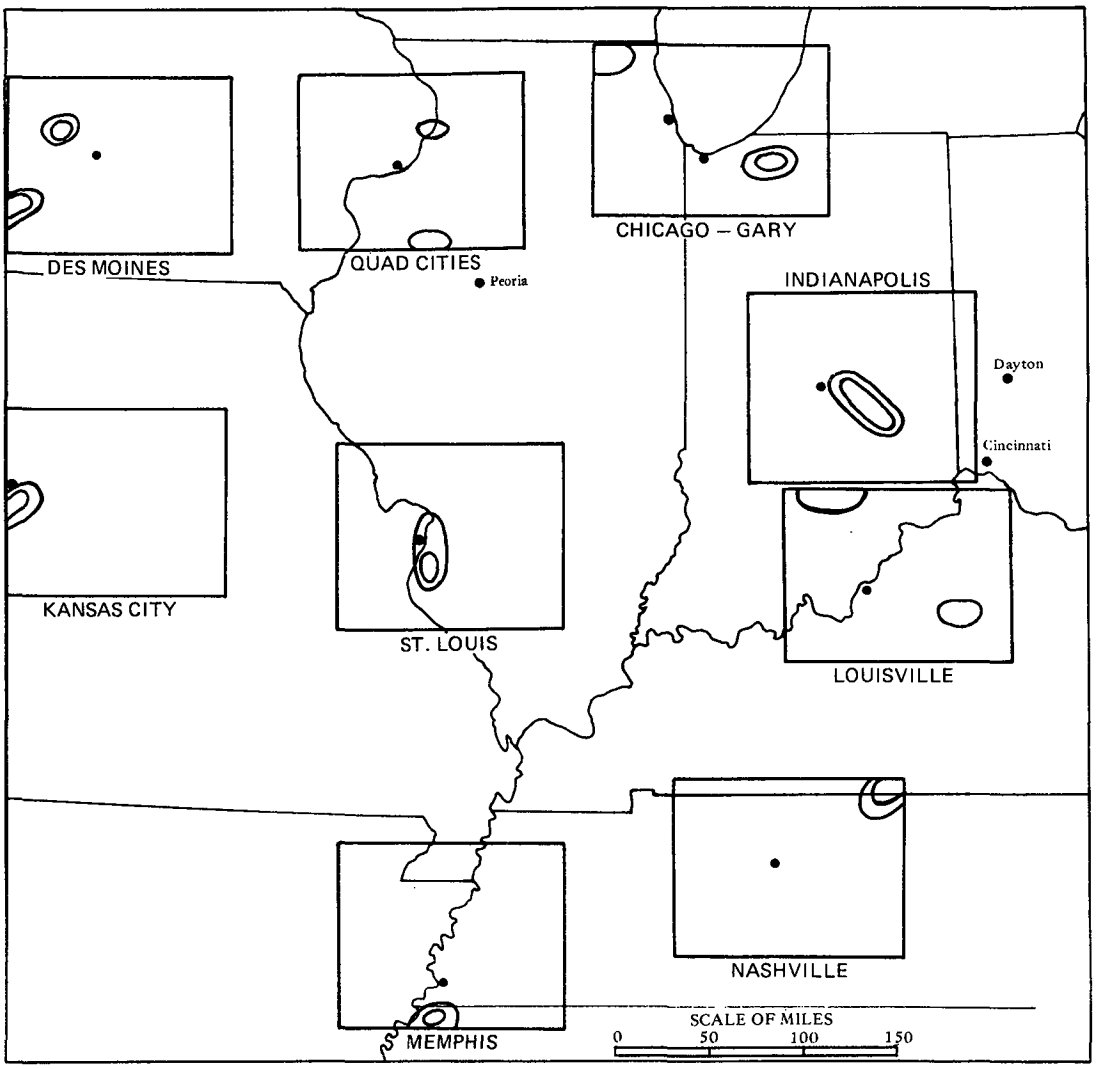


Figure 2.

Significant precipitation highs (5% and 10% residuals) as determined by trend surface analysis for the 1950-60 summer patterns in and surrounding the test cities.

area with a population equal to or greater than 300,000. Sampling areas for the various cities are shown on Fig. 2. The cities of Dayton, Peoria, and Cincinnati were also used, but were not depicted on Fig. 2 because their sampling domains overlap those of other cities on the map.

From the trend surface analyses of individual seasons, the Significant Rainfall Excess (SRE) and the Significant Rainfall Deficit (SRD) were computed. The SRE is defined as the net difference between the rainfall contained within a significant positive rainfall residual and the amount of rainfall necessary for the residual to be significant. The SRD is defined as the difference between the amount of rainfall contained within the significant negative rainfall residual and the amount of rainfall for the residual to be significant.

The excess and deficit calculations were made for each individual season and were then summed over 5- and 20-yr periods to obtain the rainfall excesses and deficits. These calculations are useful in that they represent only the rainfall that is significantly different from its surroundings. The total excess over time contains the total contribution of the significant portion of rainfall from each year and is a very meaningful value. An example of the SRE for the 20-yr period, 1950-69, is shown on Fig. 3.

The number of times that each sampling point was included in a significant high (5%) residual on summer patterns during the period 1950-69 was determined and mapped. This information, along with the information from Fig. 2 and Fig. 3 was compared in relation to the city and to the population of that city. The most consistent highs, according to persistence and location, occurred at LaPorte, St. Louis, Kansas City, and the Quad Cities. However, in regard to the Quad Cities, there are other highs of the same size and magnitude within its sampling domain (see Figs. 2 and 3). For the other cities, the high is not present on all 3 maps or the location is not consistent. Thus, LaPorte, St. Louis, and Kansas City were chosen as the effect cities.

For the cities of Peoria, Des Moines and Nashville, highs are only present in regard to SRE. Since the Peoria area overlaps that of the Quad Cities, Des Moines and Nashville were chosen as the non-effect cities. Thus, the effect cities were chosen on the basis of consistent appearance of highs and the non-effect cities were chosen on the lack of consistent appearance of highs.

For an additional control, a non-city sampling point was chosen to represent a hypothetical city. This point did not have a city with population $\geq$ 300,000 within its sampling domain. This point was designated as the "fake" city and its location is shown on Figure 4.

After the effect and non-effect (target) cities were delineated, the highs and lows downwind of these target cities were investigated. Trend surface analyses were performed on sampling areas (120 miles x 90 miles) immediately downwind of the three effect and three non-effect sampling areas defined in the previous section. The totality of these two sampling areas for each city permitted the investigation of downwind highs and lows out to distances of 200 miles. The use of two sampling areas of the same size instead of one sampling area of the size 90 x 240 miles, enables one to judge the

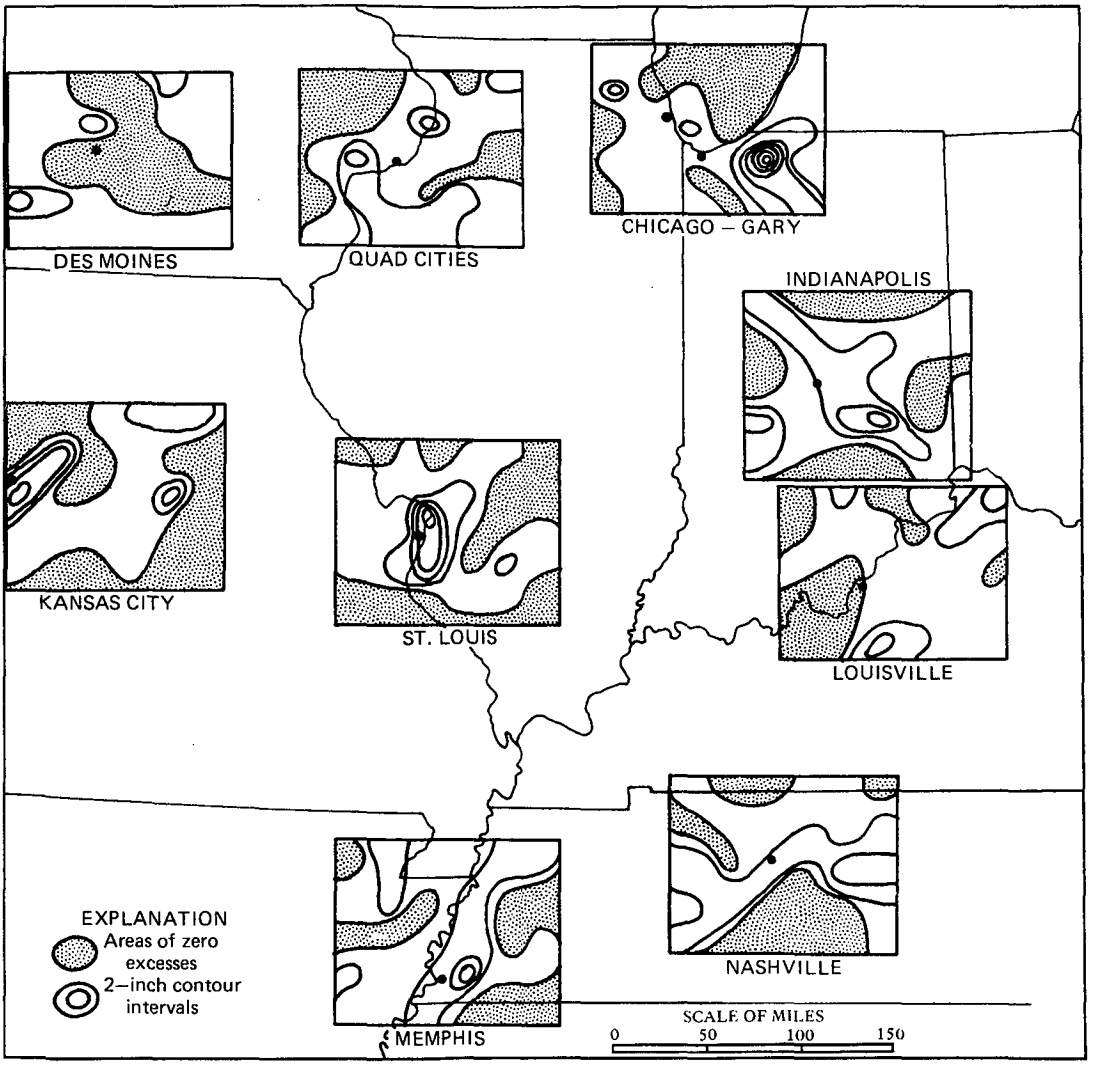


Figure 3.

Significant Rainfall Excess (SRE) in the vicinity of test cities during 1950-69 (10% level).

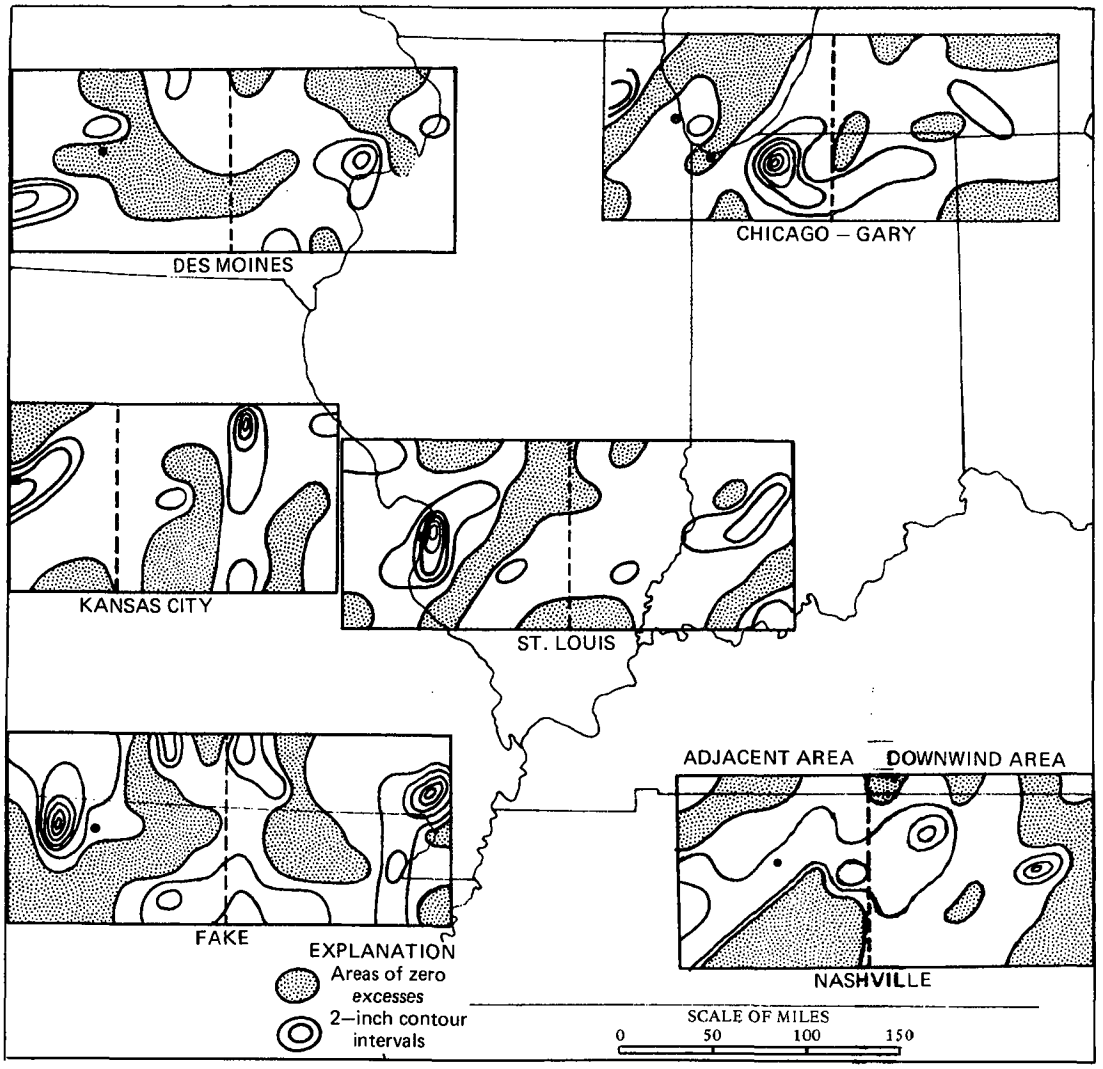


Figure 4.

Significant Rainfall Excess (SRE) in the vicinity of test cities during 1950-69 (10% level).

highs and lows in the extended downwind area on the same basis that was used to determine the effect and non-effect cities. These sampling areas are shown on Fig. 4 along with a dashed line separating the 2 sub-sampling areas, "adjacent" and "downwind."

Regions of SRE and SRD in the "adjacent" and "downwind" areas were established and the highs and lows within downwind regions of SRD and SRE were compared to the highs and lows in the city regions of SRE and SRD. These comparisons were made for cities with urban effects and cities without urban effects. Then, the spacing of the SRE and SRD regions was compared to the natural spacing of highs and lows. Also, the average excesses and deficits for 20 mile intervals upwind and downwind of the effect cities were compared to similar averages for the non-effect cities.

An analysis was made as to whether extra-area highs and lows are occurring during the same year as the city highs occur. If the joint yearly occurrence of the extra-area highs with the city high is low, and/or if the joint occurrence of the extra-area lows with the city highs is low, then it is extremely doubtful that the city is the causative factor.

To test further the areal spread of the urban effect, the general areas downwind of St. Louis and Kansas City were divided into sampling cells with outer (eastern) boundaries of 50, 100, 150, and 200 miles. The angle defining the complete set of sampling cells is 100 degrees wide centered on east with 4 subdivisions of 25 degrees each. Downwind is used in a climatic sense and encompasses the region where raincells and systems most frequently move away or downwind of the urban area. Areal means of point rainfall were then determined within each sampling area for individual months and seasons, and then determined for 5- and 20-yr periods. Also, average areal excesses (SRE) and average areal deficits (SRD) over the 20-yr period for 20 mile intervals upwind and downwind of the three effect cities were compared to similar averages for the non-effect cities.

Using the 1972 METROMEX (METROpolitan Meteorological EXperiment) data (Changnon, 1973a), the storm patterns in and downwind of St. Louis were investigated. Trend surface analyses were performed for each storm during the summer of 1972. The SRE values were computed for each storm during the summer of 1972 and the values were summed over the entire summer. The resulting downwind excess areas were compared to the urban-induced excess areas.

IV. RESULTS AND DISCUSSION

a. Natural Distribution of Precipitation Highs and Lows

The primary results derived from the extensive studies of natural rainfall patterns are listed below:

1) The significance of highs and lows in a rainfall pattern is determined by the boundaries of space chosen by the investigator. That is, a high may be judged insignificant with regard to the general pattern over a multi-state area, but may be judged quite significant in regard to a smaller sub-area. Thus, it is *critical to*

determine potential areas of influence based on a knowledge of average cell and storm system duration, speed and movement. Such determination is essential for meaningful studies of cause and effect relationships such as those involving highs or lows downwind of urban areas or areas of cloud seeding operations.

2) The determination of the natural spacing of highs and lows in patterns is highly dependent upon the definition of a high and low. The use of significant residuals from trend surfaces provides an objective method of defining highs and lows.

3) For 1-yr summer patterns, the highs have an average spacing of 75 miles, and for 5-yr patterns the average spacing is 94 miles. For the 5-yr patterns the most frequent distance between highs is in the 51-60 mile interval. These values are based on the distance to the nearest high. When the selection of the nearest high is limited to the downwind area only, the average spacing is somewhat greater. For 1-yr patterns, the mean distance is 100 miles and for 5-yr patterns the mean distance is 117 miles. The most frequent distance occurs in the 50-60 mile interval.

4) The frequency of lows is less than the frequency of highs and the spacing of lows is greater than the spacing of highs. This occurs because rainfall data are skewed and also bounded by zero. The magnitude of lows is bounded by zero, but the magnitude of highs is not bounded and takes on larger values. The mean distance between lows on 5-yr patterns is 140 miles and the median distance is 130 miles.

5) There is little difference in the spacing of highs according to summer months. However, the month of December has a greater spacing of highs than the summer months. For summer months, the mean distance to the nearest downwind high is from 105 to 116 miles. The most frequent distances lie within the range 40-60 miles. For December, the mean is 135 miles and the most frequent distance is in the 61-70 mile interval.

6) Although the spacing of highs and lows in patterns (1-yr, 5-yr, and 20-yr) tends to be largely random over a large multi-state area, the preferred location of highs over a 20-yr period (in respect to the frequency of occurrence over time) tends to be systematic. Also, there is a tendency for these preferred areas of highs to occur along lines with some degree of uniformity. An example of this uniformity is depicted on Fig. 5 for the summer patterns during 1950-69. The near-neighbor distance was 52 miles during summer and the most frequent occurrence was in the 51-60 mile interval. During the month of December, the mean near-neighbor distance was 76 miles for preferred areas of highs and the most frequent distance occurred in the 51-60 mile interval. In summer, the preferred areas of lows are further apart than the preferred area of highs with a mean distance of 120 miles and a median value of 80 miles.

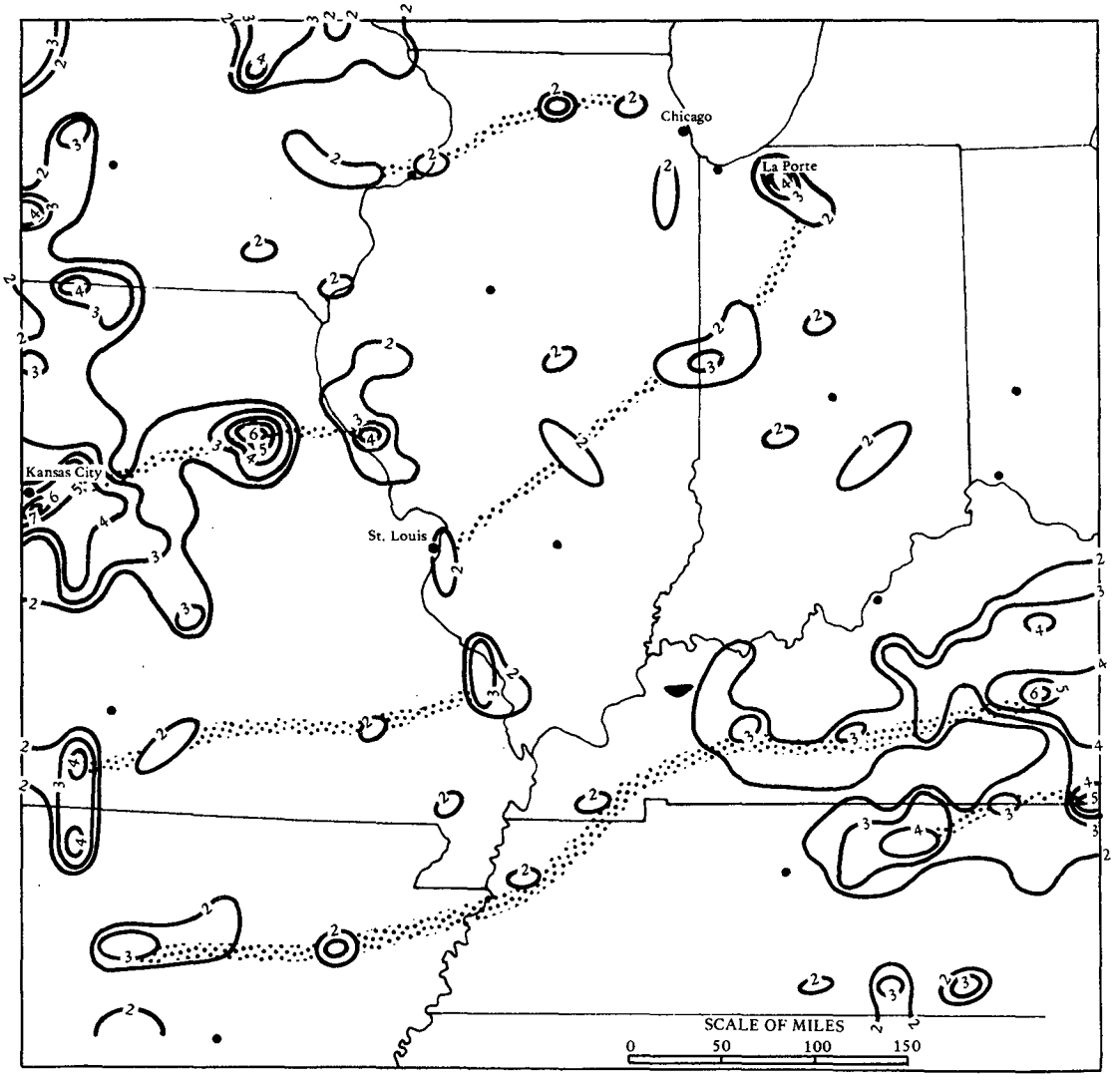


Figure 5.

The number of times that each sampling point was included in a high (5% residual) on 1-yr summer patterns during 1950-69.

7) Persistence from season to season is low in rainfall patterns. The lag 1 correlation coefficient had a maximum value of 0.5 for a given sampling point which only explains 25% of the variance in the 20-yr time series. The majority of sampling points had lag 1 correlation coefficients less than 0.3 which are insignificant. However, persistence centers were found to have a systematic areal spacing with a mean near-neighbor distance of 61 miles and a modal value of 41-50 miles.

8) Correlation coefficients of the rainfall at Salem, Illinois (center of the study area) with all other points in the study area revealed a tendency for the rainfall to be correlated up to 250 miles away. There was also a tendency for correlation cores to occur along southwest-northeast lines with some degree of uniformity. The mean near-neighbor distance was 71 miles and the average distance along lines of correlation cores was 85 miles.

9) There is a considerable amount of variability of the mean distance between highs from one 5-yr period to the next. For summer patterns the mean distance ranges from 67-136 miles and the mid-point of this range is approximately 100 miles.

Overall, the most frequent distance between highs is in the range 40-60 miles. However, on 1-yr and 5-yr patterns the mean distance between highs is 75-94 miles and when the mean distance is determined in a direction sense (downwind) the mean distance is 100-117 miles. The mean distance of persistence areas and preferred locations of highs is approximately 60 miles.

The mean distances are of particular interest for they are in the range of downwind highs reportedly due to seeding. For example, Brown and Elliott (1968) have reported downwind highs at approximately 100 miles and at 250 miles; Brown (1971) has reported highs in the range 70-100 miles downwind; and Grant (1971) has indicated highs in the range 90-120 miles downwind. Grant (1971) has also found little evidence of highs beyond 150-200 miles down-wind. Thus, the mean distances of downwind highs (natural spacing) correspond closely to the distances associated with highs downwind of seeding experiments. Since the experiments of Grant (1971) and of Brown (1971) were randomized experiments, the above results do not disapprove the presence of downwind seeding-induced highs. *However, it does indicate that the reported seeding-induced downwind highs fall in a region where highs occur naturally in the Midwest.*

It is of interest to *speculate* on physical reasons for the spacing of highs observed in the rainfall patterns. Elliott (1971) has suggested artificial cirrus seeding and precipitation pulsation as two possible mechanisms to explain some observed highs downwind of seeding sites in the west. Braham (1965) has suggested a dynamic wave mechanism to account for the spacing of radar echoes observed in Project Whitetop.

The first hypothesized mechanism (artificial cirrus seeding) states that updrafts are enhanced in the seeded area and more ice particles are thrown out the top of convection. These crystals create artificial cirrus

clouds which drift downwind and eventually descend to lower levels, where they seed cumulus in the downwind area. Calculations by Elliott show that a 60-100 mile drift during descent is reasonable.

The second hypothesized mechanism (precipitation pulsation) is based on the enhancement of precipitation due to increased cloud top heights in individual rainstorms in a squall line. Sub-cloud evaporation occurs and cloud downdrafts develop which spread forward as a pseudo cold front in low levels. This outflow induces an updraft along the leading edge which causes new cumulus to develop. If the pulsation is roughly 3 hours (Newton and Newton, 1959) and if one assumes a translational velocity of 10-20 miles per hour, the spacing of precipitation maxima would have a spacing of 60-90 miles along the movement of the squall line.

The third hypothesized mechanism (dynamic wave) is based on increased cloud growth in the seeded area. It is suggested that this increased growth may set up a stationary wave-like perturbation which spreads outward and downstream with some sort of damped harmonic motion with a wave length of 30-50 miles.

All of these mechanisms could be present in natural storm data and possibly lead to spacing of precipitation maxima similar to that observed in the natural distribution study. However, development of storms would need to occur repeatedly in approximately the same location if such regularly spaced maxima are to manifest theirselves in monthly and seasonal rainfall patterns. In seeded data, the target area provides the genesis source for the consistent creation of the first maxima and feeder storm. However, in natural data, a triggering mechanism such as pronounced topographical features, large bodies of water, or the chance creation of alternating wet and dry regions, would be required to provide favorable genesis areas from day to day. It is extremely doubtful whether moisture source regions created by chance heavy rainfalls would persist beyond a single season, certainly, not for 5- and 20-yr periods.

There are topographical features present in the PEP study area (Ozarks and Appalachian Mountains) which help to explain some of the spacing along lines such as depicted in Fig. 5. However, other lines of highs occur apart from topographical features and have no apparent explanation. Therefore, it must be assumed that the observed spacing of many highs in the natural patterns is due to mesoscale or macroscale features of the atmospheric circulation which are either not understood or not detectable in the existing meteorological observational systems.

In June there is a broad band of frequent occurrence of stationary fronts extending from Kansas City to St. Louis to Indianapolis and a band along the Missouri-Arkansas border*. The preferred frontal locations correspond closely to some of the lines of preferred areas of highs observed in June rainfall patterns. Thus, they help explain the existence of these par-

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* Unpublished data compiled by Griffith M. Morgan, Jr., of the Water Survey Staff.

ticular lines but not the observed spacing between the highs with these lines or other lines not subjected to significant topographical features.

The implications of the natural distribution study are two-fold: 1) the mean and median distances between natural occurring highs are in the range of reported downwind highs due to seeding, and 2) the broadness of the correlation pattern between points in a pattern indicate that one must be very cautious with postulating extra-area effects out to distances as great as 300 miles from the target in weather modification experiments.

b. Rainfall Patterns In and Downwind of Cities

The primary results derived from the study of rainfall patterns in and downwind of cities are listed below:

1) The spacing of excess highs downwind of the effect cities was nearly the same as the spacing downwind of the non-effect cities. The average distance between highs was determined to be 56.9 miles for the effect cities and 50.5 miles for the non-effect cities. Along W-E lines the average distance between excess highs was 60.7 miles for the effect cities and 60.2 miles for non-effect cities. The mean distances correspond closely to the modal and mean values of the natural distances between locations of preferred highs.

2) The results of the trend surface, excess, deficit, and joint frequency analyses indicated that downwind highs and lows beyond 50 miles of St. Louis, Chicago-Gary, and Kansas City were not urban induced.

3) The areal means in the downwind sampling areas of St. Louis and Kansas City indicated that a) for summer, the largest area mean occurs within 50 miles of the city, and the urban effect does not exist beyond 50 miles, b) the urban effect is non-existant in winter, c) the urban effect was stronger at Kansas City than at St. Louis, and d) the urban effect is present in all 3 months (areal means) at Kansas City, but only during June at St. Louis.

4) There is a tendency for rainfall deficits to occur in the neighborhood of excesses. The tendency is not a strong one, but it is interesting that it seems to exist in climatological data. A firm conclusion is impossible from these data and this is a subject of future investigation which will require detailed analyses of rain entities such as rain cells.

5) The results of the downwind study using storm data indicated that the major part of the downwind effect from cities occurs within 0-25 miles of the city, with a smaller effect in the area 25-50 miles of the city.

Overall, the results of these studies indicated that the urban effect is limited to 50 miles of the city, and that no downwind effect occurs beyond 50 miles. The results are similar to those obtained by Schickedanz and Huff

(1970) and Braham, et al. (1971) in regard to Project Whitetop, a randomized seeding project in the Midwest. Schickedanz and Huff concluded that the evidence of downwind effects from the Whitetop experiment is very weak. Braham et al. concluded that there is little evidence to support an overall seeding effect on precipitation outside of the Whitetop Research area (the radius of the Whitetop Research Circle was 60 miles). Furthermore, the analysis of storm rainfall patterns downwind of St. Louis indicated that the major effect occurs within 0-25 miles, with a smaller effect in the area 25-50 miles of the city.

ACKNOWLEDGEMENTS

This research was supported by the Atmospheric Water Resources Management Division of the Bureau of Reclamation under Contract 14-06-D-7197 and the National Science Foundation under Grant GI-38317. This work was done under the general direction of Stanley A. Changnon, Jr., Head of the Atmospheric Sciences Section of the Illinois State Water Survey, and Floyd A. Huff who supervised this study area. Appreciation is expressed to Stanley A. Changnon, Jr., for his review of this paper and to Floyd A. Huff for his helpful suggestions throughout the study. Appreciation is expressed to Marion B. Busch who performed most of the computer analyses and supervised other critical analyses.

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RHODESIAN NATIONAL DROUGHT RELIEF CLOUD-SEEDING OPERATION JANUARY - APRIL 1973

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1. SUMMARY

An account is given of the National Drought Relief Cloud-Seeding Operation in Rhodesia from January to April 1973, and the circumstances which led up to it. An assessment of the operation is discussed and a note is made of lessons learned for future use.

2. THE 1972-73 SEASON

All rainy seasons are different and have their own characteristics. It must be expected that the main rains can start at any time between the beginning of November and early December. If the start is delayed until after Christmas, a serious situation is likely.

In 1972, there was a preliminary early rainy spell at the beginning of October. Good rains fell on the 6th, 7th and 8th November to bring the rainfall over the country generally above average at that stage. The weather situation gave the impression that the onset of the main rains would develop in a normal manner. In the event, on the 10th November, a cold southeasterly to southerly windflow set in and reversed the onset of the rains for almost a fortnight.

There was useful rain on 24th, 25th and 26th November, then very little until the 7th December, when once again it appeared that the rains would start. But from 10th to 20th December the rainfall was sparse and there was virtually no worthwhile rain for the farmers from 21st to 29th December. By this stage the position was really serious.

On the 30th and 31st December there were a number of showers. After some rain from 5th-12th January the next rainy spell was not until the 25th - 31st January. A reasonably typical rainy season situation eventually prevailed from the 11th February to the 7th March. Remaining rainfall for the season was mainly confined to the north and northeast of the country from the 10th-22nd March.

The dry spells in 1973 were 1st-4th January, 14th-22nd January, 1st-10th February and in general from 23rd March onwards. On the dates not mentioned there were only localised showers.

This persistent shortfall of rain was due to the so-called "Botswana Upper High," which for most of the season sustained very dry air in the

middle levels of the atmosphere, i.e. approximately between 570 and 430 mbar i.e. 16,000 - 23,000 ft. or 5,000 - 7,000 metres.

3. CLOUD-SEEDING EXPERIENCE IN RHODESIA

Although the salient points of cloud-seeding in Rhodesia to date are well known to those concerned, it is convenient to summarise them here, since they were the basis of the decision to implement the Drought Relief Cloud-Seeding Operation.

The current Cloud-Seeding Research Programme was inaugurated in 1968, immediately after the 1967-68 drought. Following experience elsewhere, the silver iodide technique was favoured. Its principle is that huge numbers of silver iodide crystals in the form of "smoke", a million million or more crystals per gram of silver iodide, cause super-cooled water droplets in the cloud a few thousand feet above the freezing level to turn into ice crystals. This is an artificial means of starting the natural precipitation process. Experience shows that for the silver iodide method to be effective the temperature of the cloud-top must be as cold as $-10^{o}C$. This means that during the rainy season in Rhodesia the cloud-top must usually be at least as high as 21,000 ft (6,400 m) above sea level. For seeding by silver iodide for the augmentation of rain to be suitable, clouds have to be in the growing stage, be the right shape and satisfy other requirements as well. Selection of suitable clouds requires knowledge, skill and a good view.

For the experiments, a Rhodesian Air Force DC3 "Chaminuka" was used. A solution of silver iodide in acetone was burnt in two burners fitted outside the fuselage to dispense the crystals as a trail of silver iodide "smoke". Normally the aircraft flew through the cloud at about 14,000 ft (4,300 m), still within its performance capability but below the level likely to incur serious icing. The method relies on updraughts in the cloud to carry the silver iodide to the 21,000 ft (6,400 m) level where it becomes an effective seeding agent. Such necessary cloud penetration flying is very turbulent and uncomfortable and submits the aircraft to much greater stress than normal flying.

This method has much to commend it for effectiveness, but the flying in and out of cloud makes it difficult to get a good view. An inclinometer and specially devised ready reference tables for quick calculation were carried, in order to assess during the approach run whether the cloud-top was high enough to warrant seeding, or so high as to make penetration positively dangerous.

To overcome these difficulties, a second method of seeding from just above the cloud-top was adopted in 1971-72 for the pioneer operation to seed the Kyle and Bangala catchment areas, which was carried out in conjunction with the Rhodesia Sugar Association. In this method the silver iodide is contained in a specially manufactured cartridge fired from a Very pistol mounted in the aircraft. After being fired the cartridge burns for 30-40 seconds leaving the trail of silver iodide "smoke" behind as it falls downward through the cloud. This technique reduces, but does not eliminate,

flying through cloud, with the consequent risk of serious icing and severe turbulence. A relatively small aircraft will suffice, provided its performance can offer full manoeuverability in rough air at 22,000 ft (6,700 m). Relatively few light aircraft have this required performance.

By 1972 considerable practical experience had been gained in operational techniques, resolving technical problems and the economical deployment of aircraft and manpower. Seeding can only succeed where Nature provides the suitable clouds. The meteorologist can save most of the expense of flying "to look and see" on unsuitable days. Even on favourable days the aircraft must have a large area from which to choose the suitable clouds. In circumstances of deficient rainfall the problem is a shortage of suitable clouds, so that a small but well-managed nucleus of suitable aircraft and experienced personnel will suffice.

The experiments conducted up to 1972 using the silver iodide technique indicated that yield from a cloud which satisfied the suitability criteria, and which left alone might yield 2 or 3 mm could be enhanced some 10 mm by seeding. On a minority of occasions when formations of clouds could be seeded, general rain and showers followed over an area of some 400 km^2.

4. THE DECISION TO MOUNT A CLOUD-SEEDING OPERATION

On the 4th of January, the Secretary for Transport and Power and myself were invited to a meeting with the Minister of Agriculture and the President of the Rhodesia National Farmers' Union. The Minister asked for an appreciation of the rainy season to date, the future prospects in so far as these could be assessed, the efficacy of cloud-seeding, costs, what scale of operation could be mounted and how soon.

In reply, I stated that there was still no indication of good general rain setting in, but poor sporadic rain such as could be enhanced by cloud-seeding seemed possible. I advised him of the salient points of our cloud-seeding experience, the extent to which it could be expected to alleviate the deficient rainfall, the availability of a nucleus of suitable aircraft, equipment and seeding chemicals, pilots and meteorological officers with seeding experience, and an estimate of costs.

On this basis the Minister of Agriculture asked me to start a National Drought Relief Cloud-Seeding Operation on the following day. This was done. That this was possible was due to the recent accrual of practical experience, to anticipation, improvisation and in particular to excellent co-operation all around.

5. THE IMPROVISATION

As soon as Christmas 1972 had passed without rain setting in, it was realised that a crisis threatened and various anticipatory measures were taken. With the prompt assistance of Skywork, the cloud-seeding research aircraft, a turbo-charged Cessna 320 VP-WET, recently donated to Government

through the University, was tested out on two seeding sorties on the 29th and 30th December, when 73 cartridges were fired. From visual observation it seemed that the seeding had been very successful in the Karoi and Mangula areas.

On 2nd January, air operators were asked about suitable aircraft. Rhodesia United Air Carriers (RUAC) made their Baron VP-WAX ready for immediate conversion to cloud-seeding duties, and the Rhodesian Air Force once again promised to provide their DC3 "Chaminuka" should the need materialise.

The absolutely vital factor was that the only cloud-seeding cartridges in the country were those purchased by and belonging to the Rhodesia Sugar Association (RSA) for the repetition of seeding over the Kyle and Bangala catchments by meteorological staff. RSA agreed that their cartridges could be used in a national operation until replacement stock could be obtained.

RSA also agreed that the RUAC Cessna 210 reserved by them, could be used in the national operation, in conjunction with seeding over the Kyle and Bangala catchments.

Following the decision on the 4th January to mount the operation, two aircraft were seeding on the 5th and three on the 6th. By Monday the 8th, the fourth aircraft, the Rhodesian Air Force DC3 "Chaminuka" was ready for seeding, having been fitted up throughout the weekend. A flight of four seeding aircraft was very satisfactory although five would have been about the best number.

6. THE ORGANISATION

Treasury allocated a sum of $100,000 to the Ministry of Agriculture for the operation, to be managed by the Meteorological Department which is in the Ministry of Transport and Power. No undue difficulties arose over the involvement of more than one Ministry. An account of expenses borne by the various parties is given at Appendix I.

Most urgent measures were taken to obtain supplies of cartridges to try and avoid a breakdown through running out of stock.

The aircraft deployed and technique used by each were:

i) The Ministry of Transport and Power
Cessna 320, VP-WET . . . . . Cartridges

ii) RUAC Cessna 210 cum RSA, VP-YLT . . Cartridges

iii) RUAC Baron VP-WAX . . . . . Cartridges

iv) Rhodesian Air Force DC3 "Chaminuka". Burners

The pilots were provided by the Department of Civil Aviation, RUAC and the Rhodesian Air Force No. 3 Squadron respectively. Each of the three high-flying light aircraft had a special panel mounted in a detachable door,

in which two Very pistols were locked in position for the safe firing of cartridges.

The meteorologist in immediate charge of cloud-seeding decided each day whether conditions could be expected to be suitable for seeding, and if so the best time and the best area. He programmed the sorties accordingly. Considerable use was made of the Salisbury and Bulawayo radiosonde data which provided a measure of the water content at various levels in the atmosphere. Sorties were flown on the very marginal days, as well as on the favourable days, since the dire shortage of rainfall justified taking the chance. Flying was cancelled on the days which were considered unfavourable. On the sorties meteorological officers selected the suitable clouds and did the actual seeding.

Because the operation was improvised without the opportunity of prior planning, all aircraft had to be based in Salisbury, otherwise one aircraft would have been based in Bulawayo to the convenience of all concerned. Occasional night stops were made in Gwelo where oxygen re-charging was available.

During seeding sorties, radar fixes of aircraft positions were available from the Civil Aviation Flight Information Centre. These were valuable for navigation, logging the positions of seeding and for co-ordination on those occasions when seeding opportunities engaged more than one aircraft in the same general area.

In late January, it was decided that the operation should continue until 30th April, in order to take the best advantage of all seeding opportunities which might offer.

7. THE OPERATION

The seeding operations were carried out more expeditiously than could have been expected. Seeding was easier in the high-flying aircraft. From 21,000 ft selection was easier, but skill was required to fire the cartridge into a growing cell head. Often in the time that elapsed between selection and positioning, the cloud grew and instead of the aircraft skimming over the top, it was suddenly engulfed in a developing cloud head. The pilot had to be alert to control the aircraft and the seeding officer had to try and ensure that he fired into the updraught and not into the downdraught. Good team-work between the pilot and the seeder was developed to achieve the most efficient positioning, and the maximum effectiveness on the favourable days which offered plenty of seeding opportunity. In favourable seeding conditions there was neither the time nor a clear view to observe results.

In general isolated cloud cells were seeded once. The isolation of a cloud indicates that it is surrounded by relatively dry air. In marginal conditions seeding would therefore tend to be less successful than in moister conditions which offer more clouds closer together. The need for rain being so great, clouds were sometimes seeded when barely satisfying the selection criteria. On balance the gamble paid off, but at the expense of

a higher failure rate. Minimal clouds surrounded by relatively dry air can be unintentionally dispersed by seeding. These less favourable clouds were the ones that had the best chance of being observed after seeding.

With cloud clusters, an attempt was usually made to seed each individual cell in order to make them grow and merge together into one large area of rain or showers. When squall lines were encountered, newly developing cells ahead of the advancing line were seeded to induce extension of the general rain area.

Flying in "Chaminuka" at 14,000 ft (4,300 m) above sea level in and out of cloud, it was seldom possible to see whether rain fell from the base at about 9-10,000 ft (2,750-3,050 m) or whether there was vertical development of the top originally assessed on the inclinometer at about 21,000 ft (6,400 m). It was not possible to count the number of actual cells seeded as in the case of the cartridge technique. The number of seedings had to be deduced from the number of minutes of burner time. Most of the sorties in "Chaminuka" were rough. On one occasion one of the meteorological team was thrown violently between roof and floor of the fuselage twice and received bruises and a cut which had to be stitched. After treatment he resumed his cloud-seeding duties.

Numbers and Locations of Seedings

During the operation, daily reports of seeding sorties were issued to interested parties. Some of the pertinent operational information is given below. The distribution list is shown in Appendix II.

The number of cartridges fired was 1,991

The number of clouds seeded by cartridges was 1,554

"Chaminuka" burning times was . . . . . 420 mins.

Estimated number of clouds seeded by "Chaminuka" was . . . 150+

Estimated total number of clouds seeded was 1,704

The locations of the seeding are given in Figure 1 and in Appendix III.

It will be seen that there were three areas of comparatively concentrated seeding. One was between Karoi and Salisbury and a second was the area around Bulawayo. Apart from northeast Mashonaland where the rainfall deficiency was least serious, these areas offered the most opportunities. The third area was the Kyle catchment, partly due to the prior claim of the Rhodesia Sugar Association for seeding, and partly due to relatively favourable seeding conditions. In general whenever a choice was possible, preference was given to seeding over cultivated or ranching areas, or over the catchment of large dams. Figure 2 shows the number of clouds seeded in each degree square of Rhodesia.

FIGURE 1

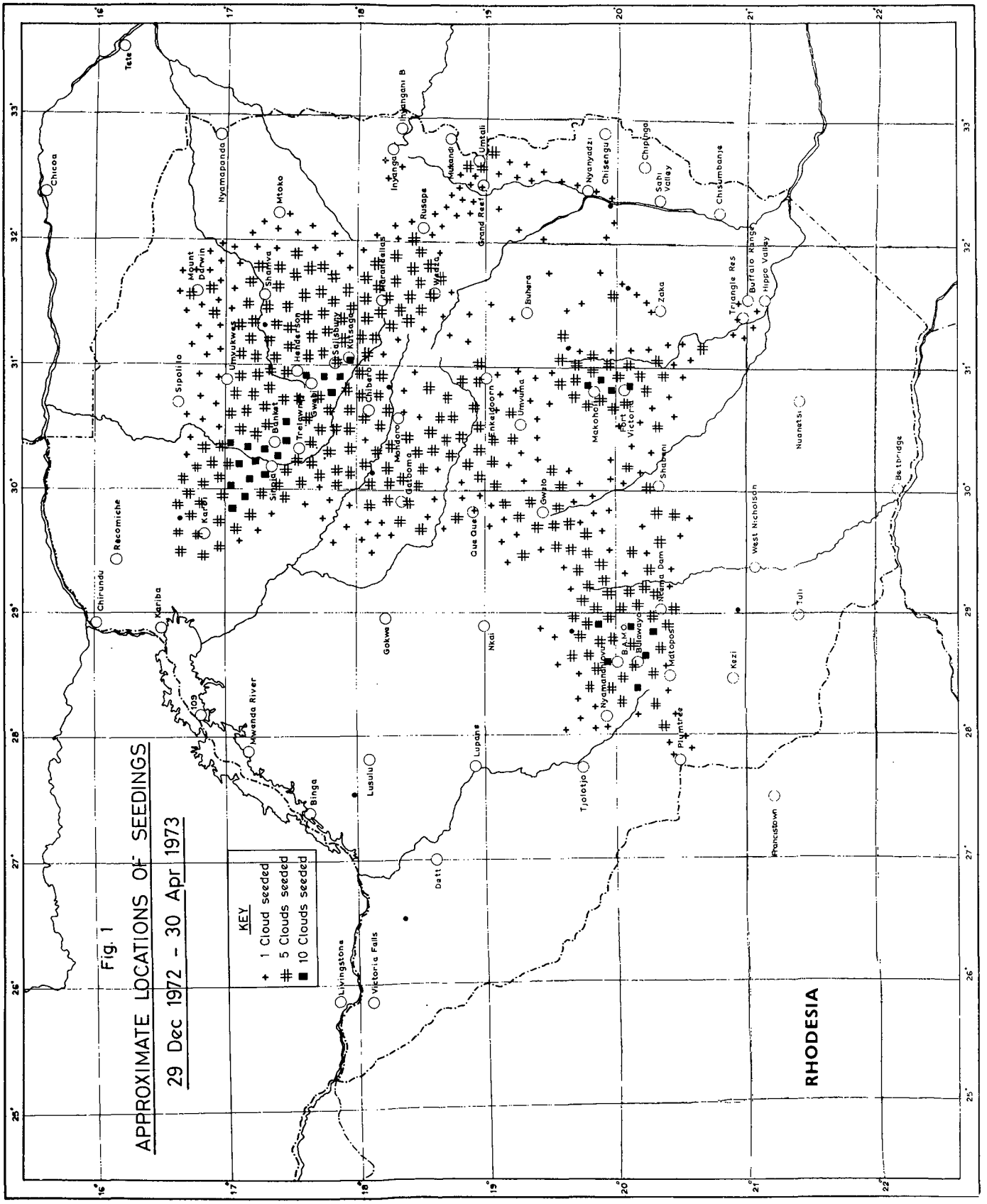
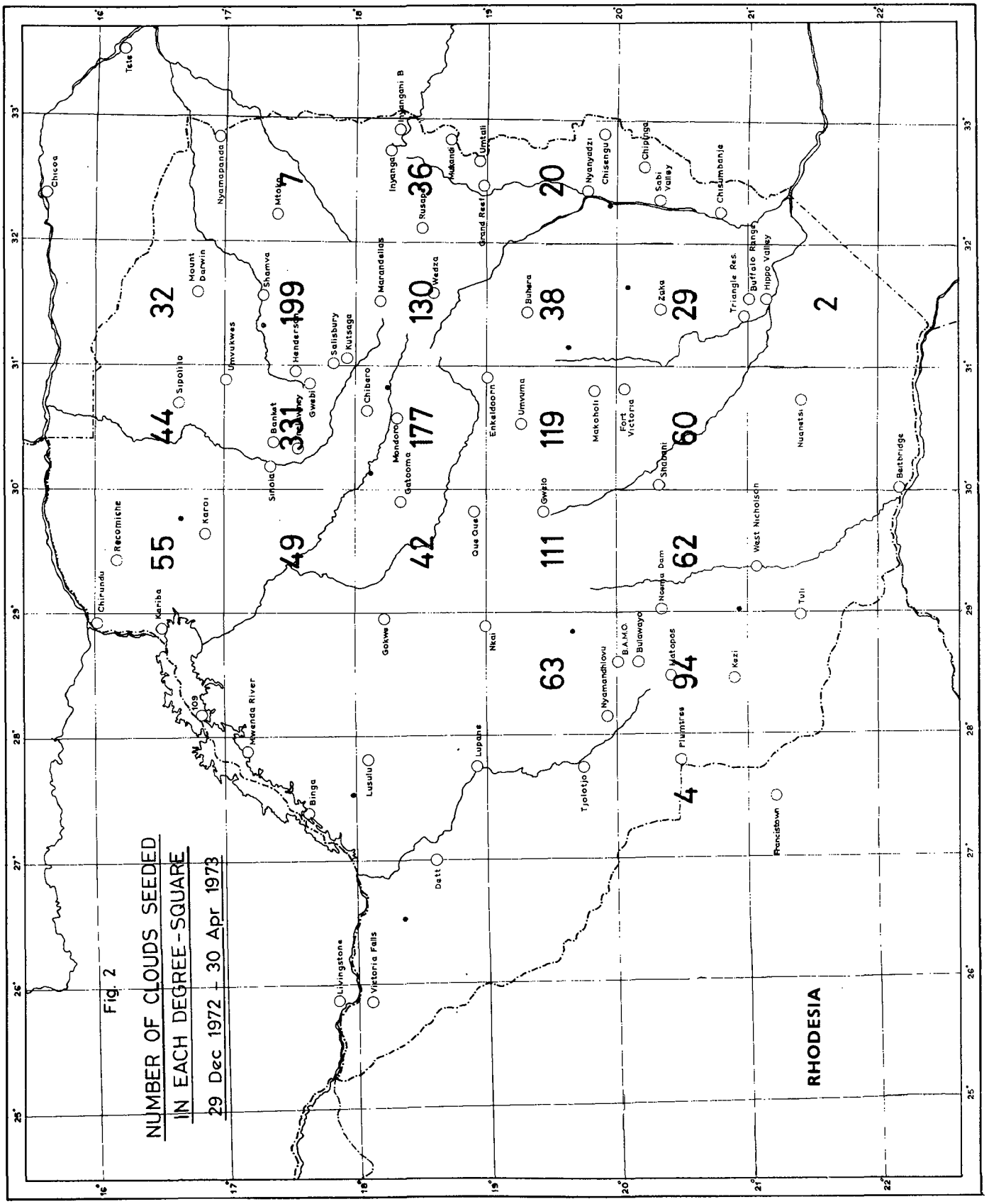

Fig. 1
APPROXIMATE LOCATIONS OF SEEDINGS
29 Dec 1972 - 30 Apr 1973
KEY
1 Cloud seeded
5 Clouds seeded
10 Clouds seeded
RHODESIA
Chicoa
Tete
Nyamapanda
Mtoko
Inyanga
Inyangani B
Mukandi
Umtali
Nyanyadzi
Chisengu
Chipinge
Sabi Valley
Chisumbanje
Rusape
Grand Reef
Mount Darwin
Shamva
Umvukwes
Sipolilo
Hartsgen
Hatfield
Buhera
Zaka
Triangle Res
Buffalo Range
Hippo Valley
Chibero
Mahoroa
Gatooma
Enkeldoorn
Umvuma
Makoholi
Fort Victoria
Shabani
Nuanetsi
Bethridge
Que Que
Gwelo
Kariba
Karoi
Sinoia
Banket
Trelawney
Ewanbi
Hartley
Selukwe
Ruttenjee
Mtarazi Falls
Recomiche
Chirundu
Gokwe
Nkai
West Nicholson
Tuli
Kezi
Matopos
Bulawayo
Lupane
Lusulu
Binga
Mwanda River
Tjolotjo
Plumtree
Francistown
Datt
Victoria Falls
Livingstone

FIGURE 2


NUMBER OF CLOUDS SEEDED
IN EACH DEGREE-SQUARE
29 Dec 1972 - 30 Apr 1973
Fig. 2
RHODESIA
Chicoa
Tete
Nyamapanda
Mount Darwin
Umvukwes
Shamva
Mtoko
Salisbury
Kutsaga
Marandellas
Inyanga
Inyanga B
Rusape
Wedza
Umtali
Grand Rest
Nyanyadzi
Chisengu
Chipinga
Sabi Valley
Chisumbanje
Buffalo Range
Hippo Valley
Triangle Res.
Zaka
Buhera
Umvuma
Enkeldoorn
Makoholi
Fort Victoria
Shabani
Nuanetsi
Beitbridge
West Nicholson
Sipolilo
Karoi
Chirundu
Kariba
Sinoia
Banket
Gwebi
Chibero
Mondoro
Gatooma
Que Que
Gwelo
Gokwe
Nkai
Lupane
Lusulu
Binga
Mtemwa Dam
B.A.M.O.
Bulawayo
Nyamandhlovu
Tjolotjo
Plumtree
Matopos
Kazi
Tuli
Francistown
Datt
Livingstone
Victoria Falls
Mowenda River
32
44
331
199
7
36
20
130
38
29
2
177
119
60
55
49
42
111
62
63
94
4

High yield multicell seeding was achieved on

30th December, near Mangula;

28th January, southwest of Glendale;

31st January, just north of Shamva;

8th February over Marula;

16th February to the northwest of Bulawayo;

19th February around Lake Kyle;

24th February, south of Lion's Den.

A number of farmers were good enough to telephone their own observations of successful seeding. In the stress of day-to-day improvisation, records of some of these cases have regrettably been lost.

A Shamva farmer reported an inch of rain after observing seeding by the Baron between 12.10 and 12.30B on 7th January.

Mr. E. E. Sugden of Zwipadze Farm, Marandellas, wrote to say that he had 20 mm of rain soon after sighting a twin-engined aircraft. He did not state a time, but "Chaminuka" was seeding in the area between 14.10 and 14.20B and 15.10 and 15.30B.

Mr. R. Carmody, recently retired from the Department of Civil Aviation, reported 17 mm of rain from a cloud near Lake Kyle seeded by the Cessna 210 at 14.15B on 20th March.

There was also a different aspect which is quite significant. On two separate occasions well-wishers wrote to thank us for rain following seeding by aircraft, when our seeding aircraft had not been in the area at the time. Without a checking system false claims would be possible.

Utilization of Aircraft

For most of the period four aircraft were available. The prospects for seeding began to diminish during March so that "Chaminuka" was released from the 16th March. VP-WET was withdrawn from the 10th April due to technical problems. On various other days aircraft had to be taken out of service for maintenance. The utilisation data is therefore as follows:

Total number of programmed days (29th-30th Dec., 5th Jan. - 30th Apr.)	118
Number of days when sorties flown	58
Percentage of programmed days	49%

Number of days flown without seeding taking place 5

Number of seeding days 53

Percentage of programmed days 45%

Total number of aircraft/days available, i.e. possible number of sorties 369

Total number of sorties flown including marginal cases . . .132

Total number of sorties flown with seeding accomplished . .120

Percentage of possible sorties on which seeding was accomplished 33%

Seeding sorties were not flown on 237 occasions because the weather was deemed unsuitable. Because all reasonable chance of seeding was followed up, 12 sorties were flown without finding clouds good enough to seed. These included two trips to the Eastern Border Mountains area including Chipinga to see whether silver iodide seeding during a guti was feasible - on these occasions it was not.

Four aircraft effected quite a good coverage. Four was a conveniently small number to operate, nevertheless over the period utilisation was only 33%. Three aircraft would have been utilized to a greater extent, but the value of the gainful opportunities missed would have been much greater than the cost of operating the fourth aircraft.

A call upon a fifth aircraft would have been desirable in order to make the most of really good days and to ensure cover of the Eastern Border and extreme southeast. Five aircraft would probably have been the best number. More than five aircraft would have incurred a higher proportion of no-go time, and considering the manpower required probably would not have been worthwhile.

8. ASSESSMENT

The obvious questions are, "Did the seeding do any good? If so, how much good did it do?" It is not possible to give categorical answers with scientific accuracy. The objective scientists are quite correct in being severely critical. With less justification they are joined by the sceptics. On the other hand the wishful thinkers are in danger of attributing almost magical powers to cloud-seeding. In between there are the farmers who need a fair idea and the planners who need a working guide on which to base decisions. Our overall experience shows quite strong indications which can give an answer. With due explanation this should serve to give a working guide.

An assessment of the results of the operational seeding must be based

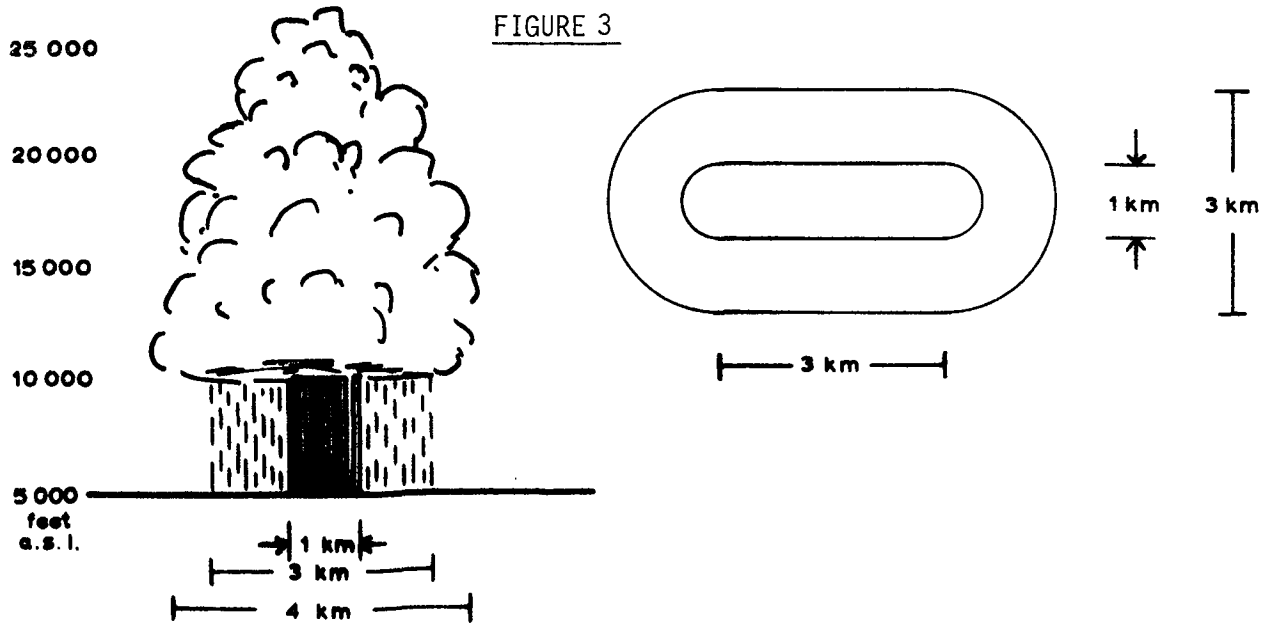
on the results obtained in the research programme. In the experiments the clouds are carefully selected according to certain criteria and, depending on a last minute randomized command, they are either seeded or left alone. In either case careful measurements and observations are made to give a comparison. The observations commence from the time the cloud is selected, until the completion of its life. This usually takes an hour and may last an hour and a half. The operation allowed no such chance for searching observation; it would be a fair generalisation to say the better the view the poorer the yield, and the worse the view the better the yield.

Yield from a Single Cloud

As already stated, the most relevant indication of rainfall yield is that clouds which satisfy the seeding criteria and give only 2-3 mm by natural processes, can be enhanced some 10 mm by seeding.

The structure and life-cycle of a shower may be complicated, but at this stage data do not warrant a serious attempt at a sophisticated model. However, the experience of many seedings has accumulated information on heights of tops and bases, shapes, diameters of a central core area of heavier rain within an outside diameter, the drift of the shower cloud during its life and the measurement of rainfall both from the aircraft traversing just beneath the cloud and from raingauges on the ground. Based on this information a very simple model of the pattern of rainfall can be devised, comprising the greater enhancement in the central core area and the lesser enhancement in the outer ring, both of which are drifting over the ground with the wind. Simplicity has the advantage of being easily understood, and also making clear the limitations of the model.

FIGURE 3



Conservative values can be allocated to a cloud which satisfied the seeding criteria, as follows:

Outer diameter of shower cloud . . . . . 4 km

Outer diameter of rain area . . . . . 3 km

Diameter of inner core . . . . . 1 km

Life of shower . . . . . .20 min.

Drift during life of shower . . . . . .3 km

Enhancement of rain falling to earth from drifting inner core . . . . . .10 mm

Enhancement of rain falling to earth from drifting outer ring . . . . . 5 mm

Area enhanced by 10 mm = $(\frac{\pi}{4} + 3)$ km^2 = 3.79 km^2

Area enhanced by 5 mm = $(2\pi + 6)$ km^2 = 12.28 km^2

Volume of extra water produced by core rain area = 37.9 10^3 m^3

Volume of extra water produced by outer rain area = 61.4 10^3 m^3

Estimated total volume of extra water produced by shower = 99.3 10^3 m^3

Say = 100 10^3 m^3

Approximately = 80 acre feet

For reference 1 acre foot = 1.23348 10^3 m^3

0.81 acre foot = 1 10^3 m^3

Assessment of Number of Seeding Successes

It is estimated that 1,704 clouds were seeded but it was only possible to make cursory observations of 659 seedings. These 659 were mainly the isolated and minimal clouds likely to have the highest failure rate. Of these 659, 117 were not observed to grow vertically or release rain after seeding, implying a failure rate of 18%. Rain or vertical growth of cloud-top was seen to follow seeding in 542 cases.

The remaining 1,045 unobserved seedings were mainly carried out in moister cloudier conditions, which obscurred observation but in which there

would have been a much lower failure rate. This is nominally set at 10%.

The number of clouds which produced enhanced rainfall is assessed as follows:

Estimated number of clouds seeded	1,704
Number of observed clouds	659
Nil development	117
Number observed to rain below or grow above	542
Number of unobserved clouds	1,045
Presumed 10% failure rate	104
Number presumed to rain after seeding	941
Total number of seeded clouds from which showers fell	1,483

Assessed Cost of Rain-water

The assessed extra water per shower is approximately	100	10^3 m^3
The assessed total volume of extra water from 1,483 showers is	148,000	10^3 m^3
The cost of the operation as described in Appendix I	$46,028	

FIRST ESTIMATE OF COST OF EXTRA RAIN-WATER

APPROXIMATELY 31c per 10^3 m^3

OR 38c per acre foot

In the moister, cloudier conditions which were in the majority, it is probable that the showers would cover a greater area and offer higher yields. In the few cases where it was possible to seed a pattern of cells which developed into a general area of rain and showers, the yield would be very much greater. The estimated cost of the extra water could be expressed as a range between one half and double the figure obtained above. This would allow a fairly wide latitude to cover unknowns, yet still indicate the order of magnitude of the cost. This leads to a

SECOND ESTIMATE OF COST OF EXTRA RAIN-WATER

BETWEEN 16 c and 60c per 10^3 m^3

OR 20c and 75c per acre foot.

Such indications as are possible from a study of the seeding over the Kyle and Bangala catchments give support to the cheaper figure.

There is a further consideration of the value of the contribution of the extra water due to seeding. In the basic case, seeding enhanced the natural fall of 2.5 mm by 10 mm to produce a total of 12.5 mm.

The natural 2.5 mm costs nothing but it is of little value. The extra 10 mm is useful and its cost has just been indicated. The total 12.5 mm is significantly more useful than the enhanced 10 mm and its cost per 10^3 m^3 is cheaper as a result of Nature's subsidy to the artificial seeding. If seeding is done before drought is established, it can give the farmer both the small natural fall plus the net enhancement which equals a useful gross fall.

Comment on Assessment

Finally I wish to put this assessment in perspective. This operation alleviated the rainfall deficiency during the past season and has provided further practical experience for future planning. An assessment of yields and costs has been given now as a guide for the time being, until the continuation of the research programme can provide further data for more critical appraisal and a closer estimate.

9. LESSONS FOR ANOTHER TIME

It is worthwhile recording certain obvious lessons from this operation which should be borne in mind for another time.

1. It is essential that arrangements be made well in advance to ensure availability of aircraft, equipment, supplies and personnel.

2. In particular, a full season's supply of cartridges must be held well before the commencement of the season. Any consignment of either chemicals or manufactured cartridges in mid-season could go astray and cause complete breakdown.

3. Preparations must be made to have a nucleus of meteorological officers available for cloud-seeding.

4. The research programme must be resumed in November 1973 as planned, in order to attain as soon as possible a closer estimation of yeilds to be expected. These better answers will serve as a quantitative basis for whatever cloud-seeding operations are required in the future.

5. In order that the meteorologist engaged on cloud-seeding research can proceed with the evaluation of techniques, an additional meteorological officer is required to take charge of the day to day operation and to cope with the considerable amount of detail involved.

6. To improve the efficiency and economy of the programming of sorties, two additional radiosonde stations are required, one in the northwest such as at Karoi and another in the southeast such as at Fort Victoria or Buffalo Range.

7. For an operation on a national scale, call upon a fifth aircraft and accompanying cloud-seeding officer would be a worthwhile advantage, especially for peripheral areas.

8. The success of this operation at such short notice confirmed two aspects which are well worth repetition:

   i) The effectiveness and economy of having one centrally co-ordinated small nucleus of aircraft, pilots and cloud-seeding officers for the country as a whole.

   ii) The operation married the advantages of enterprise in both the commercial sector and in Government's own organisation. A local air operation RUAC provided prompt, reliable, trouble-free service according to long-term plan and daily requirements. The latent specialised knowledge of scientific and technical officers was used to practical effect. This was a justification of the care taken in recruitment, training and research.

10. ACKNOWLEDGEMENTS

It is my pleasure to thank various Ministries, organisations and individuals for their goodwill and spontaneous assistance, which enabled the scheme to start without delay and continue without breakdown, and thus fulfil the request of the Minister of Agriculture.

Mention has already been made of the Rhodesia Sugar Association who made the start possible by releasing part of their stock of cartridges, and for allowing the national operation to share their chartered aircraft.

The Treasury, Ministries of Agriculture, Foreign Affairs and Defence readily facilitated authorities which ordinarily would have taken a long time.

The technical staff of the Rhodesian Air Force who worked on "Chaminuka" throughout the weekend 5th-7th January, to prepare her for seeding, and who kept the seeding apparatus serviceable, deserve special mention as do the

pilots of No. 3 Squadron who flew the roughest of the sorties.

Pilots of RUAC and the Department of Civil Aviation patiently flew on the assigned sorties including the positioning flights to Matabeleland when seeding opportunities offered there.

Mr. Colman Myers, the Managing Director of RUAC, gave all possible assistance to provide a service which was reliable in every way.

The cartridge manufacturer sympathetically listened to our desperate needs. He diligently set production in motion immediately the factory opened after the Christmas and New Year recess, and went to exceptional lengths to import the necessary chemicals by air freight, and to send batches of cartridges to us as they became available by urgent air freight.

Many meteorological staff worked considerable extra hours either to seed or to release others from their duties at the bench to make up the team of cloud-seeders. Two officers were exclusively devoted to cloud-seeding, Mr. D. L. McNaughton in immediate charge, who also took most of the rough rides in "Chaminuka", and Mr. I. H. Gordon-Comming who did most of the seeding over the Kyle catchment. The other cloud-seeders doubled up with their duties in the Forecast Offices. Mr. M. J. Withers of the Central Forecast Office was the reserve officer in charge of cloud-seeding. Of the members of Salisbury Airport Meteorological Office who did most of the seeding in the eastern half of the country, Mr. A. C. Davidge was the principal cloud-seeder. Messrs. A. H. Quail and S. J. Medcalf carried out most of the seeding over Matabeleland and still maintained the forecast services at Thornhill. The Deputy Director, Mr. J. D. Torrance, exercised estimable supervision. My thanks go to all these colleagues for their devotion to duty and invaluable assistance in this improvised project.

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APPENDIX I

COST OF DROUGHT RELIEF CLOUD-SEEDING OPERATION.

29TH, 30TH DECEMBER 1972 : 5TH JANUARY - 30TH APRIL 1973.

Cartridges			
Old TB2 159 @ $2.00	318		
New TB1 500 @ $6.19	3 095		
New TB2 5 350 @ $4.35	23 273		
Freight and Handling charges	852	27 538	
Chaminuka Chemicals			
Sodium Iodide 2 kg @ $6.33	13		
Silver Iodide 8 kg @ $42	336		
Acetone 200 litres @ $0.43	86	435	
Aircraft Operating Costs			
Cessna 210 VP-YLT 110 hrs @ $65	7 150		
Baron VP-WAX 77 hrs 55 @ $100	7 792		
Cessna 320 VP-WET 100 hrs 02 @ $80	8 003		
Chaminuka 39 hrs 35 @ $80	3 167	26 112	
Other Aircraft Charges			
Crew-hire, Land Fees, S & T	140		
Insurance			
VP-WET Hull and 3rd Party	1 026		
Public Liability	400	1 566	
Total Outlay			55 651
LESS Cartridges on hand			
313 New TB1 @ $6.19	1 937		
3 863 New TB2 @ $4.35	16 804		
12 Old TB2 @ $2.00	24	18 765	18 765
NET COST TO GOVERNMENT			36 886
Cost of Seeding Kyle/Bangala Catchment			
5 January - 15 April 1973 -			
borne by Rhodesia Sugar Association			
Aircraft hire	7 708		
170 Cartridges used @ landed cost	822		
Insurance	612	9 142	9 142
TOTAL COST INCURRED BY OPERATION			$46 028
neglecting salaries			

PROPORTION OF BEARING COSTS

Allocated to Ministry of Agriculture	44 823	
LESS unused cartridges	18 765	26 058
Ministry of Defence		
P.O.L. Chaminuka	3 167	3 167
Ministry of Transport		
Wear and Tear, P.O.L. VP-WET	5 800	
Insurance VP-WET	1 426	
Chemicals for Chaminuka	435	7 661
Rhodesia Sugar Association	9 142	9 142
		$46 028

APPENDIX II

DISTRIBUTION LIST OF DAILY CLOUD-SEEDING REPORTS

The Secretary for Transport and Power

The Secretary for Agriculture

Director of Conservation and Extension

Provincial Conservation Officers,
Mashonaland North,
Mashonaland South,
Matabeleland,
Manicaland,
Midlands,
Victoria.

President, R.N.F.U., and staff

President, Matabeleland Branch of R.N.F.U.

Chairman, Natural Resources Board

Chief Hydrological Engineer, Ministry of Water Development

Treasury

Chief of Air Staff

Rhodesia Sugar Association

Director of Civil Aviation

Ministry of Information

Internal.

APPENDIX III

LIST OF CLOUD SEEDINGS

TEST FLIGHTS 29TH, 30TH DECEMBER 1972

OPERATION 5TH-31ST JANUARY 1973

DATE	N.W. MASHONA-LAND	N.E. MASHONA-LAND	S.E. MASH./ MANICALAND	MIDLANDS	MATABELE-LAND	VICTORIA S.E. LOWVELD
29/12	26					
30/12	33					
5/1	35	24				
6/1	23			5		3
7/1	21	3	19	3		6
8/1	25	17	19	9		8
9/1			2			12
10/1	9		8	7		
11/1	19	9	2	22		3
12/1		6	20	9		2
13/1	9		1			
14/1						
15/1	28	8		7		2
16/1						
17/1						
18/1						
19/1						
20/1						
21/1						
22/1	5		4			
23/1		14				
24/1	7			19	10	
25/1	22		2	1	4	5
26/1			14	1	24	7
27/1	19			12	8	3
28/1	44	18	11	4		
29/1	18		5	6	32	5
30/1	4	17	10	12	11	12
31/1	2	22	22			

APPENDIX III CONTINUED

LIST OF CLOUD SEEDINGS

1ST-28TH FEBRUARY 1973

DATE	N.W. MASHONA-LAND	N.E. MASHONA-LAND	S.E. MASH./ MANICALAND	MIDLANDS	MATABELE-LAND	VICTORIA S.E. LOWVELD
1/2	9					
2/2						
3/2						
4/2						
5/2						
6/2				15		11
7/2				4	20	
8/2					27	
9/2						
10/2	7	8		6	10	
11/2	5	4		3	8	13
12/2	4	6				12
13/2	16					11
14/2			11	12	10	3
15/2	3		1	13	12	14
16/2	2	2	9		27	11
17/2	5		1	13		
18/2	9					
19/2	4					23
20/2	17	5				
21/2		3				
22/2	3					
23/2	6	4	25	23		
24/2	13		6	15	3	16
25/2	2	3		2		1
26/2	14					
27/2						
28/2						

APPENDIX III CONTINUED

LIST OF CLOUD SEEDINGS

1ST MARCH-30TH APRIL 1973

DATE	N.W. MASHONA-LAND	N.E. MASHONA-LAND	S.E. MASH./ MANICALAND	MIDLANDS	MATABELE-LAND	VICTORIA S.E. LOWVELD
1/3						
2/3						
3/3				11	9	
4/3			2	21	18	1
5/3		12				
6/3						
7/3	12	6				
8/3						
9/3						
10/3	1	2			20	
11/3						
12/3						
13/3						
14/3						
15/3						
16/3						
17/3						
18/3						
19/3	1		10			1
20/3	9	5				9
21/3	6		14	12		
22/3			17	13		
23/3 - 7/4 - Conditions were too dry for seeding						
8/4	16	15	16			
9/4 - 30/4 - Conditions were too dry for seeding						
TOTALS 513		213	251	280	253	194

GRAND TOTAL - 1 704

REPORT ON CLOUD-SEEDING OPERATION - KYLE AND BANGALA CATCHMENT AREAS, NOVEMBER 1972 - APRIL 1973

J. E. Stevens

Department of Meteorological Services
Belvedere, Rhodesia

This report follows monthly submissions during the season. It should be read in conjunction with the Report on the National Drought Relief Cloud-Seeding Operation. The Kyle seeding operation was scheduled from 15 November 1972 until 15 April 1973. It became merged with the National Operation from 5 January on the understanding that the RUAC Cessna 210 gave first priority to the Kyle and Bangala catchment areas, whenever seeding conditions there were expected to be favorable. Without the willingness of the Rhodesia Sugar Association to share their aircraft and stock of cartridges on hand, an immediate start of the National Operation would not have been possible. It was my pleasure to record thanks to the Rhodesia Sugar Association for this cooperation in the Report on the National Operation.

Rainfall over the catchments was very poor. Apart from the northeast of the country, the general serious deficiency of rainfall affected your area. In 1972/73 the mean rainfall over the Kyle catchment was approximately 280 mm, compared with an average of 620 mm. By coincidence the Bangala catchment also had a mean of approximately 280 mm, compared with an average of 747 mm. To start run-off into Lake Kyle, the rainfall would have had to be increased by some 40%, which is beyond the scope of cloud-seeding over an area throughout a whole season. Any increase in run-off due to seeding was therefore confined to Lake Kyle and its immediate environs. This increase is estimated to be of the order of 650 $10^3 m^3$.

First, however, the augmentation of the very meager rainfall by cloud-seeding during last season should be considered. As was explained in last year's report an operation does not permit the close evaluation made from careful comparative measurements in a controlled experiment. Amounts quoted are therefore broad estimates.

Figure 1 of the main report shows the approximate positions of clouds seeded from the 29th of December until the 30th of April. During the whole 1972/73 season, including the poor months of November and December, 192 clouds were treated over the Kyle and Bangala catchment areas and the Estates.

Of these clouds, the results of 96 were observed, mainly on fairly clear days when the air was not moist enough to offer many clouds, and when conditions were only just suitable for seeding. Of the 96 clouds observed, 73 appeared to respond while 23 did not rain after seeding.

This failure rate is typical of marginal rather than average conditions, when poor clouds were seeded because there was nothing more to lose, other than the price of one cartridge per attempt. The remaining 96 seedings were unobserved, but being in more favorable cloudier conditions would be expected to give a 90% success rate, which is approximately 86. The total number of successful seedings is therefore set at 159.

For the 1972/73 season, the rainfall over the catchment area, i.e., the target (T), has been compared with rainfall over the surrounding control area (C). There was a relatively large amount of seeding over the target area because of its prior claim to treatment by the seeding aircraft. Also, in contrast to 1971/72, there was relatively more seeding opportunity over the catchments compared with over the neighboring area.

However, there was in 1972/73 a small amount of seeding done in the surrounding ring area, whereas in 1971/72 there was none. This seeding in the control area would tend to reduce the T/C ratio, and so give a conservative result and not an optimistic one.

Ratios of target/control rainfall have been worked out for all seasons from 1952/53 until 1970/71. 1952-53 was the first season in which the higher density raingauge network was installed and 1970/71 was the last of the seasons with purely natural rainfall before seeding operations commenced. The ratios have been arranged in descending order of magnitude in Table A, utilizing stations which sent in complete rainfall returns during 1972/73. Because weather conditions virtually prohibited seeding over the Kyle and Bangala catchments during November 1972 and April 1973, Table A has been constructed using December to March rainfalls only. 1972/73 ranks second out of 20 in the listing. This is a 9 to 1 indication that the seeding increased the rainfall. This probability is not high enough to justify a separate assessment of additional rainfall over the catchment areas beyond that given in the report on the rational operation. The conservative assessment of yield is therefore 159 showers at 100 $10^3 m^3$= 15, 900 $10^3 m^3$.

Since seeding tended to be more intense over the Lake Kyle area than elsewhere in the target, another ranking exercise was done, using only rainfall stations within 7 km of Lake Kyle for the target, and those stations in that part of the control ring area lying to the east and west of Lake Kyle. The result is shown in Table B, in which 1972/73 comes at the top of the list. This implies a 19 to 1 chance that at least part of the higher rainfall there was due to seeding.

If the natural ratio between the target and control rainfalls for 1972/73 fell in 10th position out of 20, this would imply a percentage increase of 17.4%. Experience indicates that just as seeding suitability over the Kyle catchment often seemed unlucky last year, it was relatively less unlucky in 1972/73. This improvement would have placed the natural position of the 1972/73 season higher in the ranking order, perhaps 5th or 4th, rather than 10th. If this were so, then the increase due to the seeding would be more likely to lie between 5% and 10%, say 7½%.

The Lake area in 1973 was taken as 36 km^2. Its rainfall from December to March was approximately 258 mm. This is the basis for assessing that seeding would have produced an extra 18 mm of rain or approximately 650 $10^3 m^3$ of water directly upon the Lake.

TABLE A

RATIOS OF TARGET/CONTROL RAINFALL RATIOS, WHERE THE TARGET CONSISTS OF ALL KYLE-BANGALA CATCHMENT STATIONS WITH COMPLETE 1972/73 RETURNS

SEASON	RATIO T/C, DEC. TO MAR.	
1970/71	1,153	
1972/73	1,131	Seeded year, 2nd position
1954/55	1,101	
1956/57	1,099	
1964/65	1,095	
1957/58	1,082	
1960/61	1,082	
1953/54	1,077	
1962/63	1,072	
1965/66	1,059	
1966/67	1,058	Median ratio, 1952-1971
1969/70	1,045	
1963/64	1,029	
1961/62	1,023	
1952/53	1,019	
1967/68	1,004	
1955/56	1,003	
1959/60	992	
1958/59	981	
1968/69	966	

TABLE B

RATIOS OF TARGET/CONTROL RAINFALL RATIOS, WHERE THE TARGET CONSISTS OF STATIONS VERY CLOSE TO LAKE KYLE

SEASON	RATIO T/C, DEC. TO MAR.	
1972/73	1,307	Seeded year, 1st position
1953/54	1,256	
1954/55	1,239	
1970/71	1,225	
1969/70	1,205	
1958/59	1,183	
1957/58	1,172	
1959/60	1,159	
1960/61	1,130	
1962/63	1,120	
1968/69	1,113	Median ratio, 1952-1971
1967/68	1,090	
1965/66	1,083	
1952/53	1,081	
1956/57	1,075	
1966/67	1,060	
1964/65	1,038	
1961/62	992	
1955/56	988	
1963/64	815	

POTENTIAL VALUE OF SATELLITE CLOUD PICTURES IN WEATHER MODIFICATION PROJECTS

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South Dakota School of Mines and Technology
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ABSTRACT

Satellite imagery for one summer of cloud seeding in the northern Great Plains has been surveyed for its usefulness in weather modification programs. A few illustrative examples of simple satellite imagery analysis are cited and discussed, along with local weather observations and the seeding decisions made. The analysis indicates a definite correlation between satellite observed cloud patterns and the type of cloud seeding activity undertaken and suggests a high probability of better and/or earlier decision making for weather modification projects if the satellite data were used in real time.

1. INTRODUCTION

The value of any source of information to a meteorologist depends upon many factors, including his training, the timeliness of the data presented, and other sources of data simultaneously available to him. A good method of evaluating the worth of satellite cloud pictures in weather modification projects would be to make the pictures available to meteorologists conducting such projects and let them work out by trial and error the weight which they should assign to the cloud pictures in relation to their other sources of information. If they seized upon satellite pictures in the manner in which meteorologists late in World War II seized upon weather radar, we could be certain of the value of satellite cloud pictures in weather modification projects.

So far the weather modification projects of the Institute of Atmospheric Sciences have not had weather satellite data available in real time, apart from APT pictures read out on a facsimile machine. The facsimile pictures are of lower quality than the present state-of-the-art products and therefore do not provide a fair test of the potential value of satellite cloud pictures.

An alternative approach has been followed here. The author has examined cloud pictures obtained by the ATS-III and NOAA-1 satellites covering

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two experimental cloud seeding projects in the western Dakotas. These projects were particularly valuable for the present study in that one of them had the dual objectives of increasing rainfall and suppressing hail, and different seeding procedures were used for the two objectives. Hail threats were determined by the project meteorologist on the basis of actual hail reports and of radar observations of storm heights and maximum reflectivity factors. In the present study, conditions in the area as determined from the satellite images have been compared with other weather data and with the operational logs for the seeding projects to see if the satellite pictures would have been useful in the making of decisions regarding seeding treatments.

2. DESCRIPTION OF THE STUDY

a. Description of seeding projects

A number of cloud seeding projects were operated in the Dakotas during the summer of 1971, including two research projects, the North Dakota Pilot Project and Project "Cloud Catcher."

The North Dakota Pilot Project was primarily concerned with the effects of silver iodide seeding on rainfall and hailfall from convective clouds, although seeding of stratiform clouds was included in the project design. The target area for the project was McKenzie County, an area of roughly 2700 square miles, with a field office located near Watford City (Fig. 1). The project was conducted on a seven-day week basis from May 1 through August 15, 1971 (Schock, 1971), seeding operations being performed mainly during daylight hours. The operational period was broken into a series of time blocks consisting of eight consecutive 24-hour periods. Out of each eight-day block, a two-day block was chosen by chance in advance of the project for control purposes and left unseeded. The operational day started at 1000 CDT and lasted 12 hours. An M-33 10-cm acquisition radar, slightly modified to increase its effective range, was used for storm detection, for monitoring storm development and motion, and as an aid in directing seeding aircraft.

The only research project in South Dakota in 1971 was Project Cloud Catcher, which was operated five days a week from June 7 to August 12. It differed from the North Dakota project principally in that it involved floating target areas and seeding effects were evaluated with the aid of data collected by radar and instrumented aircraft. The main objective was to increase the ability to detect seeding effects in convective clouds. Two alternative ways to modify convective clouds were used: First, the stimulation of cloud growth by silver iodide seeding to release latent heat and second, the release of collodial instability through seeding with finely ground sodium chloride. In the summer of 1971 a further specific objective was the introduction of numerical cloud modeling (Dennis, 1971), into the decision framework of the project. The models were used to estimate the effects of salt seeding upon precipitation from vigorous convective clouds and to determine if small convective showers could be intensified through dynamic effects of silver iodide seeding.

b. Information available and procedures for forecast and decision making

Meteorological information available to the meteorologists of the two research projects was more or less the same as that at a Class A weather station of the National Weather Service. This included facsimile and teletype information of surface and upper air observations and charts, prognostic charts, severe weather forecasts, etc.

The North Dakota Pilot Project meteorologist stood by for seeding operations if he expected precipitation development within the next few hours. Seeding to increase rainfall was initiated on the sign (visual or radar) of developing towering cumulus and/or rain showers. Decisions for hail suppression were primarily based on radar observations, hail suppression starting when the maximum echo height exceeded 40,000 ft MSL, or when the maximum radar reflectivity factor was 55 dBz or greater. If no development was expected within the next 12 hours, no operation was conducted on that day.

In the Cloud Catcher Project around Rapid City, additional information available included radiosonde data from Circuit "C" teletype and the output of a computer cloud model based on the morning sounding and indicating the suitability of the day for seeding and the type of seeding preferred. This output included the maximum expected updraft speed for unseeded clouds and the increase in cloud height that would result from silver iodide seeding (Dennis, 1971). Occasionally APT satellite pictures were also available.

c. Procedure followed in this study

The primary purpose of the present study was to determine whether the availability of imagery from weather satellites in real time might have helped the project meteorologist to do a better job. As such imagery was not available to us in real time, after-the-fact examination has been made to infer its probable value in the real-time situation.

The imagery was provided from two sources. One source was NASA Application Technology Satellite ATS-III, positioned roughly 80°W during mid-June to August 1971, which had the northern Great Plains well within view and provided the desired morning coverage. The other source was the polar-orbiting NOAA-1 spacecraft. It provided IR imagery for our desired area near about 0300 hours local time and vidicon pictures for the afternoon at about 1500 hours.

Enlarged views of the area around the State of South Dakota, both for ATS-III and NOAA-1 imagery, were most helpful in identifying cloud type and cover over the desired area. The prints were properly gridded with latitude and longitude lines and state boundaries. When state boundaries were not properly shown, a prepared transparency showing state boundaries was superimposed over the prints for identification of location.

In identifying the cloud type and pattern, general guidance has been

taken from the relevant literature (e.g., Widger et al., 1965; Anderson et al., 1969; Anderson and Smith, 1971; and Ashman et al., 1971). Analysis and interpretation of the satellite cloud pictures have been mainly subjective. The characteristics such as brightness, pattern, structure, texture, shape and size have been used to detect the presence of cloud layers and to identify the type of cloud wherever possible, and make some inferences about temperature, wind, and stability fields of the atmosphere. In large scale features the vorticity, troughs, ridges, fronts, etc., have also been identified when related to the local cloud pattern over the area of interest. With the few IR images obtained a similar procedure has been followed except that the higher clouds were identified mostly by their relative brightness. It is possible to use the same procedure with proper calibration of the shades to obtain specific cloud top heights.

Most individual clouds could not be seen in the pictures because of their small scale and so were not identified. The resolution of the cameras also does not permit detection of many small scale features and it is from the gross features that the natures of the clouds are identified.

3. ILLUSTRATIVE EXAMPLES

The cloud descriptions along with the satellite pictures for a few days are cited here to illustrate the possible use of the satellite imagery as an aid to weather modification programs. The examples selected refer particularly to the North Dakota Pilot Project. We have chosen a few days that represent, for this area, days of little cloud activity, and days when cloud seeding for rain increase and hail suppression were carried out. Weather observations and forecasts were obtained from operational and weather logs of project meteorologists of the areas.

June 8, 1971: According to the random selection, this was a seed day for the North Dakota Pilot Project, but seeding was not carried out for lack of suitable clouds. Observations indicated mostly layer type stratiform clouds over the area. The forecast for the Rapid City area was for partly cloudy weather with a few showers on the Black Hills, and observations indicated rain showers late in the afternoon in some portions of the area.

Satellite images for three different times were available for this day. The prepared transparency showing state boundaries was used over an enlarged view to identify locations.

The early morning IR picture (0402 MDT, Fig. 2a) indicates high cloud tops over a large area in the extreme eastern part of South Dakota extending over to the neighboring eastern states. This suggests a severe storm in that area. To the south and west are clouds of lower heights. Central and southwest Nebraska also have high cloud cover associated with convective activity. There seems to be thin cirrus or perhaps low cloud cover all over North Dakota, part of South Dakota, and Nebraska. The late morning ATS-III video picture (1153 MDT, Fig. 2b)* indicates a quite active frontal

*The three-state area (North Dakota, South Dakota, Nebraska) outlined on the ATS photographs is emphasized in Fig. 1.

cloud pattern (the same pattern was seen on the previous day) extending over a major part of North Dakota and South Dakota with severe activity in eastern Nebraska. Comparatively little activity appears around the Black Hills area but there is probably some cumulus development north of it. The afternoon NOAA-1 vidicon picture (1459 MDT, Fig. 2c) indicates weakening of frontal activity around North and South Dakota with probably some clouds dissipating. The whole cloud pattern over North and South Dakota is a part of the large cloud system showing the vortex form in the northwest. A few severe local storms are visible in southwest Nebraska.

As can be seen (Fig. 2a, 2b, 2c), except for early morning convective activity over eastern South Dakota, both North and South Dakota were covered with frontal clouds that had very little convective activity. The western part of North Dakota in particular was not suitable for any seeding operations over a large area and, in fact, none were conducted. The eastern part of South Dakota was more suitable for operations for rain increase, and a number of places in southwestern Nebraska might have required hail suppression activity.

In Project Cloud Catcher, the erroneous decision to stand by for the day perhaps could have been avoided from the satellite observation of little activity over the Black Hills and the weakening tendency around the area.

June 12, 1971: This was another seed day for the North Dakota Pilot Project in which seeding was not carried out for lack of enough cloudiness over the area. Most of the day was clear in McKenzie County with some scattered cumulus in the afternoon. It was a non-operational day in the Rapid City area.

The early morning IR image (0349 MDT, Fig. 3a) indicates that most of the southeastern part of South Dakota was covered with high clouds, with the most severe activity around the south central part of the state. The activity extended slightly into Nebraska and also to the east. Central North Dakota also had some high cloud cover probably associated with storm activity.

The late morning picture from ATS-III (1150 MDT, Fig. 3b) indicates that the severe activity has moved slightly southeast. Major cloud cover is now over the southern part of South Dakota extending into Nebraska, with more severe activity over eastern Nebraska and south of it. Less dense and scattered clouds cover the rest of North and South Dakota with slightly more dense clouds over northeastern North Dakota. There is not much cloudiness around the Black Hills. By afternoon the NOAA-1 picture (1445 MDT, Fig. 3c) shows a severe local storm (hail likely) over the southern Black Hills area. Other large storm areas are over central and eastern Nebraska; the latter has extended into the extreme southeastern corner of South Dakota. North Dakota has cumulus activity in the northwest with a large cell on the northern border, and there is scattered cloudiness all over North and South Dakota.

Although the McKenzie County area did not have suitable clouds for seeding operations, the region north of it seems, from the satellite pictures,

quite suitable for rain increase operations during the afternoon. Cloud developments and movement over South Dakota (as observed from satellite pictures) indicate that, barring the northwestern corner, the remaining portion of the state might have been suitable for rain increase operations during early hours. No enlarged view of the morning ATS-III photograph for the area was available to judge better the convective nature of the cloud cover. In the afternoon a localized hail suppression activity could have been conducted in the southern Black Hills area. The eastern storm zone of Nebraska could have been treated in the early hours. By afternoon extensive cirrus cover had developed over the region, while the storm zone in central Nebraska seems to be in proper stage for hail suppression activity at this time.

June 18, 1971: This was a no-seed day in the North Dakota Pilot Project. There were a few light showers in the morning over McKenzie County, mostly from stratiform type clouds. In the afternoon hail was predicted when the radar echo-top began to reach 45,000 ft in height, and a hail shower occurred over the area about 1630. For the area around Rapid City, the forecast was for numerous heavy thunderstorms in the afternoon and early evening with a few severe thunderstorms with hail and possible tornado activity. Observations indicated heavy thunderstorms that moved through the northern part of the area in late afternoon. Severe weather also occurred in the southwestern part of North Dakota.

No early morning IR image is available for this day. The late morning ATS-III picture (1159 MDT, Fig. 4a) shows one severe storm area (probably with hail) over northeastern Nebraska; its cirrus cover extends northeast. North and northwest North Dakota have cloud cover that seems more scattered and is probably composed mostly of layer-type clouds (enlarged view not available). Some cloudiness also appears over the western sides of South Dakota and Nebraska. The afternoon NOAA-1 picture (1425 MDT, Fig. 4b) indicates that the severe storm seen earlier in Nebraska has weakened and moved south with its cirrus top extending into Iowa. Severe storms have developed in the southwestern part of North Dakota and extend into extreme northwestern South Dakota. There are two distinct storm zones here with a clear area in between; both are in the developing stages and indicate possible hailstorms or tornados. This storm development was not seen in the morning ATS-III picture. Convective cloud developments are also seen over most of western North Dakota in the region north of the severe storm area.

This was a most suitable day for hail suppression activity over western North Dakota and northwestern South Dakota. The early detection of large storms can facilitate proper operation of the hail suppression activity. It is unlikely for radar (that detects precipitation cells only) to observe the full extent of the severe activity region. Furthermore, early detection by radar in this case would not have been possible from Watford City, which was too far away from the severe storm region. The convective activity in northwestern North Dakota as detected by afternoon satellite imagery also seems suitable for conducting seeding operations for rain increase.

June 20, 1971: For the North Dakota Pilot Project this was a seed day and seeding was carried out for rain increase. McKenzie County had

mostly convective clouds. There was a shower at about 2000 hours, and the maximum radar echo height observed was 24,000 feet. It was a non-operational day in the Rapid City area.

There was no early morning IR photograph available. The late morning ATS-III picture (1204 MDT, Fig. 5a) shows cloud cover (with convective activity) over a large region east of the Black Hills that extends both to North Dakota and Nebraska. Apparently the Black Hills area is clear; no enlarged view is available. Part of northeastern North Dakota seems covered with thin middle or high clouds. By the afternoon NOAA-1 picture (1418 MDT, Fig. 5b), the convective activity seen earlier has moved southeast with cloud cover extending across Nebraska. There are signs of heavy cumulus activity around the Black Hills and to the north and east, but the most intense activity is to the southeast of the Hills extending into Nebraska. Some large cumulus are also seen over northwestern North Dakota; otherwise most of North Dakota and part of South Dakota are covered with clouds of small convective activity.

Even the main cloud cover area (over South Dakota-Nebraska) does not show very severe activity except for a few large cells over southeastern Nebraska. Although generally a suitable day for seeding throughout North Dakota, the small scale of convective development suggests that rainfall amounts would be light. A more promising situation exists over the area north and east of the Black Hills. However, the most suitable situation for rain increase operations is in southern South Dakota and Nebraska, and it is quite probable that southeastern Nebraska clouds are also suitable for hail suppression activity.

July 10, 1971: This was a seed day for the North Dakota Pilot Project. Seeding was carried out around noon for rain increase and later for hail suppression. McKenzie County had mostly convective clouds with associated stratocumulus, altocumulus, and cirrus. Thunder was heard over the area and the maximum echo height observed by radar was 45,000 feet. It was a non-operational day in the Rapid City area.

No early morning IR photograph was available for this day. The late morning ATS-III photograph (1155 MDT, Fig. 6a) indicates cloud cover over the eastern part of North and South Dakota that is part of a large system lying over the states to the east. Some cloudiness appears in the Black Hills area. The rest of the three states is clear but another cloud system is approaching North Dakota from the northwest with severe activity just north of North Dakota. Two bright, isolated clouds in eastern Montana near the southwest corner of North Dakota could be considered threatening due to the presence of a sharp weather front lying northwest-southeast in that area.

Afternoon NOAA-1 pictures (1440 MDT, Fig. 6b) indicate a severe storm in northwest North Dakota near McKenzie County that has already developed extensive cirrus cover. There is another severe storm developing just west of McKenzie County in Montana. Both of them seem to be hailers and are part of the large frontal system in the north. The eastern parts of North and South Dakota have cumulus, with more towering clouds in North Dakota than in South Dakota. The remainder of the three states, including

the Black Hills area, is essentially clear.

It appears to be a most suitable day for hail suppression activity over the northwest region of North Dakota. At the time of Fig. 6b, the storm in the north is in the mature stage, so it would be appropriate to give more emphasis to the storm in the west that is developing and approaching McKenzie County. It would be appropriate also to seed for rain increase in the eastern part of North Dakota.

July 27, 1971: This was also a seed day in the North Dakota Pilot Project and seeding was carried out for rain increases. Observations in McKenzie County indicated convective clouds over the region and there were nice showers through the eastern part. In the Rapid City area it was cloudy with a few sprinkles; the decision was for no seeding operation in the absence of any indication of a possibility of low level convective clouds.

There was no early morning IR photograph available. Observations with late morning ATS-III photographs (1211 MDT, Fig. 7a) indicate overcast skies over most of the three-state region. Clouds are more dense over the Black Hills area and northeastern South Dakota. Cloud cover is light and spotty over the major part of Nebraska. Convective development is embedded in clouds over most of the region and particularly over North Dakota. The semicircular cloud pattern is part of a large system that has its vortex center in the north. By 1400 MDT the NOAA-1 afternoon photograph (Fig. 7b) shows that the main pattern has moved east and a decrease of cloud cover is apparent over the three states. The wide semicircular band of cloud cover still runs along the southern part of South Dakota extending from southeast to northwest through the Black Hills area and seems composed mainly of stratiform clouds. North Dakota is covered with cumulus and stratocumulus clouds, of which a few in the north may be towering, and probably a few cumulonimbus cells in the extreme east. A few stormy clouds can also be seen in eastern Nebraska but the main severe activity is further east.

Most of South Dakota had clouds of stratiform type with little or no instability and seems unsuitable for any seeding operation, but a major part of North Dakota with clouds of more convective nature had a better chance for rain increase with seeding. None of the clouds of the three states were suitable for hail suppression activity.

4. DISCUSSION AND CONCLUSIONS

The results of this preliminary survey are summarized in Table 1. It is concluded that weather satellites can now provide timely views of cloud conditions that furnish additional intelligence for weather modification programs extending over appreciable areas, even where conventional observations are dense.

When available in real time, satellite imagery alone could lead to proper decisions for many weather modification projects. Incorporated with the other meteorological information normally available it would make decision making easier.

Table 1.

Possible Input of Satellite Data to North Dakota Pilot Project (NDPP) Decisions for the Six Days Studied

Date (1971)	NDPP Weather	Possible Input from Satellite Date
8 June	Stratiform clouds	Stand down at 1500 due to lack of convective buildups from stratiform deck.
12 June	Scattered cumulus	Stand down at 1150 as all important convective activity was already to the east and southeast.
18 June	Hail around 1630	Nothing at 1159. Hail alert at 1425 due to severe convective storms in SW corner of North Dakota and to SW of Black Hills.
20 June	Rain showers	Pictures at 1204 and at 1418 indicate moderate convective activity with no hail threat to project areas.
10 July	Hail threat; severe hail to SW and south in the evening as storms moved from NW to SE.	Hail alert at 1155 due to two sharp, isolated clouds in eastern Montana. Picture at 1440 confirms severe convective storms in NE Montana. (Note: Hail threat was actually identified by radar between 1600 and 1700.)
27 July	Rain showers	Limited value. Picture at 1400 suggests shower activity will be mainly to the east.

Satellite data would be of greatest value in area seeding projects requiring surveillance of mesoscale and synoptic scale cloud systems. Individual clouds are not seen in the pictures because of their small scale and cannot be identified in the same way as they can be from the ground. This seems likely to limit the usefulness of the satellite imagery in single-cloud or cloud-cluster seeding experiments such as Cloud Catcher.

The satellite data appear to have special value in work with severe local storms, e.g., in hail suppression. Severe local storms are characteristically separated from other cloud cover and, although each severe storm is observed as a large unit with little internal detail, their convective nature is easily identified. Estimates of cloud heights are better using IR pictures. When simultaneous daytime video and IR photographs are

available, it will be easier to judge the stages of the convective developments.

The potential value of satellites has further increased with the advent of geo-synchronous satellites that can provide imagery at regular short intervals, which adds the capability of observing motions and developments in cloud patterns. Such information could be of considerable additional value when it become available to weather modification programs in real time.

ACKNOWLEDGMENTS

The North Dakota and Cloud Catcher projects were supported principally by the Atmospheric Water Resources Management Division of the Bureau of Reclamation, U.S. Department of the Interior, but the North Dakota Pilot Project was supported in part by the McKenzie County Weather Modification Authority.

The present research was supported by the National Aeronautics and Space Administration, Washington, D.C., Office of University Affairs, under Grant NGL 42-001-004.

The author expresses his gratitude to Dr. R. A. Schleusener, Director of the Institute of Atmospheric Sciences, and to Dr. A. S. Dennis, under whose direction the present work was performed. The comments and suggestions of Dr. P. L. Smith, Jr., and Dr. P. V. Hobbs are gratefully acknowledged.

The author expresses his thanks to Dr. Clifford A. Spohn and Mr. Leslie A. Watson, Jr., of the National Environmental Satellite Service for supplying copies of satellite photographs and to Mr. William Roos for making photocopies of the illustrations.

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FIGURE LEGEND

Figure 1: Map showing location of cloud seeding projects.

Figure 2a: June 8, 1971, 0402 MDT: NOAA-1 IR image.

Figure 2b: June 8, 1971, 1153 MDT: ATS-III picture

Figure 2c: June 8, 1971, 1459 MDT: NOAA-1 video picture.

Figure 3a: June 12, 1971, 0349 MDT: NOAA-1 IR image

Figure 3b: June 12, 1971, 1150 MDT: ATS-III picture; (no enlarged view was available.)

Figure 3c: June 12, 1971, 1445 MDT: NOAA-1 video picture.

Figure 4a: June 18, 1971, 1159 MDT: ATS-III picture; (no enlarged view was available.)

Figure 4b: June 18, 1971, 1425 MDT: NOAA-1 video picture.

Figure 5a: June 20, 1971, 1204 MDT: ATS-III picture; (no enlarged view was available.)

Figure 5b: June 20, 1971, 1418 MDT: NOAA-1 video picture.

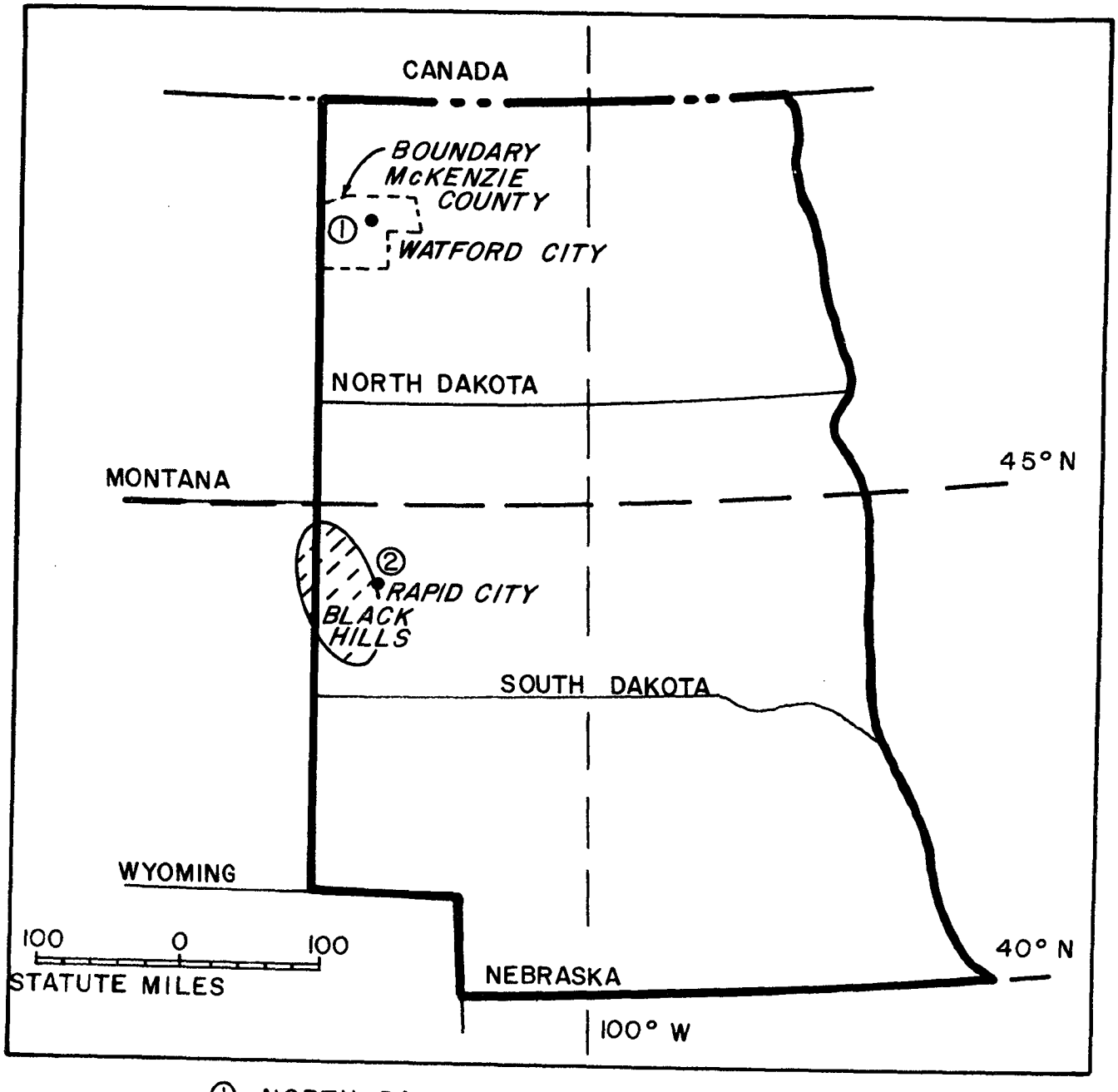
Figure 6a: July 10, 1971, 1155 MDT: ATS-III picture.

Figure 6b: July 10, 1971, 1440 MDT: NOAA-1 video picture.

Figure 7a: July 27, 1971, 1211 MDT: ATS-III picture.

Figure 7b: July 27, 1971, 1400 MDT: NOAA-1 video picture.

FIGURE 1



① NORTH DAKOTA PILOT PROJECT

② PROJECT CLOUD CATCHER

FIGURE 2a

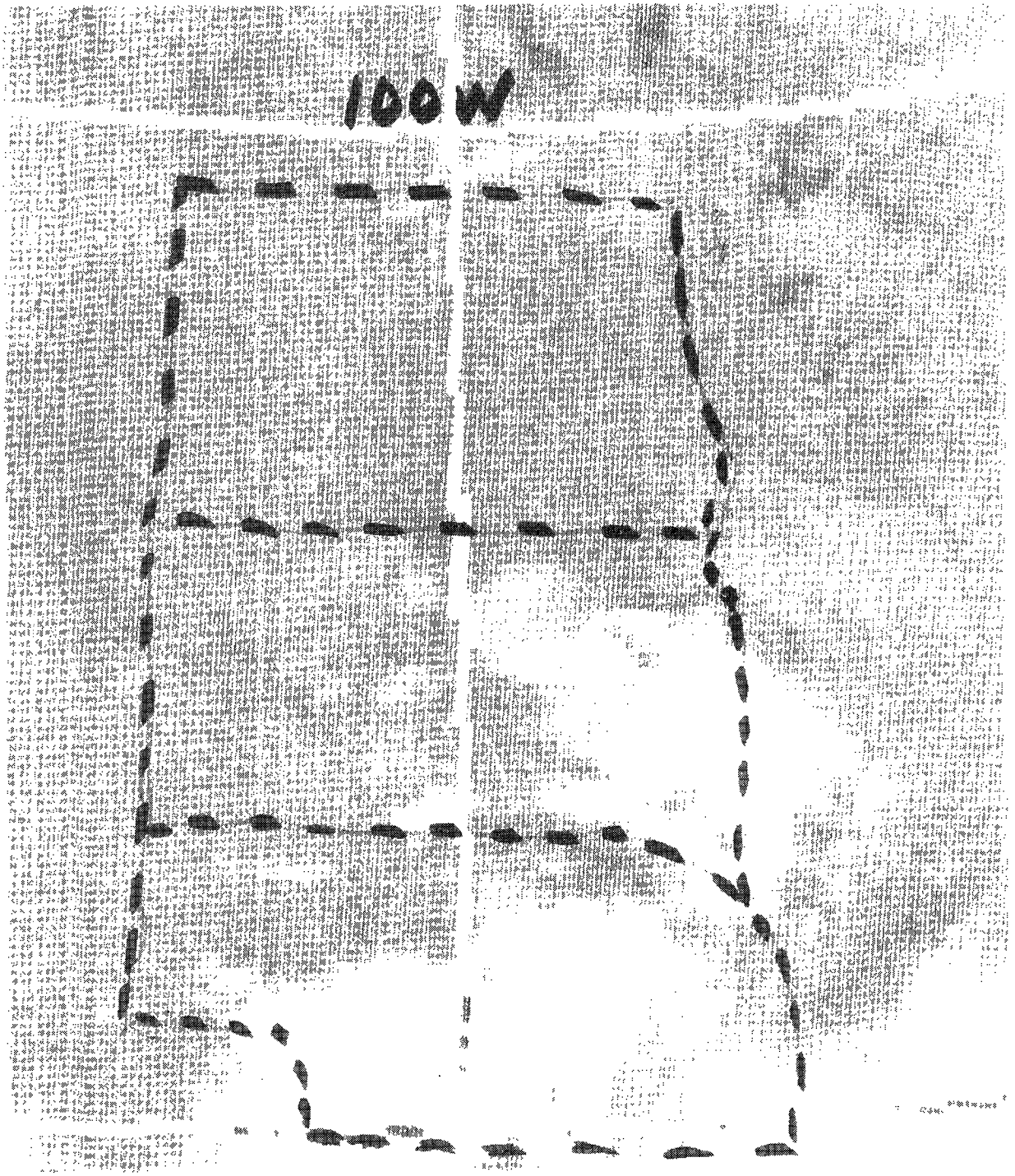


FIGURE 2b

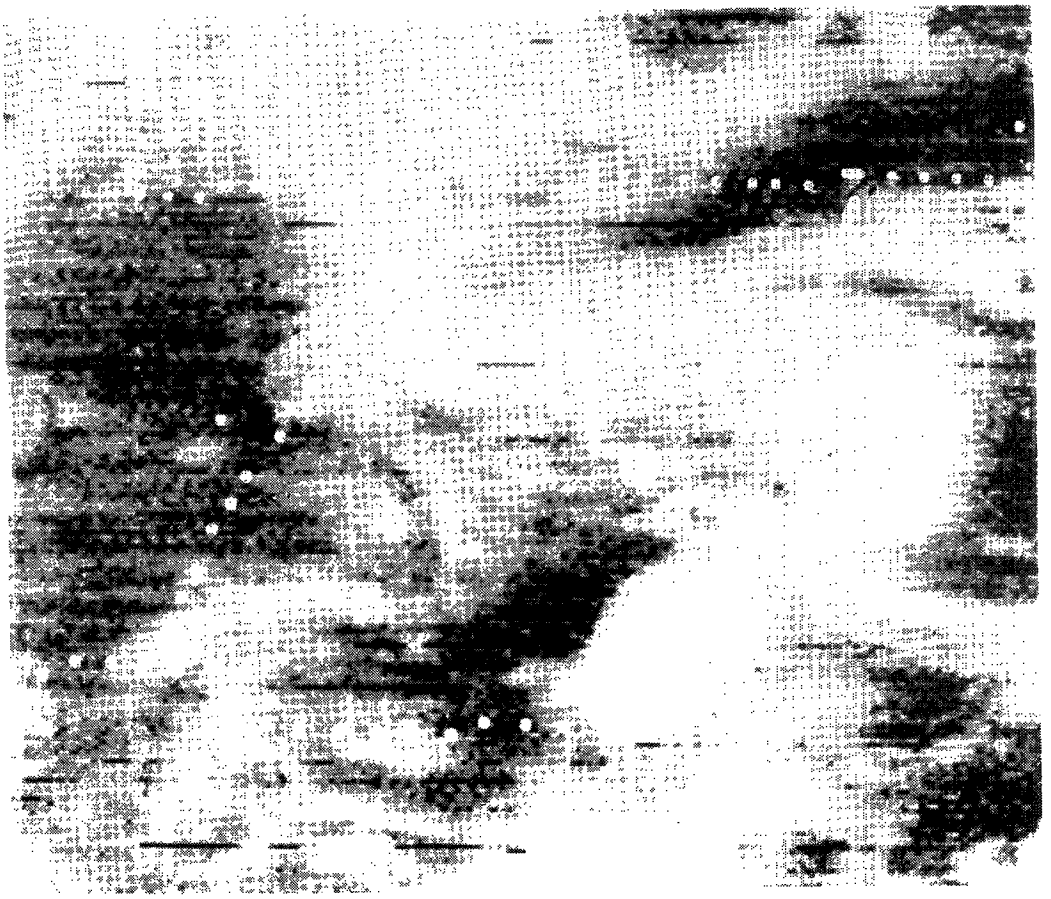


FIGURE 2c

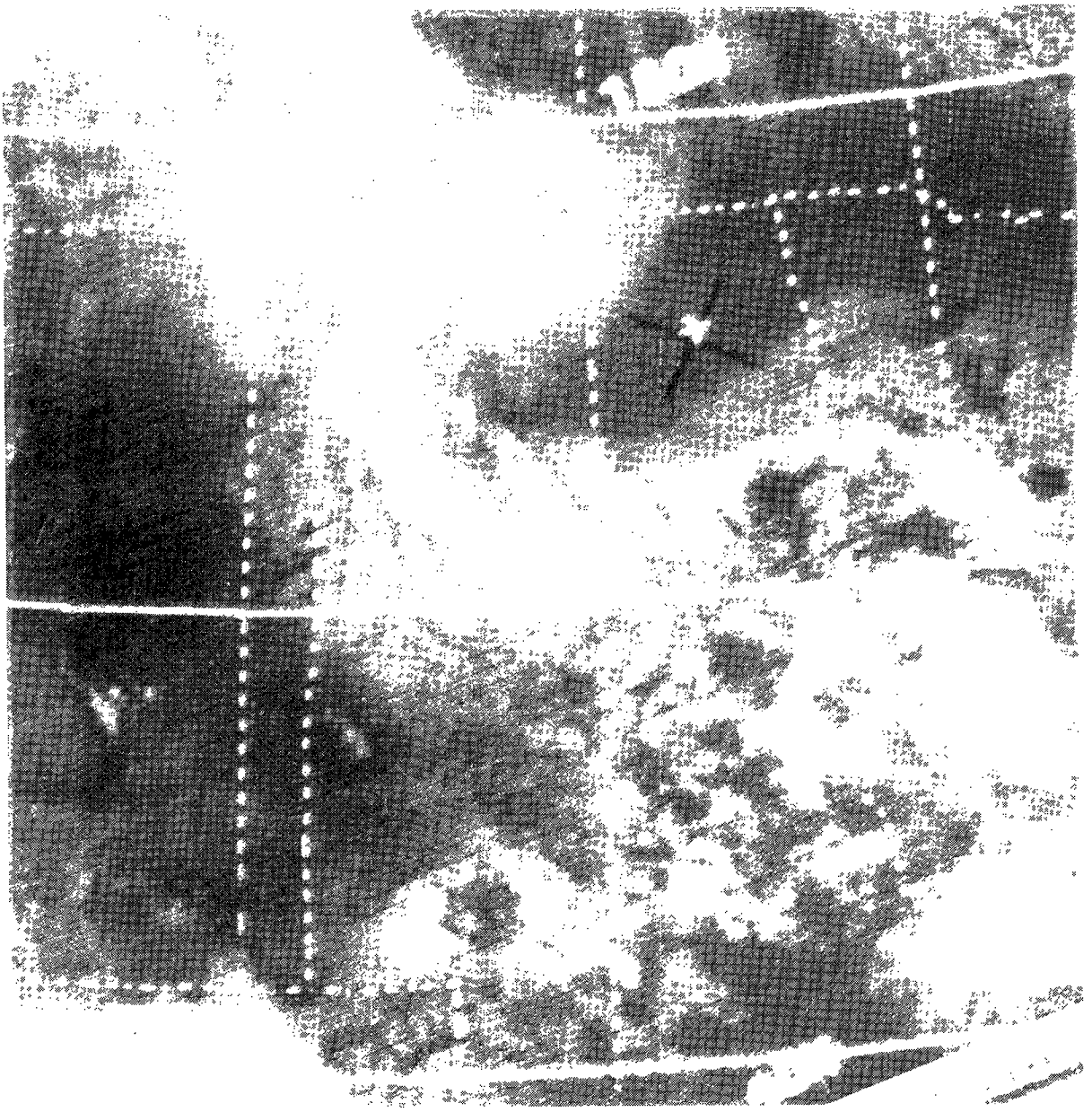


FIGURE 3a

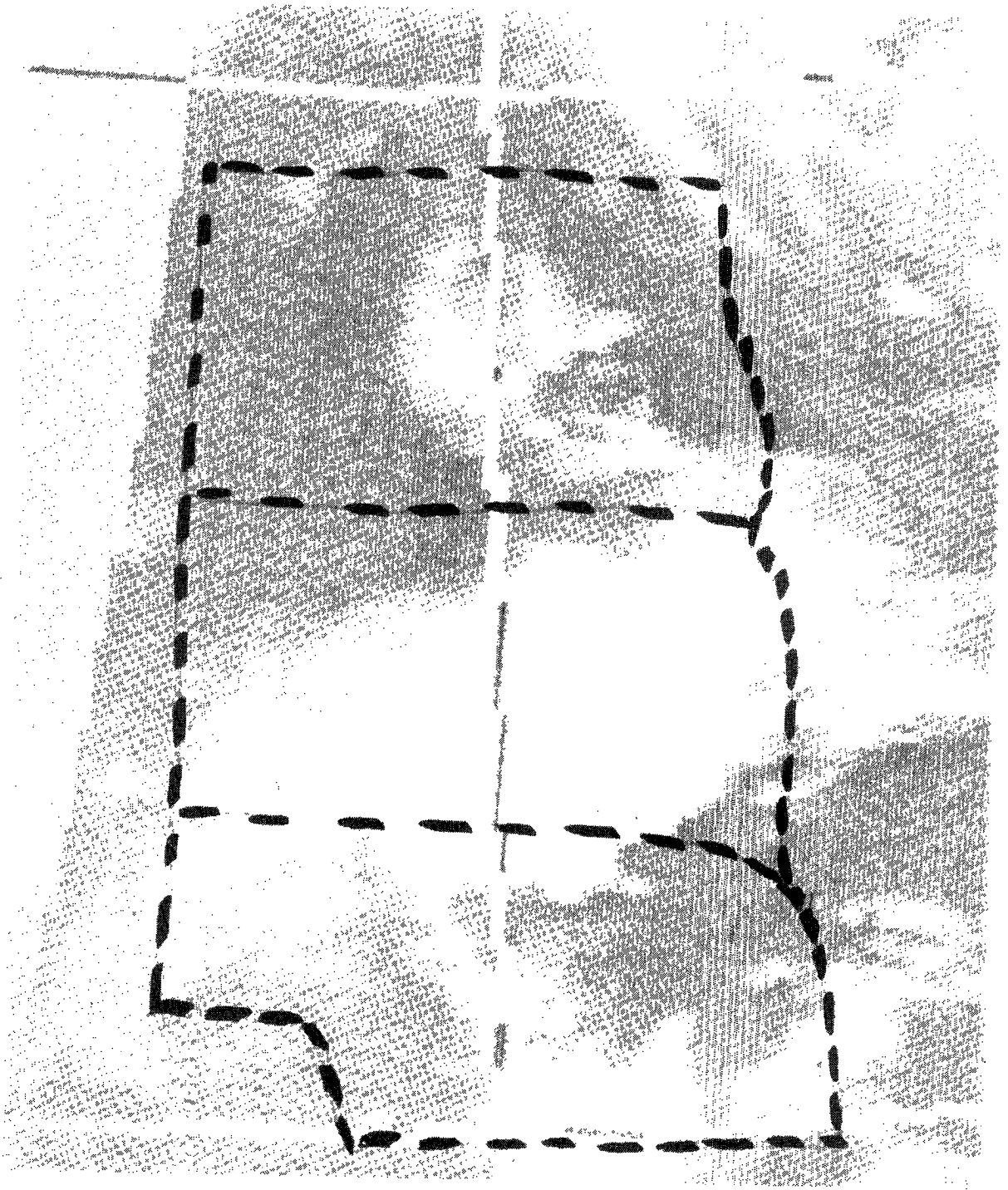




FIGURE 3b

FIGURE 3c

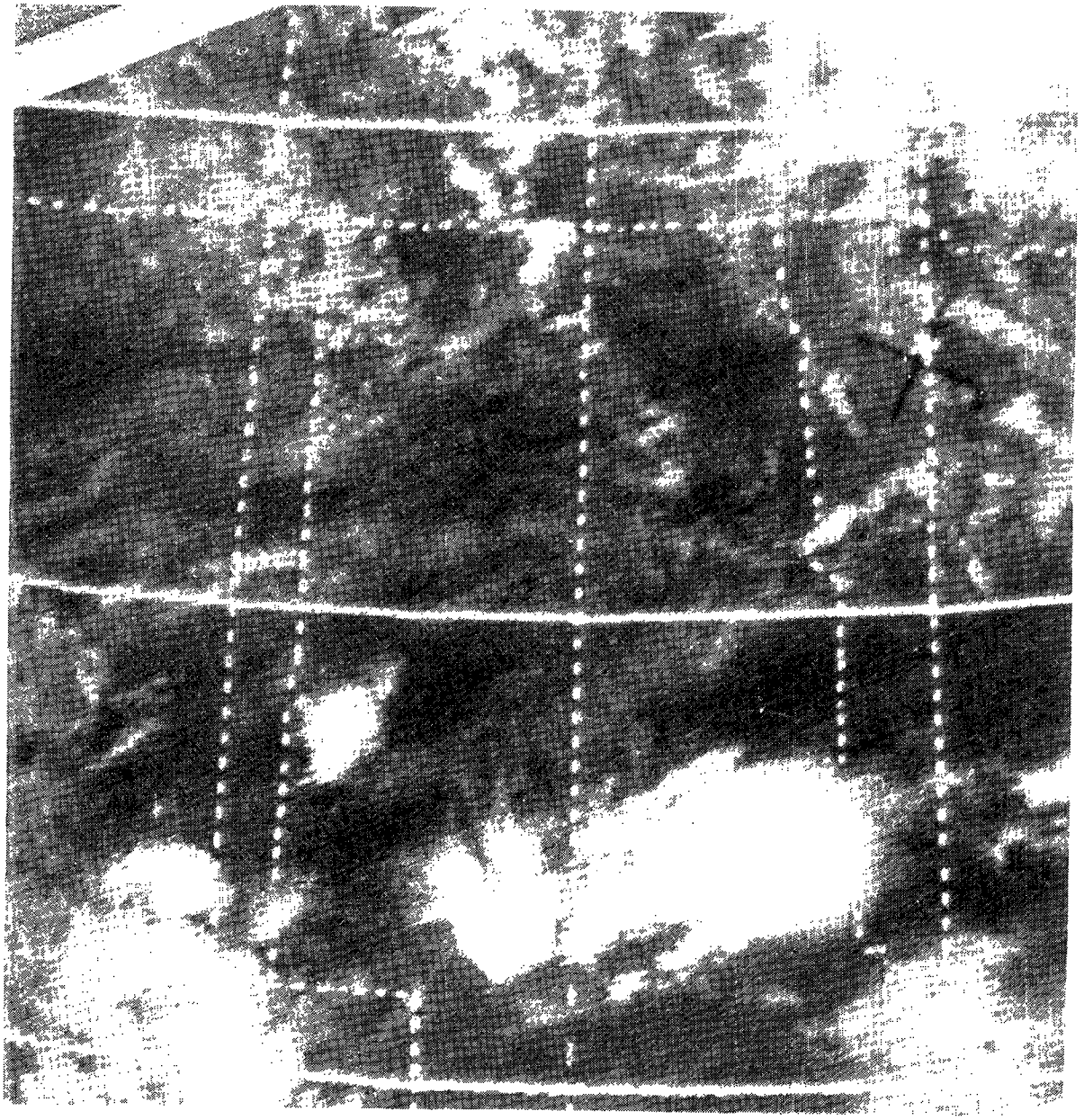




FIGURE 4a

FIGURE 4b

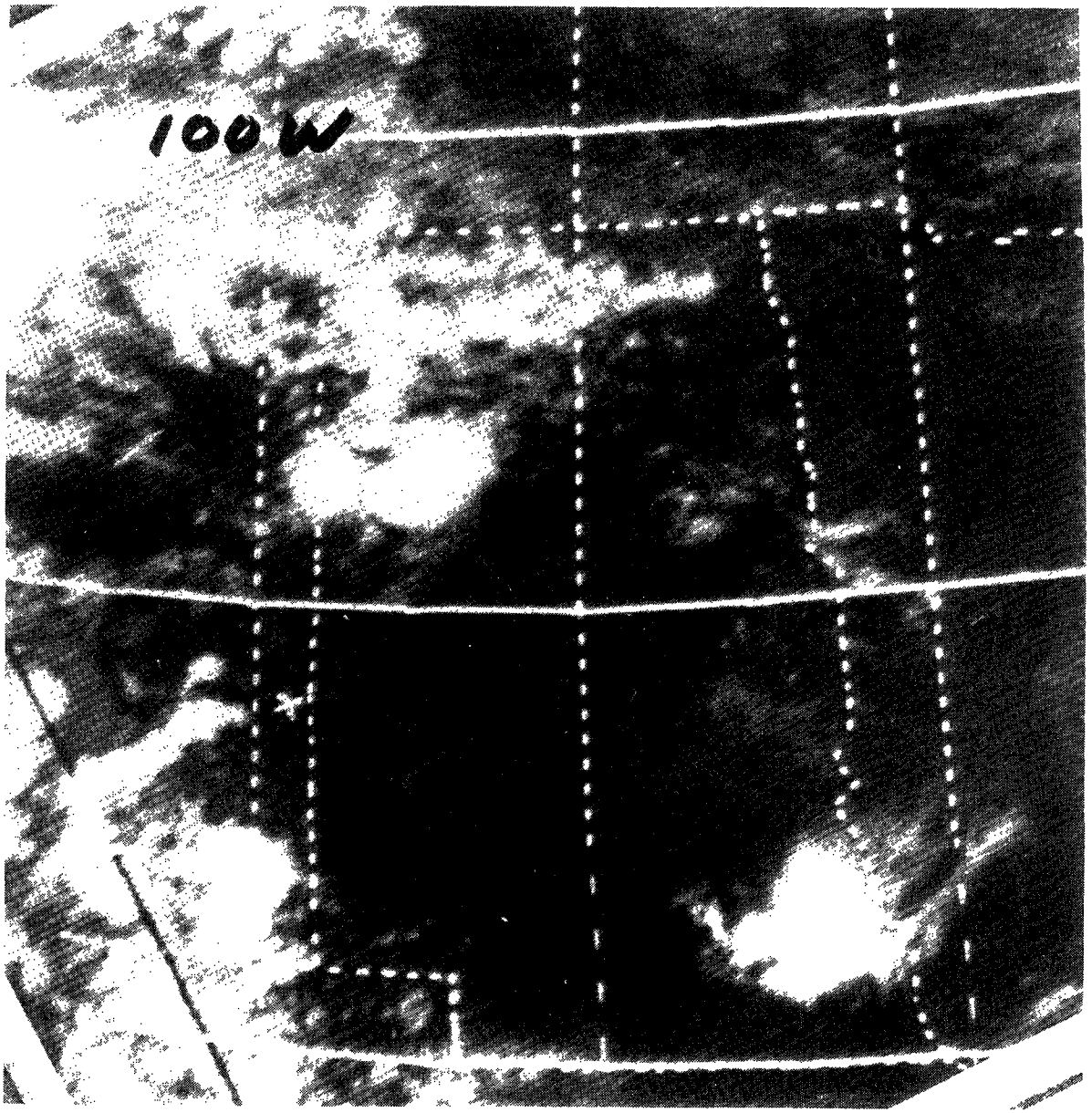


FIGURE 5a



FIGURE 5b

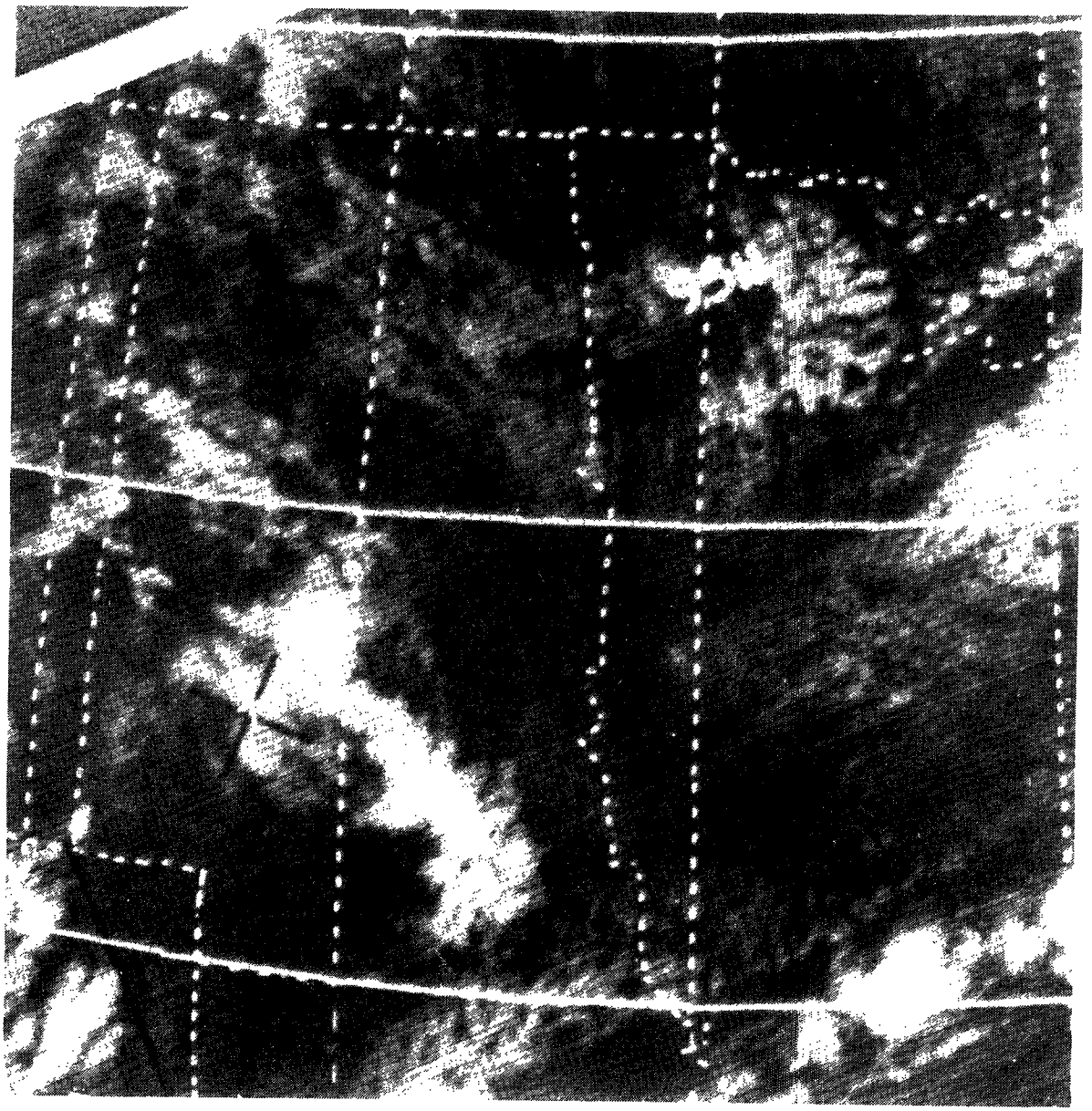


FIGURE 6a

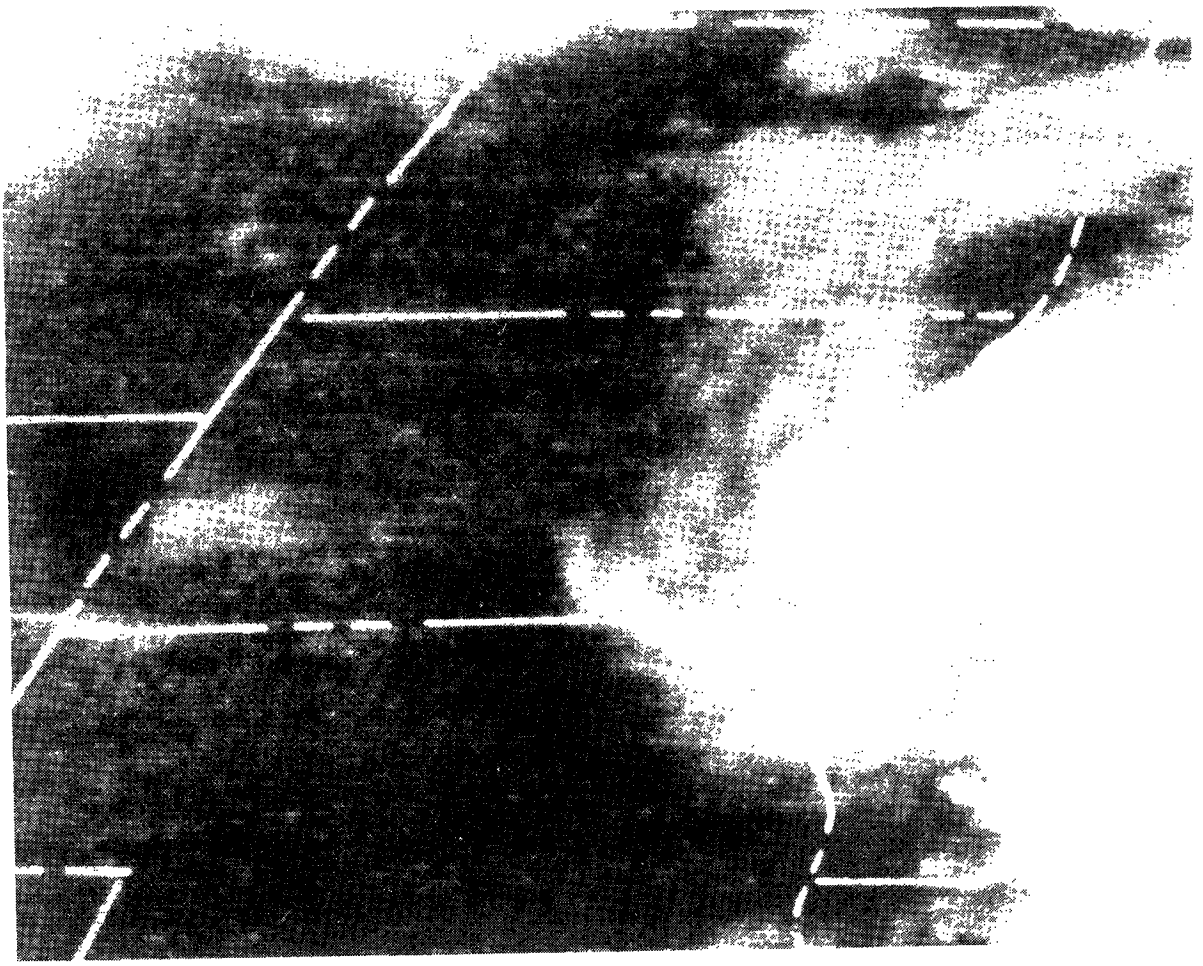


FIGURE 6b

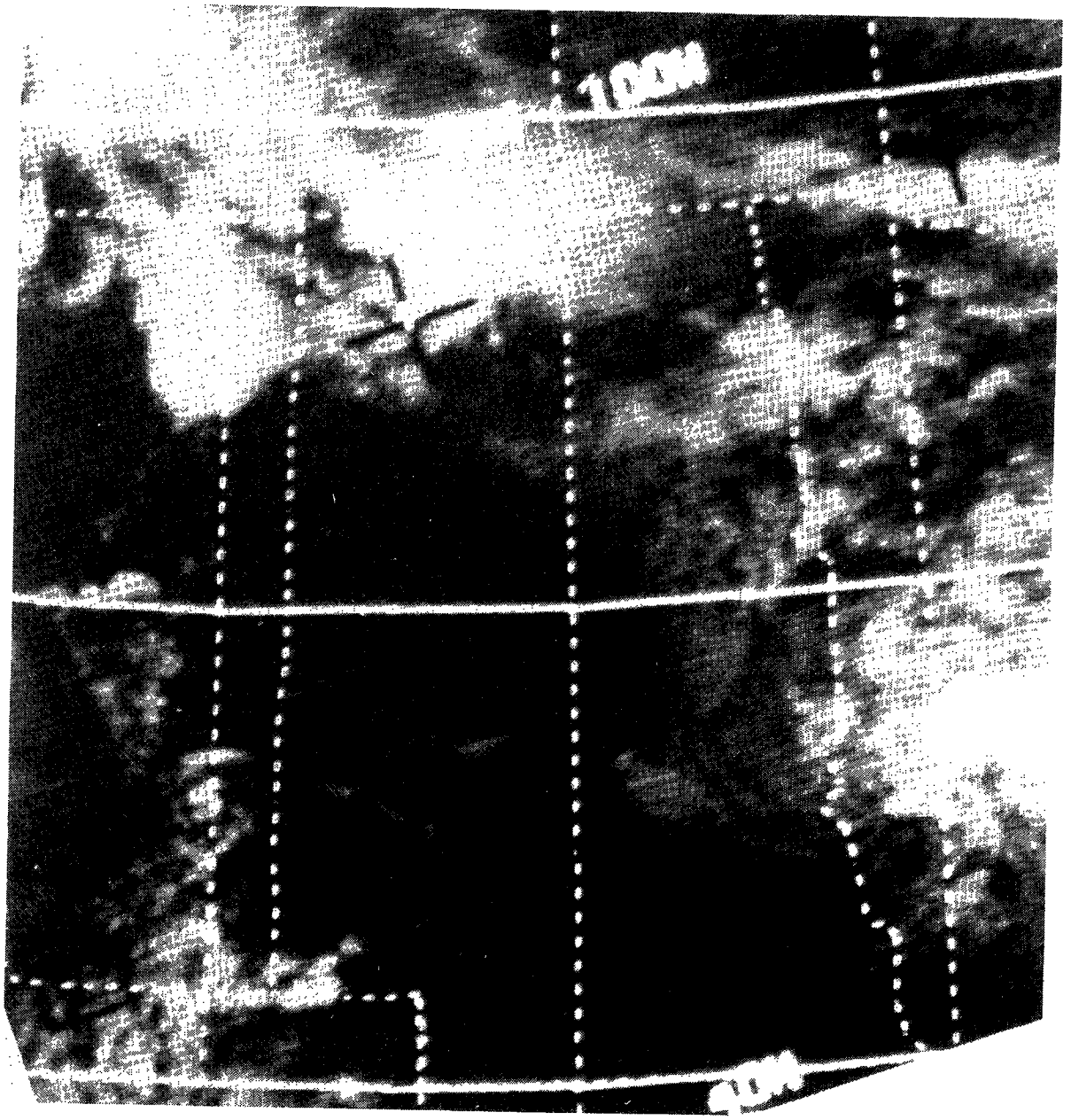
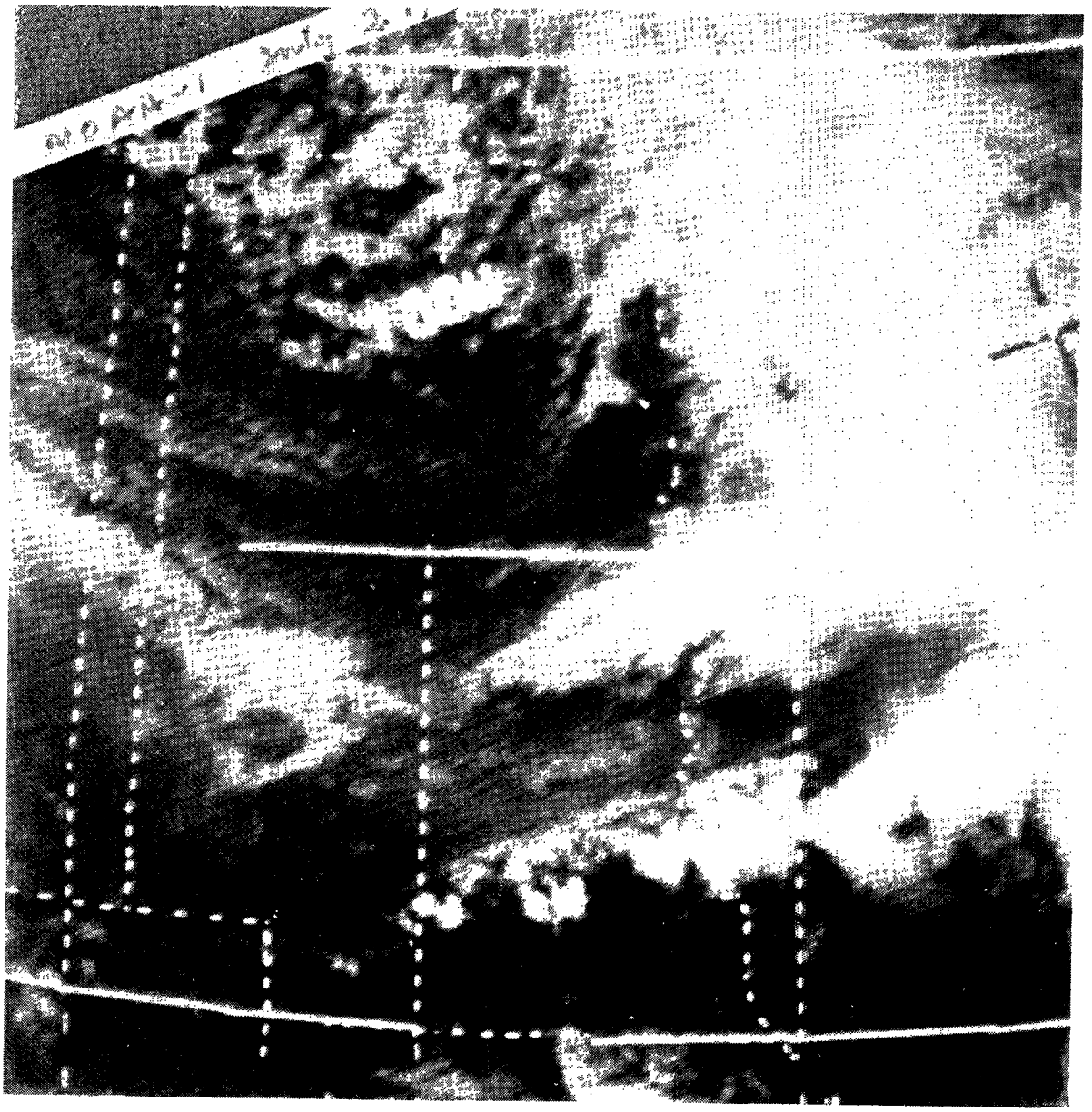


FIGURE 7a



FIGURE 7b



REVIEW OF A MOLECULAR MODEL APPLIED TO PRENUCLEATION WATER CLUSTERS*

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ABSTRACT

A molecular model has been developed to describe the formation of prenucleation water clusters. A review of this model and its application to the calculation of nucleation rates of water and ice is given. Extensions of the model to macroscopic application are discussed.

INTRODUCTION

A molecular description of the nucleation process was motivated by the failure of the classical liquid drop model (1) to reproduce experimental nucleation rates (2) and to survive theoretical scrutiny. The latter failure was noted by several authors (3) who found that, surprisingly, the translational and rotational energies were absent from the energy of formation of the cluster. Efforts (4) to revise the classical liquid drop model resulted in nucleation rates which differed from experiment by factors up to 10^{17}. Kassner (2) made the first quantitative measurements of homogeneous nucleation rates of water from the vapor as a function of super-saturation and noted that even the unrevised liquid drop model predicted values which were several orders of magnitude too large. This, together with the generally unsatisfying feature that small water clusters (2-100 molecules) were described with bulk thermodynamic properties, led Kassner (5) to suggest the need for a molecular model. The unmanageable cluster integrals, he postulated, could be avoided by considering a small number of specific structures determined mainly by the hydrogen bonding properties of water molecules. (6) He suggested that Pauling's clathrate model (7) (the regular dodecahedron) was a reasonable candidate for the basic structure unit of small clusters (see Figure 1). These ideas have been pursued in a number of papers (8) since 1969. The first calculation in which many of the individual contributions to the energy of formation for clathrate-like water clusters were evaluated from first principles was published in 1972 by the present authors. (9)

In this summary, we briefly describe the model and its subsequent development. Details have been published elsewhere (10), and we offer this particular review to those scientists working in weather modification who have been less concerned with interactions on a molecular level.

* Supported in part by the Atmospheric Sciences Section, National Science Foundation, GA 32386.

A QUALITATIVE DESCRIPTION OF THE MODEL

The goal in developing the model is to be able to calculate nucleation rates for ice and water droplets under atmospheric conditions. In order to produce a value for the nucleation rate, one must first find the equilibrium size distribution of ice or water clusters. This can be obtained from the so-called "free energy of formation" of each size cluster, under the specified atmospheric conditions. We begin by assuming a specific structure for each size water cluster. The structures we have adopted thus far are clathrate-like composed of five-membered rings or ice-like composed of six-membered rings. The next step is to evaluate the canonical partition function for each structure. This is done in a straightforward way by assuming that the partition function can be factored. The factors are evaluated from the calculated vibrational frequencies of the molecules in the cluster structure and from binding energies obtained from calculations on small clusters with up to five molecules. Configurational entropy is included and the model's major advantages are that the partition function and hence the "energy of formation" can be estimated without resorting to complex cluster integrals and that, at the same time, the model requires no use of bulk thermodynamic properites such as surface tension. Once the energy of formation has been evaluated, the nucleation rate can be calculated in a straightforward manner. (11)

THE QUANTITATIVE RESULTS OF THE MODEL FOR HOMOGENEOUS NUCLEATION (12)

The energies of formation calculated from the molecular model for clathrate and ice-like clusters are shown in Figure 2. A comparison of the results from the classical liquid drop model and from the molecular model for clathrate clusters is shown in Figure 3 for a temperature of 273K and a supersaturation ratio of 5. These calculations and others at a variety of temperatures (13) indicate that the formation of ice-like clusters from pure supersaturated water vapor is much less likely than the formation of a more highly-bonded, spherical structure such as the clathrates.

Rates for homogeneous nucleation calculated from the molecular model for ice-like and clathrate water clusters are compared with those calculated using the classical liquid drop and the "Lothe-Pound" (14) corrected liquid drop models* in Figure 4. This figure also shows the experimental nucleation rates measured by Kassner and Biermann (15). Thus the experimental rates are bracketed by those obtained from the theoretically unsatisfactory classical liquid drop model and from the clathrate structure molecular model. We feel that the remarkable agreement of the molecular model can be further improved by reducing the rigidity of the clathrate structure by including other structures with similar bonding schemes, for example, or by distorting the structure by weakening some of the hydrogen bonds.

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*"Lothe-Pound"model implies that only translational and rotational energies have been added to the classical liquid drop calculation of the energy of formation. No replacement terms have been included.

The critical supersaturation ratio is another quantity which is more readily measured. This quantity was calculated from the uncorrected classical liquid drop formalism and from our molecular model for clathrate and ice-like clusters. These calculations are compared with experimental results from several authors in Figure 5.

The quantitative results of our molecular model have been quite encouraging and indicate, we believe, that the qualitative description of the molecular clusters embodies the most essential features of the water aggregates. However, we recognize that homogeneous nucleation is not important under most atmospheric conditions. Our primary concern now is to extend our molecular model to the description of heterogeneous nucleation. For example, we have already examined the formation of ice clusters on an idealized ice-like surface and have estimated nucleation rates for this process. (12)

APPLICATION OF THE MOLECULAR MODEL TO MACROSCOPIC PROBLEMS IN CLOUD FORMATION

A major problem confronting workers in weather modification is evaluation of the relative nucleating efficiency of artificial nuclei which can be introduced into clouds. What is needed is a list of properties which a good nucleating agent must possess. We feel that our molecular model is uniquely suited to such a study. Since the interaction is modeled on a molecular scale, differences in chemical nature, crystal structure, and surface impurities and imperfections can be explicitly included. These studies should enable us to predict which materials can act as effective ice or cloud condensation nuclei.

Our molecular model can also be applied to the question of the supercooling of water droplets. Our studies on homogeneous nucleation have indicated the difficulty associated with ice formation from the vapor. For the case of microscopic droplets, we feel that the molecular model can yield information about the dependence of supercooling on the size of droplets and on the size and type of impurity. Temperature studies on the relative stability of a variety of cluster structures including impurities give direct information about the conditions necessary for the freezing of the supercooled cluster.

Once nucleation has taken place, the next problem is the mechanism and rate of the subsequent growth of the ice crystal. Surface deposition, diffusion, and the nucleation of new crystallographic planes are all questions which can be addressed by a molecular model.

COMMENTS

We hope that this review has been informative to those working in the area of weather modification. The authors are most interested in any comments or suggestions of a general nature or with respect to applications of our model. We feel that a regrettably large gap exists between the

workers in weather modification and those who have specialized in microscopic phenomena. We hope this gap is closing and this review and any dialogue stimulated by it will be a step toward that end.

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FIGURE CAPTIONS

Figure 1: The twenty molecule clathrate cluster composed of five-membered rings.

Figure 2: Free energy of formation vs. cluster size (in number of molecules). The points marked Δ include strain energy calculated by Hagen (16).

Figure 3: The free energy of formation vs. cluster size (in number of molecules) at S = 5 and T = 273K is plotted for: 1) the liquid drop model (solid line), 2) the molecular model (crosses), 3) the molecular model with strain (16) (triangles), and 4) the least square fit to the molecular model (dashed line).

Figure 4: Comparison of theoretical and experimental (x) homogeneous nucleation rates for vapor phase water clusters.

Figure 5: Comparison of critical supersaturation ratios (with respect to liquid water) and critical cluster size (in number of molecules) vs. temperature. (□, +, ⊙ experimental points (17)).

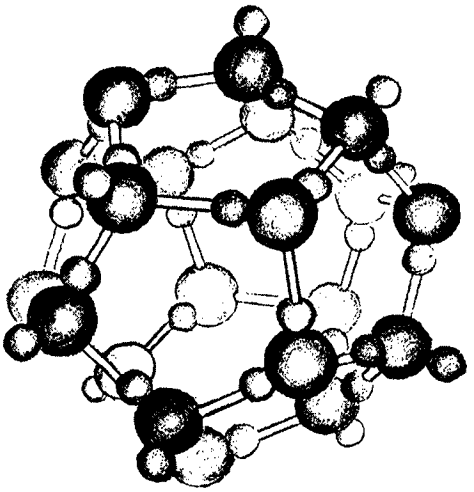


FIGURE 1

FIGURE 2

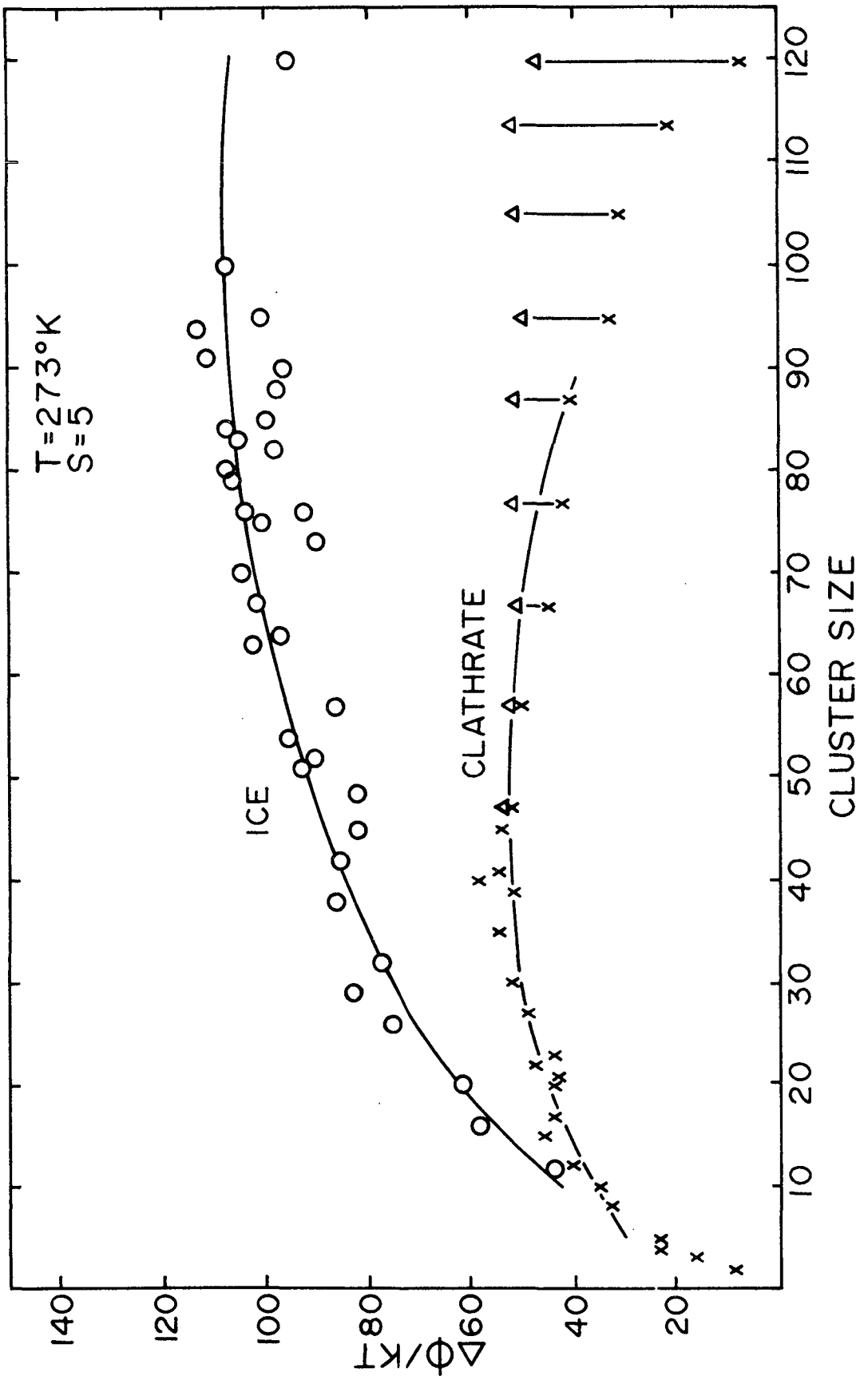

T=273°K
S=5
ICE
CLATHRATE
CLUSTER SIZE
ΔΦ/KT
10
20
30
40
50
60
70
80
90
100
110
120
20
40
60
80
100
120
140

FIGURE 3

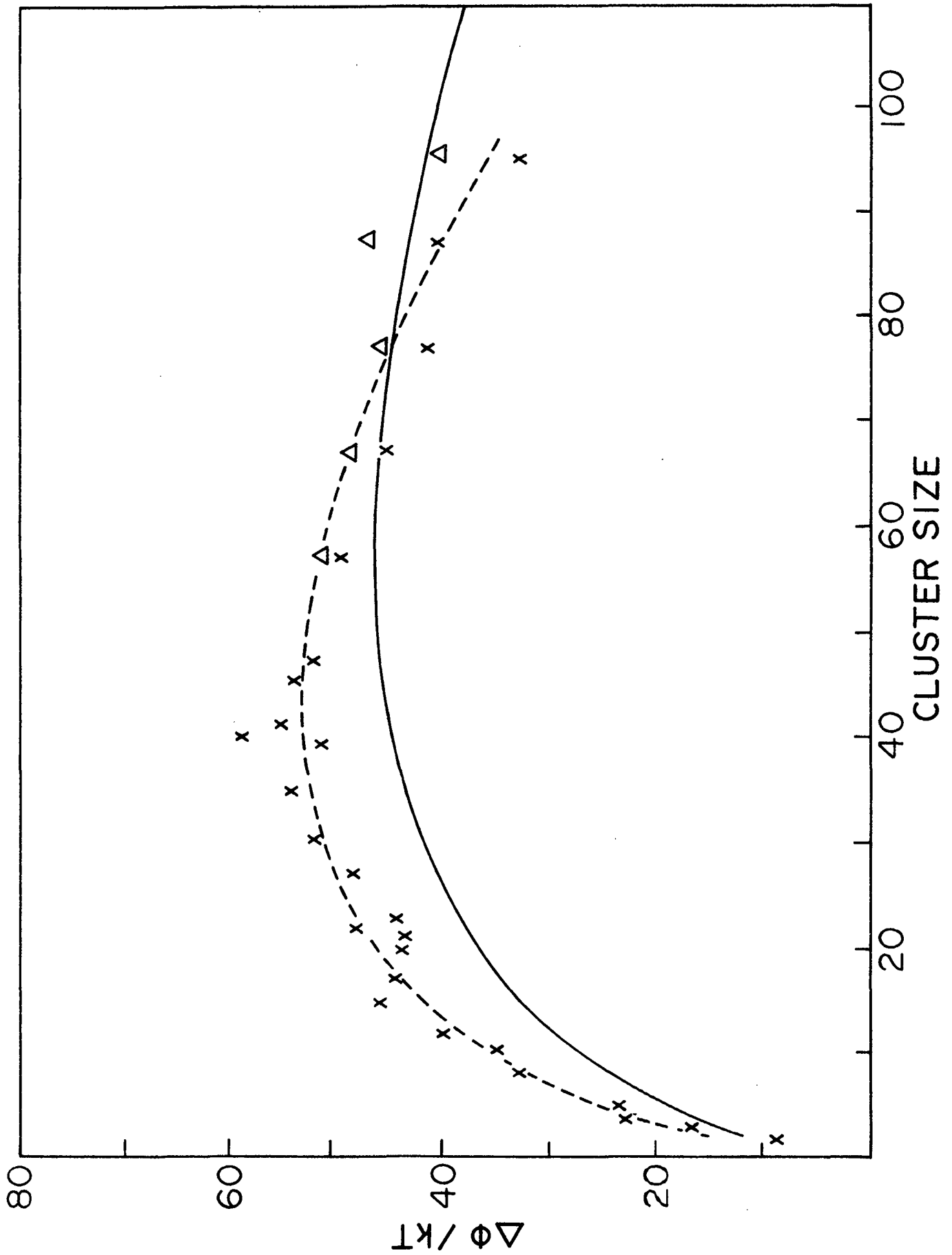


FIGURE 4

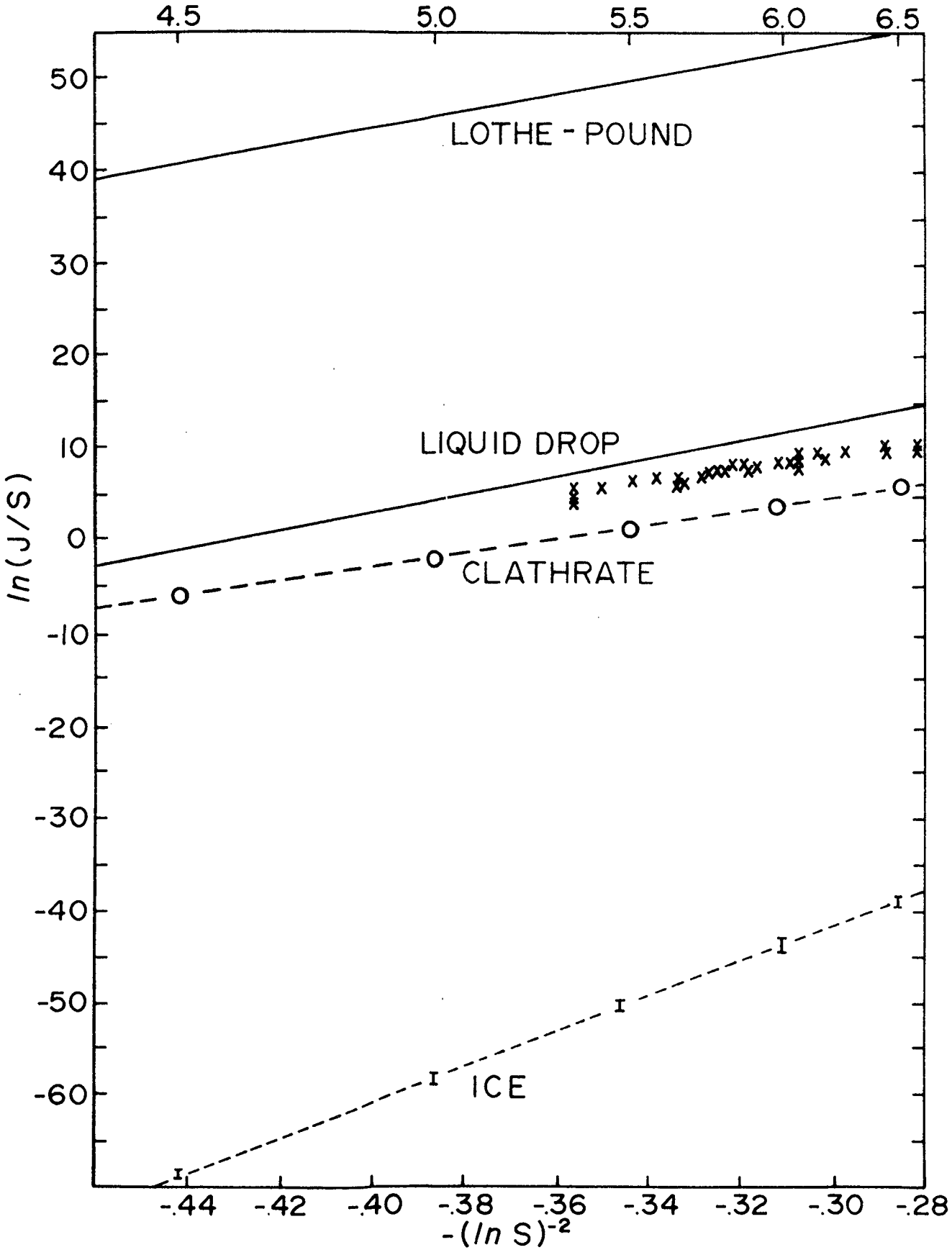
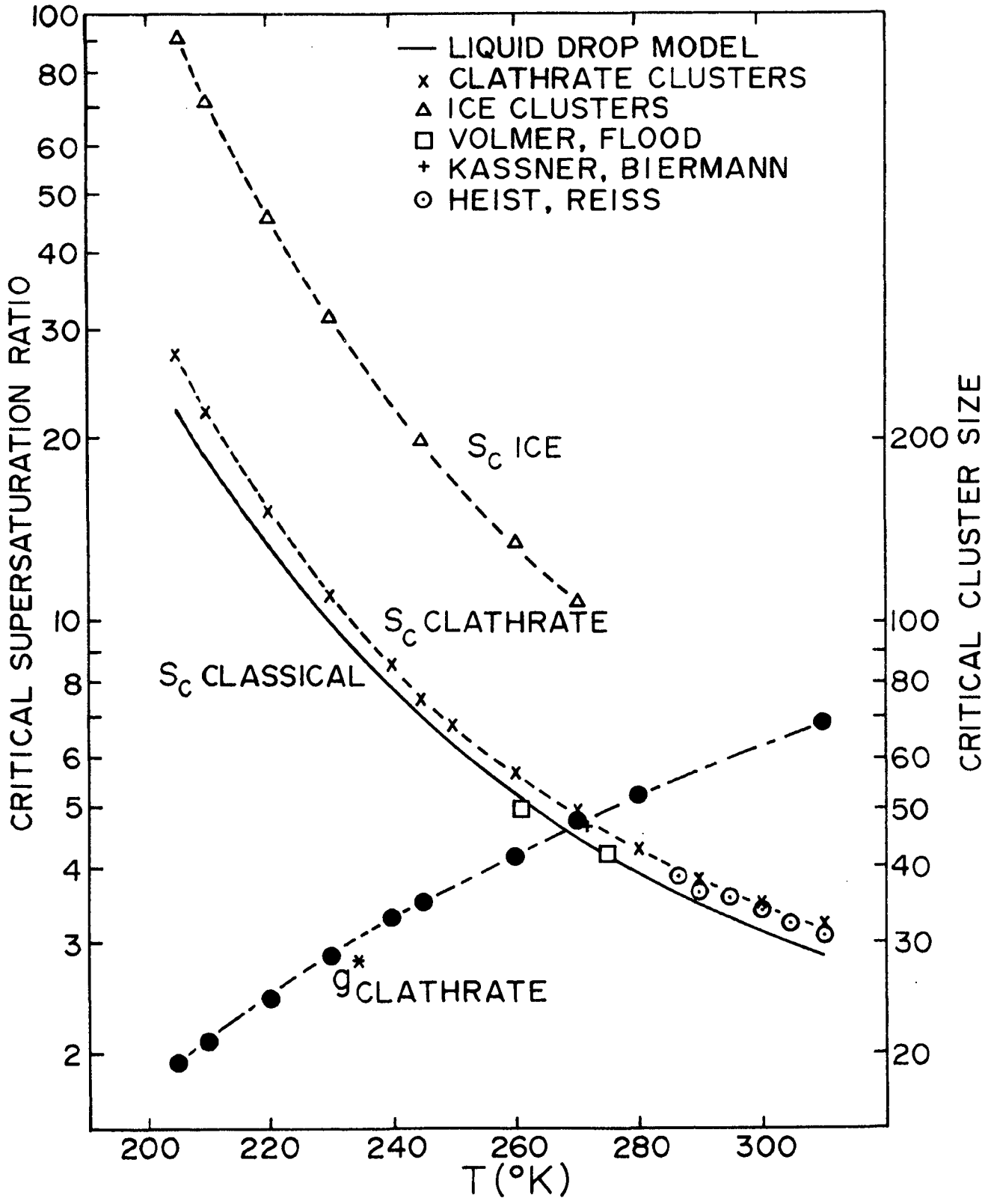

4.5
5.0
5.5
6.0
6.5
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
LOTHE - POUND
LIQUID DROP
CLATHRATE
ICE
ln(J/S)
-.44
-.42
-.40
-.38
-.36
-.34
-.32
-.30
-.28
-(ln S)^-2

FIGURE 5


— LIQUID DROP MODEL
x CLATHRATE CLUSTERS
△ ICE CLUSTERS
□ VOLMER, FLOOD
+ KASSNER, BIERMANN
⊙ HEIST, REISS
S_c ICE
S_c CLATHRATE
S_c CLASSICAL
$g^*_{CLATHRATE}$
CRITICAL SUPERSATURATION RATIO
CRITICAL CLUSTER SIZE
T (°K)
100
80
60
50
40
30
20
10
8
6
5
4
3
2
200
100
80
60
50
40
30
20
200
220
240
260
280
300

A UNIQUE PHYSICALLY RESPONSIVE METHOD OF ENTRAINMENT FOR ONE-DIMENSIONAL CUMULUS MODELS

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ABSTRACT

A new representation of entrainment that is responsive to environmental properties known to affect cloud dynamics is discussed. This entrainment mechanism is based on a nondimensional parameterization of differences in buoyancy, water loading, and saturation vapor pressure between cloud and environment. It is examined using a steady-state one-dimensional cumulus model. Experiments were designed to show the model sensitivity to responsive entrainment, to compare clouds developed by this new entrainment with those developed using Stommel entrainment and those developed using the experimental meteorology model of Simpson and Wiggert. The model was run on four soundings from the Miami, Florida area and two from northeastern Colorado. The results of these experiments showed how the cloud model was sensitive to responsive entrainment. The clouds developed by the model were reasonably similar to those observed on the experimental days. The responsive entrainment may be an improvement over the conventional Stommel entrainment.

INTRODUCTION

The simple parameterized Stommel entrainment (1951) is known to be an inadequate simulation of natural entrainment. This form of entrainment is used in many one-dimensional steady-state numerical models to simulate the effect of atmospheric mixing on cumulus development. Important shortcomings of this form of entrainment are its insensitivity to the external changes within the environment, the way cloud development may change the environment, and the effect of internal cloud properties (buoyancy, water loading, and evaporation) on the entrainment rate. The model developed by Perkey and Kreitzburg (1973) is used to simulate both the external and internal effects. This paper compares results of the Perkey model applied to selected soundings using Stommel entrainment with the model results using a new form of entrainment that is responsive to internal cloud properties. These results from the Perkey model were also compared with those from the EMB-68 model (Simpson Wiggert, 1969) which uses Stommel entrainment and does not simulate changes in the environment.

THE MODELS

One-dimensional steady-state Lagrangian models of cumulus clouds have

been used to objectively simulate parcel dynamics. The basic cloud dynamics and microphysics of models developed by Weinstein and Davis (1968), Simpson and Wiggert (1969), Danielsen, et al., (1972), and Perkey and Kreitzburg (1973) are very similar. These models use a parameterized form of the relationship developed by Stommel (1951) in which their entrainment is an inverse function of cloud core radius. All of these models are very sensitive to cloud radius changes. However, only the Perkey-Kreitzburg (P-K model) is sensitive to environmental changes. The P-K model includes the processes affecting the environment surrounding the cumulus cloud such as cyclonic or mesoscale lifting, surface heating and eddy mixing, environmental subsidence induced by the cloud, subcloud evaporation of precipitation, and horizontal mixing of the dissipating cumulus cloud.

The P-K model is capable of developing a series of clouds each of which is affected by the environmental changes induced by the previous clouds.

The initial cloud of each experimental sequence of clouds in the model is unaffected by the environmental response to other clouds. Thus, this first cloud is similar to those of other more simple one-dimensional models and can be compared directly. This comparison was made with results from the Experimental Meteorology Branch 1968 version of their steady-state cumulus model (EMB-68).

Clouds which develop after the initial cloud are affected by the environmental changes caused by the previous clouds. The changes due to mixing, subsidence, and subcloud evaporation are weighted according to the percentage of cloud area. Percent of cloud cover is based upon the assumption of an initial fuel layer depth determined by the parcel thickness. (See Perkey and Kreitzburg, 1973).

MODEL ENTRAINMENT

Virtually all one-dimensional steady-state cumulus models assume dynamics of a steady-state jet, rising plume, or spherical vortex. These models parameterize the effect of entrainment using an empirical relationship developed by Stommel (1951) and Squires and Turner (1962). This relationship states that the entrainment parameter is

$$\mu = \frac{A}{R} \quad , \qquad (1)$$

where A is an empirical constant ranging from 0.1 to 2.0 and R is the active cloud core radius in kilometers (see Danielsen, 1972). All cloud models using this relationship are very sensitive to changes in cloud radii which may make significant differences in total cloud development. Of course, the basic assumption of an entraining jet or rising plume is that the larger the saturated core, the smaller will be the effect of mixing environmental air into the cloud. Thus, the larger the cloud radius the further it will grow. The entrainment parameter A is constant and does not have any explicit relationship to the cloud dynamics or environment. However, it should

be recognized that within the model's parcel dynamics there is implicit interaction with the cloud environment.

A more naturally aesthetic and physically responsive entrainment mechanism would be one which is explicitly defined by properties that affect cloud buoyancy, water loading, and evaporation. Thus, the constant term A of the Stommel relationship (Eq. 1) can assume the functional form

$$A = f(\rho, W_L, e) \tag{2}$$

where ρ is the density, W_L is the water loading, and e is the vapor pressure. One form of A which is currently under experimention is

$$A = K*g \left(\frac{\Delta\rho}{\rho} - W_L\right) + \frac{\Delta e}{e} \tag{3}$$

where $\Delta\rho$ is the differential density between environment and cloud, W_L is the water loading effect, g is the acceleration of gravity, K is a proportionality constant having units of sec^2/m, and Δe is the difference in vapor pressure between the cloud and the environment. Thus, under unstable conditions of high buoyancy we have larger amounts of entrainment due to more turbulent mixing. Although this is implicit in the Stommel entrainment relationship through the effect of mass continuity on the inverse relationship between cloud radius and velocity, the explicit function in Equation 3 adds another degree of freedom.

Under conditions of rapid precipitation growth, water loading may counterbalance the effect of buoyancy and thus reduce the turbulent mixing. Thus, this factor is considered in the net turbulent mixing, i.e., the first term on the right side of Equation 3. Very dry environmental conditions also have a dominant effect on cloud growth. Thus, the contribution of cloud water evaporation is considered through the vapor pressure differences between cloud and environment.

The entrainment is still considered inversely proportional to the cloud core radius so that the responsive form of entrainment becomes

$$\mu = \left[K*g \left(\frac{\Delta\rho}{\rho} - W_L\right) + \frac{\Delta e}{e} \right] \frac{1}{R} \tag{4}$$

Thus, entrainment is now a direct function of buoyancy, water loading, and degree of cloud supersaturation over its environment.

THE EXPERIMENT

A series of experiments were run using the P-K model to study the development of two sequential clouds. The experiments were made using soundings observed in the Miami, Florida area by Simpson and Wiggert (1971) and soudings observed in northeastern Colorado by the National Hail Research Experiment (NHRE, see Fankhauser, 1972). The experiments were designed to show the model sensitivity to responsive entrainment, to compare clouds developed by this new entrainment with those developed using the Stommel

entrainment, and those developed using the EMB-68 model of Simpson and Wiggert. The P-K model was run with an initial cloud core radius of 1.0 km using both the Stommel and responsive entrainment mechanisms on each of the soundings. Profiles of internal cloud properties were plotted for each entrainment case. Each profile consisted of the superimposed plots for the two clouds of the responsive entrainment experiment (solid curves of Figure 2 and 3) and those for the Stommel entrainment. These superimposed plots enabled ready comparison of internal model differences. Soundings showing the influence of the cloud on the environment and the relative cloud and environmental temperatures were also plotted. The results of the experiment are discussed in the following section.

RESULTS

Both conventional Stommel (1951) entrainment and responsive entrainment were compared in the Perkey-Kreitzburg model using National Hail Research Experiment soundings taken on July 14, 1971, and soundings from the Experimental Meteorology Laboratory (Simpson and Wiggert, 1971). Identical initial conditions were used for the experiment with the entrainment being the only different parameter in the model. Preliminary model-predicted cloud tops for clouds having 1.0 km radius verified well with radar-observed tops for both stommel and responsive entrainment experiments.

Table 1 summarizes model results for responsive, Stommel, and EMB-68 experiments. Here, the cloud top and maximum vertical velocity for the two sequential clouds are compared with the observed cloud tops and the maximum velocity predicted by the EMB-68 model. In four of six cases the responsive entrainment initial cloud tops were within 300 m of the observed cloud tops. The second cloud top was 0.7 to 2.2 km lower in the Miami cases and 0.5 to 0.7 km higher in the case of the NHRE raobs. The responsive vertical velocity was consistently lower (by 30 to 50 percent) than that predicted by the EMB-68 model. Although these results refer to a small sample of observed clouds, they are encouraging in that there is a reasonable semblance to natural observed clouds.

More detailed studies of internal modeled cloud profiles of a Miami, Florida case (Figure 2) and a Sterling, Colorado case (Figure 3) reveal the exact model response to changes in entrainment. Unfortunately, aircraft observations of internal cloud profiles are unavailable for comparison. Changes in the environment through the effect of subsidence, mixing, lifting, and surface heating are reflected in the second cloud's development (see Perkey and Kreitzburg, 1972).

MIAMI CASE STUDY

Figure 2 provides a composite of cloud model soundings and cloud profiles for case study of May 27, 1968, using the Miami raob observed at 1,200 G.M.T. This composite figure shows sounding conditions for the responsive and Stommel entrainment experiments. The cloud and evaporative raob shows the cloud and environmental temperatures and dewpoints. The relative positive area of clouds is shown from cloudbase to cloud top

(region where dewpoint and temperature coincide). Beneath cloudbase the environmental temperature, subcloud temperature due to subcloud evaporation effect only, and subcloud temperatures are plotted. The modified sounding indicates the net result of subsidence, mixing, subcloud evaporation, and mesoscale lifting. The final sounding indicates the total change of temperature and dewpoint for the sequence of two clouds. The arrows indicate the direction of change for these from first to final cloud. In the case of the MIA sounding, the cooling due to lifting was greater than the warming effects due to subsidence and mixing so that the net effect was sounding destabilization. This destabilization produced larger positive areas in the case of the second clouds for both responsive and Stommel entrainment, which in turn produced higher vertical velocities. These larger vertical velocities reduced the time for microphysical precipitation development, thus reducing the second cloud's precipitation. However, the net effect of subcloud evaporation of the initial cloud's precipitation was to increase the subcloud relative humidity so that the amount of subcloud evaporation of precipitation from the second cloud was less. This is shown in Figure 2 by the sounding changes and the percent of precipitation reaching the ground. It should be noted that the second cloud is significantly affected by the environmental changes of the first so that the effects of entrainment differences are masked.

The principal effect of the responsive entrainment parameter of Equation 3 is to create a cloud which responds to direct environmental effects. The direct effect of responsive entrainment on cloud properties is best shown by the profiles for the first clouds in Figure 2. The cloud profiles of virtual temperature excess, vertical velocity, cloud water content, rainwater, and subsidence show how these properties vary with height in the model for the first and second clouds (labeled 1 and 2, respectively) of the responsive (solid line) and Stommel (dashed line) experiments. Shaded areas delineate the difference between the responsive and Stommel profiles for the first cloud of the two-cloud experiment. Positive shaded areas indicate that the values for the responsive cloud case were greater than corresponding values for the Stommel case.

The value of responsive entrainment is very close to that of the Stommel near cloudbase then increases to a value in excess of Stommel between 1.8 and 4.1 km in the Miami case (Figure 2, Entrainment Comparison). The responsive entrainment reaches a peak value 69 percent greater than that of the Stommel entrainment at 2.6 km. This larger entrainment produces a 13 percent decrease in vertical motion at the 3.1 km level. The responsive entrainment then falls below the Stommel values from 4.3 km to cloud top. This produces a net excess (+) vertical velocity of the responsive cloud from the 7.0 km level to cloud top. At 8.3 km the responsive cloud has a vertical velocity 60 percent greater than the Stommel cloud.

The excess of virtual temperature of the cloud over the environment is smaller for clouds developed using the responsive entrainment in the lower half of the cloud than for clouds that developed under the Stommel entrainment. The virtual temperature excess of both the Stommel and responsive clouds is similar from cloudbase to the 2.3 km level. From 2.5 to 7.0 km the responsive cloud is about 0.3C colder than the Stommel cloud.

From 7.0 km to near cloud top the responsive cloud is from 0.2C to 0.4C warmer than the Stommel cloud. These variations are directly related to corresponding changes in the vertical motion of the two-cloud cases.

Cloud and hydrometeor water profiles for the responsive cloud show similar patterns of cloud water content and corresponding hydrometeor water content lower than Stommel entrainment at the 3- to 5-km level in the cloud. From 6 to 10 km, however, higher values of cloud and hydrometeor water developed in the responsive cloud (see Figure 2). The net effect on precipitation of these liquid water profiles was a 36 percent increase in the precipitation of the responsive cloud.

Observed maximum cloud tops in the case of May 27, 1968, at Miami, Florida, were 10.12 km MSL for natural clouds. The model predicted tops of 10.22 km for the initial cloud and 8.72 for the second cloud in the case of responsive entrainment; whereas the first top was 8.72 km and the second top was 10.47 km in the case of Stommel entrainment. The Experimental Meteorology Laboratory steady-state cumulus model (EMB-68) using Stommel entrainment and a cloud tower radius of 1.0 km predicted tops of 10.0 km (Simpson, Wiggert, 1971). This top was in close agreement with the initial top predicted by the Perkey model using responsive entrainment.

Examination of the maximum vertical velocity of the responsive cloud in this experiment shows a 41 percent reduction of velocity below that predicted by Stommel entrainment in the EMB-68 model (see Table 1). The second cloud predicted by Perkey model using Stommel entrainment had a maximum vertical velocity of 14.5 m sec^{-1}, which was very similar to the 14.0 maximum vertical velocity predicted by the EMB-68 model.

STERLING, COLORADO CASE STUDY

Cloud top development in this case was in close agreement with observed cloud tops for both responsive and stommel clouds. The model cloud tops were within 300 m of the observed tops.

The virtual temperature excess of the responsive entrainment case, Cloud No. 1, was less than that of the Stommel cloud case. This deviation of virtual temperature excess ranged from 0.2C to 1.0C and reached a peak difference at the 5.8 km level where the responsive cloud was 1.0C colder than the Stommel cloud.

Vertical velocity profiles closely correspond to the smaller virtual temperature excess of the responsive cloud. The vertical velocity of the responsive cloud was less than that of the Stommel cloud throughout the cloud as would be expected from the temperature excess discussed above.

Cloud water content of the cloud is substantially less than the Stommel cloud water from 5 to 8 km. Small regions of increase above the Stommel cloud occurred at the base and top of the cloud. The rainwater differences between the responsive and Stommel clouds showed a pattern similar to the cloud water in the lower half of the cloud; however, the upper region of the responsive cloud had higher rainwater. This resulted

in a net increase in responsive cloud precipitation of 74 percent more than the Stommel cloud. The value of responsive entrainment was greater than the Stommel entrainment from 5.6 to 7.1 km, having a value of 24 percent to 92 percent larger than the Stommel entrainment. Above 7.1 km the responsive entrainment was generally 40 to 70 percent less than the Stommel entrainment. One level where the responsive entrainment exceeded the Stommel value was at 8.6 km. This was due to the abrupt change in model calculations of vapor pressure for liquid and ice.

The model uses an abrupt phase change in vapor pressure calculation at -25C. All calculations above -25C are made with respect to liquid whereas for all temperatures below -25C, vapor pressure is calculated with respect to ice. In this case the cloud temperature was a warm -24.2C, whereas the environmental temperature was -25.1C. Consequently, the cloud's vapor pressure was calculated with respect to liquid whereas the environment's was with respect to ice.

In summary the responsive clouds tended to agree with observed clouds better than the Stommel clouds in both the Miami and the Colorado sounding experiments.

CONCLUSIONS

The preliminary results of this set of experiments are encouraging. The responsive form of entrainment is shown to predict clouds that agree with those observed with reasonable accuracy. Although a more complete set of cloud observations and simultaneous representative soundings is needed to aid in detailed comprehensive verification, the basic tendency of cloud top and vertical velocity appears to be in the direction of better realism in responsive entrainment cases. This closer semblance to natural observed clouds in both the cloud top verification and the vertical velocity reduction is consistent with recent suggestions by Warner (1972). This form of responsive entrainment appears to have potential for improving the one-dimensional steady-state cloud models. Further experimentation and development of the parameterization will be conducted to improve its realism.

It should be noted that a critical cloud observation and sampling problem exists that restricts comprehensive evaluation of model predictions of internal cloud structure. This is a twofold problem of instrumentation technology and economics. Verification of modeled cloud structure requires simultaneous observations of cloud properties at several levels. These experiments require several instrumented aircraft. Observations from these aircraft are limited by sample volume, sample times, and natural time and space changes within the cloud. Another problem arises in comparing observations with cloud model predictions - one of interpretive comparison of data. Interpretive comparison involves selective smoothing of aircraft observations to fit the temporal and spatial averages performed by the numerical integration of the model. Both the aircraft observations and the interpretive comparison problems must be resolved to comprehensively determine the degree of realism of numerical cloud models.

ACKNOWLEDGMENTS

Much thanks go to Dr. Don Perkey and Dr. Carl Kreitzburg for permitting exploration with their mesocumulus model. Thanks are also expressed to Mr. Clem Todd and Dr. Douglas Fox whose ideas regarding entrainment have spurred much of this research. Acknowledgment is made to the National Center for Atmospheric Research, which is sponsored by the National Science Foundation, for use of its computer system.

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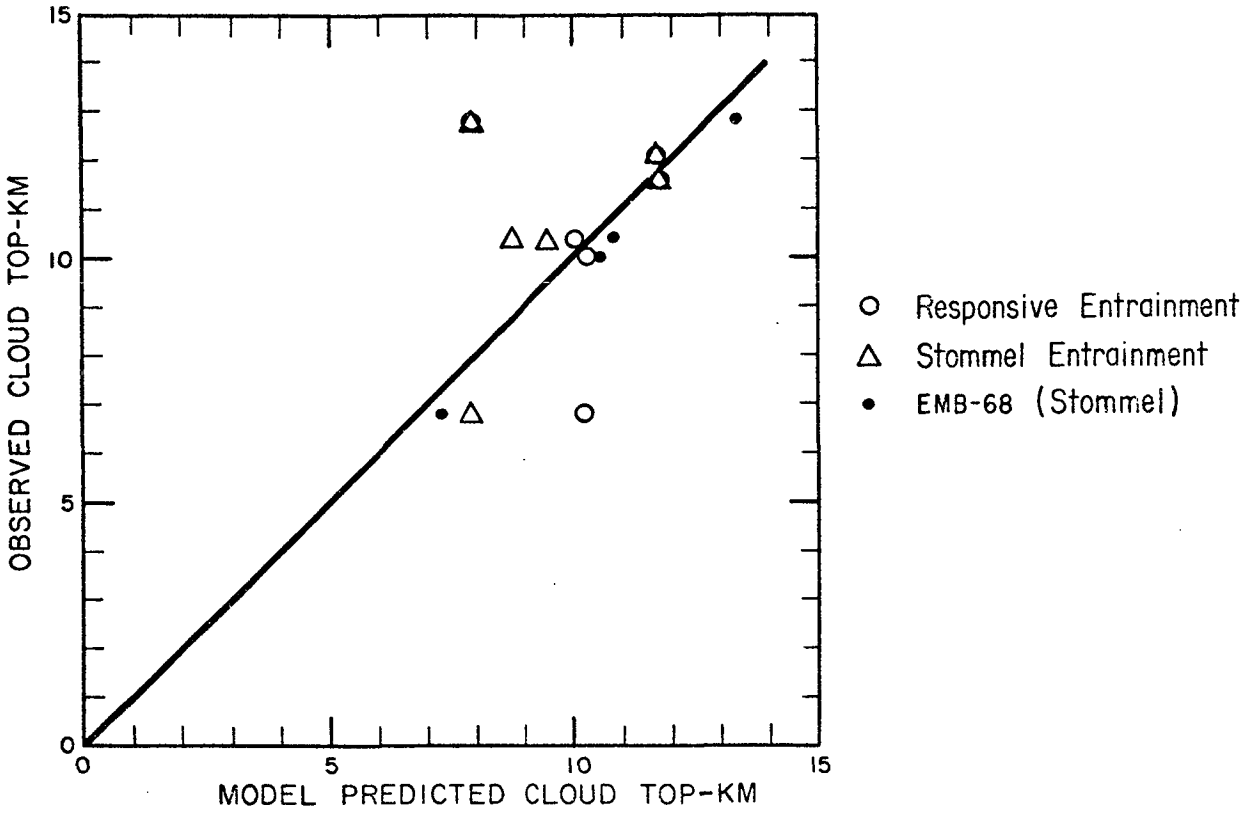
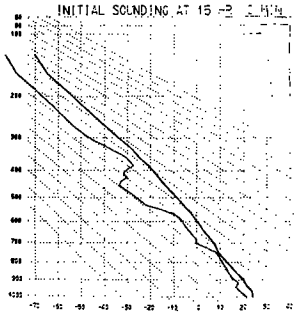


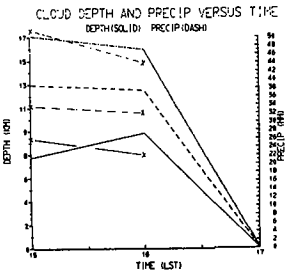
Figure 1. Observed cloud top versus model predicted cloud top.

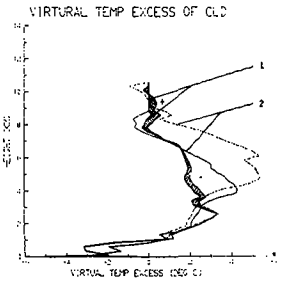
Date / Sta / Time	Radius		Cloud Top						Maximum vertical vel M Sec^{-1}				
			Obsvd	Responsive		Stommel		EMB-68	Responsive		Stommel		EMB
	Obsvd	Model	(Km)	Cld 1	Cld 2	Cld 1	Cld 2	(Km)	1	2	1	2	
5/21 MIA 2050	1.2	1.0	S 12.8	7.9	7.2	7.9	7.9	S/NS 13.3/10.1	8.5	9.1	10.1	12.2	16.0
5/26 NQX 2000	.8	1.0	6.8	10.2	8.0	8.0	9.5	7.4	7.0	8.1	4.5	11.1	14.5
5/27 MIA 1200	1.0	1.0	10.1	10.2	8.7	8.7	10.5	10.0	8.5	9.5	9.0	14.5	14.0
5/28 MIA 1800	.75	1.0	S 10.4	10.5	9.2	9.7	10.2	10.6/8.4	8.2	9.0	8.0	14.0	11.8
7/14 STK 1250	2.7	1.0	11.5*	11.7	12.4	11.7	12.4		8.0	8.2	9.0	10.6	
7/14 STK 1450	4.5	1.0	12.0*	11.7	12.2	11.7	12.2		8.1	8.3	11.1	9.0	

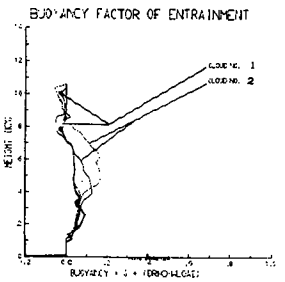
*Radar RHI estimate

Table 1. A comparison between observed clouds and model results for Responsive and Stommel Entrainment Cases.



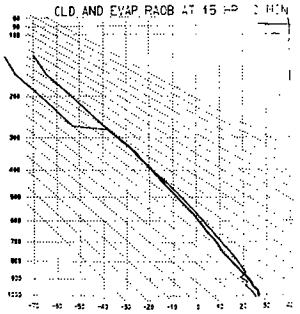


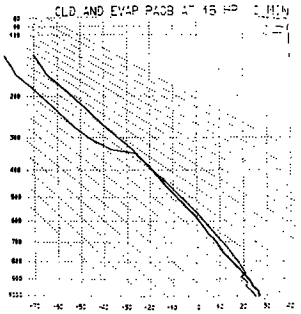


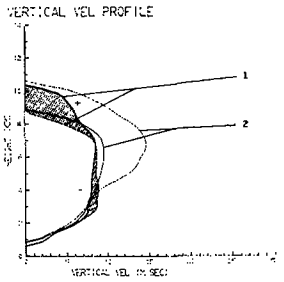


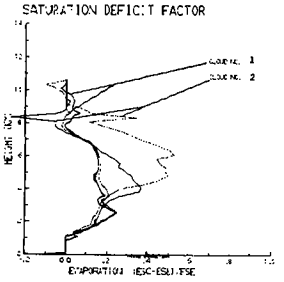
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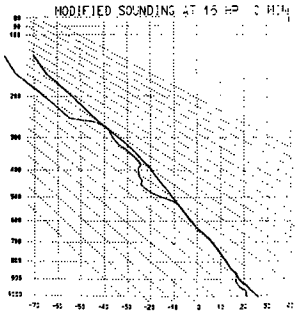
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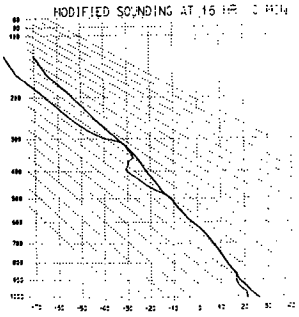


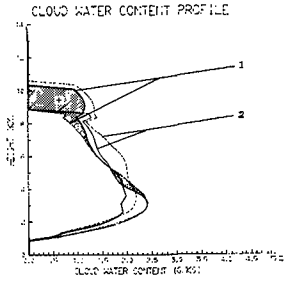


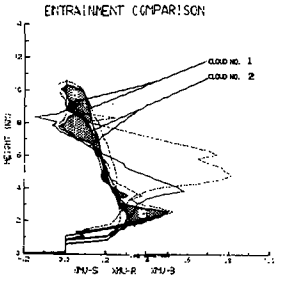


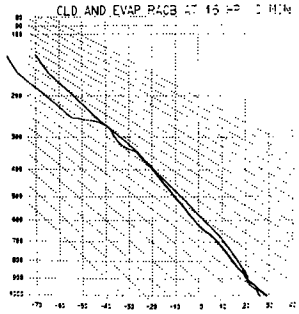


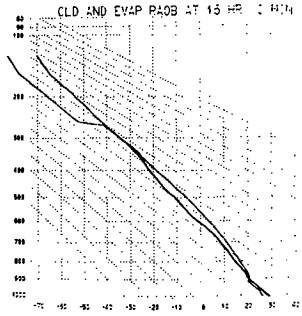


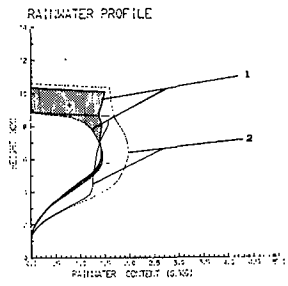


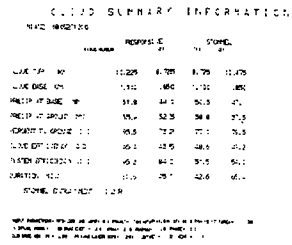


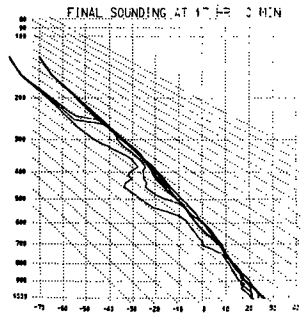


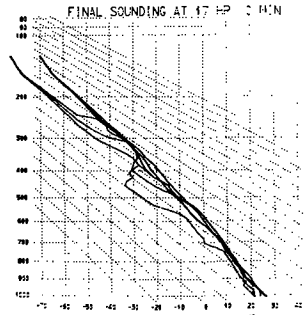












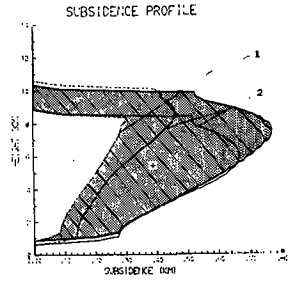
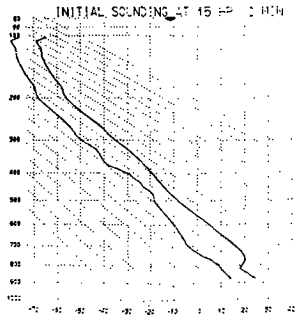
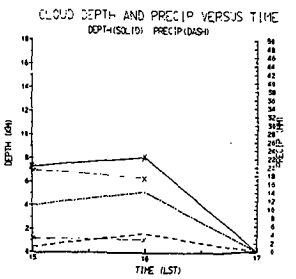


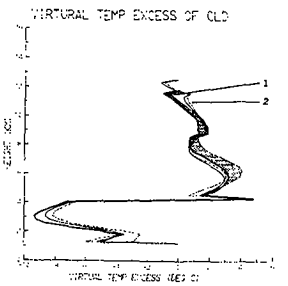
Fig. 2: Composite sounding changes, cloud profiles, & entrainment factors for responsive and Stommel experiments. Initial sounding was for Miami observed on May 27, 1968, 1200 GMT.

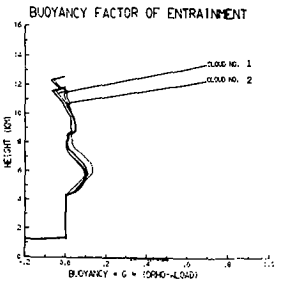


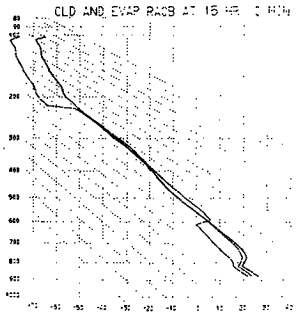
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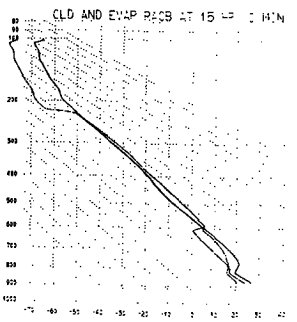


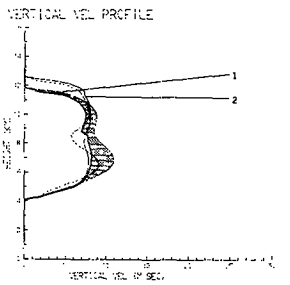
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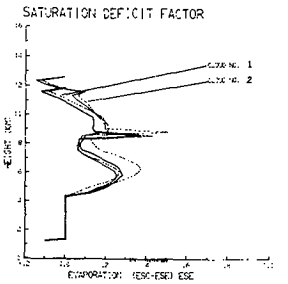


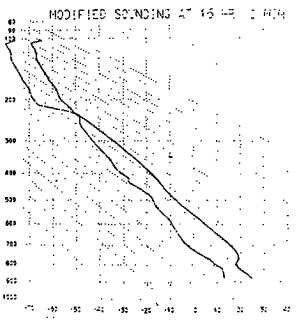


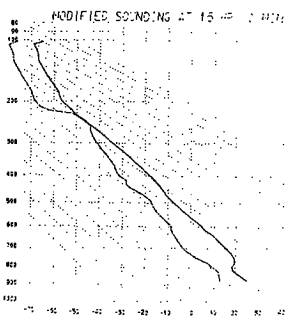


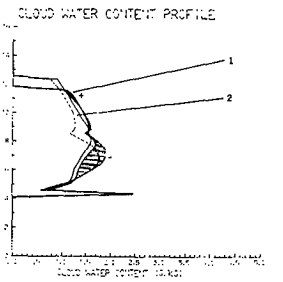


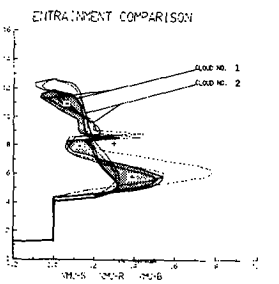


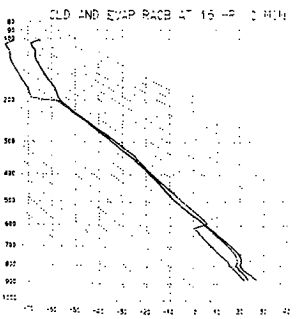


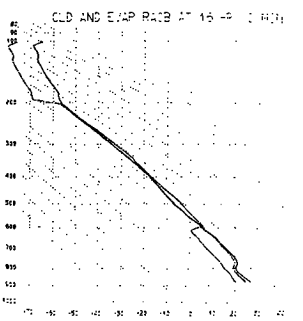


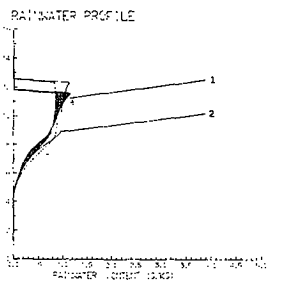


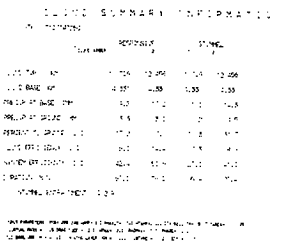


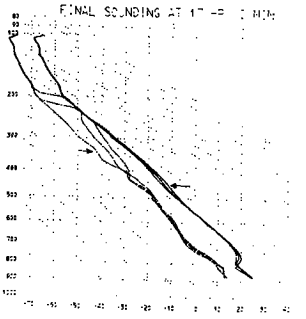


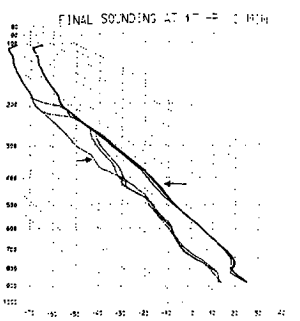












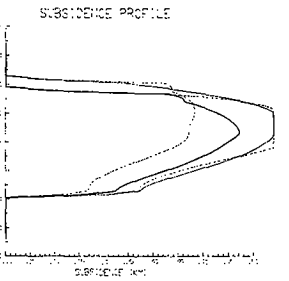


Fig. 3: Same as Fig. 2 for the Sterling, Colorado sounding observed on July 14, 1971 at 1250 LST.

USE OF CONDENSED WATER-PRECIPITATION RELATIONSHIPS IN ANALYZING EFFECTS OF CLOUD SEEDING

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ABSTRACT

The data from Project Cloud Catcher, a cumulus cloud seeding experiment, were analyzed to produce an estimate of condensed water and precipitation from each test case. A very good correlation exists between the cube roots of condensed water and precipitation. This relationship reveals a pattern which infers that the salt-seed cases produced more rainfall than the no-seed cases from both small and large clouds. The silver iodide seed cases produced more rainfall than the no-seed cases from smaller cloud systems which yielded about 100 to 200 acre-feet of water, but less rainfall from larger cloud systems.

INTRODUCTION

Precipitation enhancement can work in two different ways. One way is by increasing the efficiency with which a cloud turns its condensed water into rain. The other is by increasing the amount of water the cloud processes. This paper considers the first of these mechanisms. Using the data from a cumulus cloud seeding experiment, estimates of total water processed and total water precipitated from individual test clouds were made. A very good correlation between these two quantities was found. This close relationship provided a useful tool for evaluating the hypothesis that seeding increases the precipitation efficiency.

THE EXPERIMENT

The Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, conducted a cloud seeding experiment (termed "Project Cloud Catcher") near Rapid City, South Dakota, from approximately June 1 to August 15 of 1969 through 1972. The details of this project are described by Dennis and Koscielski (1972) and Koscielski and Dennis (1972).

Project Cloud Catcher was a randomized field experiment designed to determine the effects of salt and silver iodide seeding upon convective clouds in the northern Great Plains. The primary data acquisition sources were radar, instrumented aircraft, time-lapse cameras, and a rain gage network. Test cases were declared on clouds ranging from small, isolated cumuli to groups of towering cumuli already showing radar echoes. Values of Z_e, the equivalent radar reflectivity factor, were recorded on magnetic tape. Rainfall for each test case was estimated through the use of Z-R relationships.

a. Precipitation estimates

Two different radars were used in the project. A 3.2 cm radar was used during the first 2 years, and a 10 cm set was used the last 2 years. Consequently, two different Z-R formulas were used to translate radar reflectivity to rainfall. Rainfall in the test cases of 1969 and 1970 was estimated by converting the equivalent radar reflectivity factors at 10,000 feet to rainfall rates by the relation $Z_e = 200\ R^{1.6}$. The formula $Z_e = 360\ R^{1.7}$ was used in computing rainfall for the 1971 and 1972 cases. Z_e is in mm^6/m^3 and R is the rainfall rate in mm/hr. The precipitation from each test case was obtained by summing the contributions of precipitation from all cells within the test case. In some cases only a fraction of the cells precipitated.

b. Condensed water estimates

The total water condensed by a cell is defined by the following equation:

$$CW = \int_0^{t^*} A\ W\ \rho\ \Delta MR\ dt \qquad \text{(Eq. 1)}$$

A is the area of the updraft at some level, W is the updraft speed at that level, and ρ is the air density, again at the same level. ΔMR is the mixing ratio difference between base and top of cell, and t* is the duration of the updraft.

The updraft speed and updraft area are difficult to measure accurately, especially on a continuing basis throughout the cloud's active stage. The MR term can be estimated directly from the radiosonde information with minimum uncertainty once the cloud top height is determined by radar. Likewise, the air density can be determined from the sounding information. The duration can be established with fairly good accuracy by radar data analysis and analysis of time-lapse photographs.

For the investigation discussed here, the following procedure was used in estimating the condensed water for each test case:

(1) Condensed water was estimated for each cell within the test cases. An average value for each term in Equation 1 over the duration t* was determined.

(a) The updraft area and duration of cell life were estimated from radar data and time-lapse photographs.

(b) The updraft speed was obtained utilizing the output from a one-dimensional, steady-state convective cloud model (Hirsch, 1972). This model was run on a representative sounding for each experimental day. It predicts different cloud depths depending on the updraft radius that is assumed. The model-generated cloud depth chosen as the one representative

of each case generally was the one closest to the actual cell having the largest depth. The maximum updraft speed in the model-computed updraft profile was the one used in the computation of condensed water.

(c) The air density was computed for cloudbase height.

(d) ΔMR was computed from a thermodynamic chart considering average cloudbase and top characteristics.

(2) The total condensed water for each case was a summation of the condensed water for all cells in that case.

c. Data sample size

Table 1 summarizes sample size characteristics of the Cloud Catcher data. Of the 122 cases that were analyzed, there were nearly twice as many cases obtained during the first 2 years compared with the last 2 years and there were significantly more single-cell cases during the first 2 years. Forty percent of the cases fell in this category while less than 10 percent of the cases were so characterized during the last 2 years. Because of this difference, and also because there were changes in the manner of selecting test cases and significantly different types of radar were used to estimate precipitation, it is appropriate to treat each 2-year segment separately during the analysis. The Cloud Catcher scientists have also partitioned the data in this manner.

RESULTS

Figures 1 through 3 are scatter diagram plots which depict the relationship between condensed water and precipitation for each case for the years 1969-70, 1971-72, and 1969-72, respectively. A cube root transform was done on these quantities in order to normalize the distribution of points (see Stidd, 1953). This minimizes the chances that a few points will dominate the regression lines that are fitted to the sets of data. The least squares method was used to compute the best-fit regression lines and correlation coefficients for the no-seed, silver iodide seed, and salt-seed cases. The regression curves have been drawn in and the correlation coefficients plotted adjacent to each curve.

Linear regression equations provided the best fit of the data points for the first 2 years of data (Figure 1), for the combined 4 years (Figure 3), and for the salt-seed cases during 1971-72. A hyperbolic function provided the best fit of the points for the natural and silver iodide seed cases of 1971-72 (Figure 2), although the linear function also gave rather high correlations too (0.878 and 0.889, respectively). The small number of cases in these categories (13 and 8) may be the reason why the linear equation did not provide the best fit. In all cases the correlations were quite high, ranging from about 0.89 to 0.95.

The pattern that emerges generally is the same on all three figures. That is:

(a) The salt-seed cases produced more rainfall than the no-seed cases for both small and large precipitating cloud systems.

(b) The silver iodide seed cases produced more rainfall than the no-seed cases for cloud systems producing less than about 100 to 200 acre-feet of water, but less rainfall for more productive cloud systems.

A linear covariance analysis of the cube root of condensed water versus the cube root of precipitation was carried out. The results of this analysis are shown in Table 2. For the 1969 and 1970 data, the difference between salt-seed and no-seed is significant at the 2.5 percent level and between silver iodide seed and no-seed around the 10 percent level. The difference between silver iodide seed and salt-seed is significant at the 1 percent level. No significant difference shows up in the 1971-72 data using this test. The reason for this may be due to the fact that the best fit regression equations for two of the curves are not linear.

For reasons mentioned previously, it was deemed appropriate to separate the first 2 years' data from the last 2 years' for analysis purposes. However, as a matter of interest, all 4 years of data have been considered in Figure 3. The difference between salt-seed and no-seed is significant at only the 10 percent level and no significant difference shows up between the silver iodide seed and no-seed cases. As occurred in the 1969-70 data, the difference between silver iodide seed and salt-seed is significant at the 1 percent level.

DISCUSSION

The total precipitation from a cloud system is dependent upon the amount of condensed water processed and the precipitation efficiency of the system. This relationship in equation form is:

$$\text{PRECIP} = (\text{PRECIP EFF}) \times \text{CW} \qquad \text{(Eq. 2)}$$

and expanding CW from Equation 1:

$$\text{PRECIP} = (\text{PRECIP EFF}) \int_0^{t^*} A\, W\, \rho\, \Delta MR\, dt \qquad \text{(Eq. 3)}$$

PRECIP EFF is a function of many things, such as updraft profile, cloud liquid-water profile, cloud duration, cloud depth, wind shear, cloud droplet spectra, and mixing. But condensed water is also a function of many of these factors. So with precipitation efficiency being related to condensed water, it is no surprise that a good relationship has been found to exist between precipitation and condensed water.

The results of some recent theoretical cloud modeling experiments (Orville, Kopp, and Hubbard, 1973) lend support to the results discussed in the last section. Their initial experiments indicate that when compared with the natural cloud, the heavy continuous ice-phase seeding yields less rain and graupel while light continuous ice-phase seeding yields more rain for the shallower clouds but less for the deeper clouds. The modeling experiments also showed that hygroscopic seeding yields more rain for a broad range of cloud sizes.

The present investigation has considered only precipitation efficiency changes that might have occurred following seeding. If any dynamic effects occurred in the seeded cases, they have not been considered. Dynamic effects were disregarded not because they were known to be of minor importance, but rather because of the difficulty involved in estimating them. It is conceivable that a dynamic reaction to seeding could have occurred and exerted a very important influence on the clouds studied. For instance, in the results section it was pointed out that for a given amount of water condensed the silver iodide seed cases seemed to produce less rainfall (for the larger cloud systems) than the no-seed cases did. One possibility is that the ice-phase seeding could have caused the cloud to become more buoyant, thereby growing larger, lasting longer, and consequently processing more water. However, in the process the precipitation mechanism could have been made more inefficient through a freezing up of cloud water and precipitation particles as well as a significant increase in updraft speed. While these clouds may appear to produce less rainfall per unit of condensed water than natural clouds, it is still possible that they are more productive than if they had been left unmodified. The seed to no-seed differences indicated by the procedure used would tend to be concealed if the estimate of condensed water was increased by dynamic effects.

An attempt was made to isolate those cases in which no further cloud growth was observed following the declaration of a test. It is theorized that the microphysical effect in these clouds due to seeding would be predominant. A sample size of 25 cases was found from the 1969-70 data set in which 11 were no-seed, 9 were salt-seed, and 5 were silver iodide seed. A comparison was again made between the cube root of condensed water and the cube root of precipitation, and the resulting regression lines showed the same basic pattern as appeared in Figure 1. However, the correlations turned out to be much higher. Whereas the correlation coefficients for all the data points of 1969-70 were 0.901, 0.945, and 0.911 for no-seed, salt-seed, and silver iodide seed cases, respectively, they turned out to be 0.947, 0.982, and 0.981 for this sample. Because of the small size of this sample, not too much emphasis should be placed on these results. But it should be mentioned that there is at least an implication that the precipitation efficiency term in Equations 2 and 3 is very closely related to the same factors that comprise condensed water when the clouds reach a semisteady-state character.

COMPARISON OF RESULTS

In their analysis the Cloud Catcher scientists found a relatively good

relationship to exist between cloud depth and the cube root of estimated rainfall for the 1969-70 data (1973 Annual Report on Project Cloud Catcher). Figure 4 illustrates a scatter diagram and regression lines which depict this relationship (reprinted from 1973 Annual Report). The correlation coefficients for the regression lines are 0.91 (no-seed), 0.85 (salt-seed), and 0.86 (silver iodide seed). However, when this relationship for the 1971-72 data is depicted on a scatter diagram (see Figure 5), the quality of fit decreases substantially. The correlation coefficient for the refression line of the no-seed cases is still rather high (0.90) but is only 0.76 and 0.20 for the salt-seed and silver iodide seed, respectively. This would seem to imply that the physical mechanisms which influence precipitation are very interactive, and individual factors may dominate some of the time and exert a small influence on other occasions. To the degree possible it would seem to be judicious to consider all the factors which influence the precipitation process.

When one combines the information from Figures 1 and 4, an interesting inference becomes evident. Figure 1 indicates that for silver iodide seed cases there was less rain per amount of condensed water than from the other clouds, while Figure 4 indicates that there was more rainfall per unit of cloud depth. Thus, it would seem that silver iodide seeded clouds yielded more condensed water per unit of cloud depth than other clouds. This might mean that they had greater updraft diameters, more vigorous updrafts, or lasted longer - or a combination of all three.

FUTURE ANALYSES

In this investigation, analyses were carried out on a case-by-case basis, where each case was comprised of anywhere from one to six cells. The next investigation will consider the cell as the basic unit. The relationship between condensed water and precipitation will again be checked. The relationships between cell depth and updraft diameter, and cell depth and cell lifetime, will also be looked at. If good correlations between these quantities are found to exist, it will not only lead to an easier method of estimating condensed water, but will also enhance the chances of being able to estimate dynamic changes that might have occurred.

ACKNOWLEDGMENTS

The author is grateful to Mr. Clem Todd and Dr. Wallace Howell for their helpful comments and suggestions. Thanks also goes out to Mr. Alex Koscielski for preparing the data in the appropriate format.

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Orville, H.D., F.J. Kopp and K. Hubbard, 1973: Numerical simulation of cloud seeding experiments. Book of Abstracts. Intern. Conf. on Weather Modification, Tashkent, USSR, Hydrometeor. Serv. of the USSR, 26-27.

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TABLE 1

NUMBER OF CLOUD CATCHER CASES ANALYZED AND THE NUMBER OF INDIVIDUAL CELLS INVOLVED

Percentage of total is shown in parentheses

	1969-70	1971-72	1969-72
Number of cases	80	42	122
Natural	33 (41%)	13 (31%)	46 (38%)
Salt Seed	29 (36%)	21 (50%)	50 (41%)
Silver iodide	18 (23%)	8 (19%)	26 (21%)
Number of cells	170	117	287
Cases with one cell	32 (40%)	4 (9%)	36 (30%)
Cases with two cells	23 (29%)	15 (36%)	38 (31%)
Cases with three cells	13 (16%)	13 (31%)	26 (21%)
Cases with four or more cells	12 (15%)	10 (24%)	22 (18%)

FIGURE LEGENDS

Figure 1. Scatter diagram comparing the cube root of estimated condensed water and the cube root of radar-estimated rainfall for no-seed, silver iodide seed, and salt-seed cases (1969-70 Cloud Catcher data). Best fit regression lines and corresponding correlation coefficients are shown.

Figure 2. Scatter diagram comparing the cube root of estimated condensed water and the cube root of radar-estimated rainfall for no-seed, silver iodide seed, and salt-seed cases (1971-72 Cloud Catcher data). Best fit regression lines and corresponding correlation coefficients are shown.

Figure 3. Scatter diagram comparing the cube root of estimated condensed water and the cube root of radar-estimated rainfall for no-seed, silver iodide seed, and salt-seed cases (1969-72 Cloud Catcher data). Best fit regression lines and corresponding correlation coefficients are shown.

Figure 4. Scatter diagram comparing the cloud depth and the cube root of radar-estimated rainfall for no-seed, silver iodide seed, and salt-seed cases (1969-70 Cloud Catcher data). Best fit regression lines are shown.

Figure 5. Scatter diagram comparing the cloud depth and the cube root of radar-estimated rainfall for no-seed, silver iodide seed, and salt-seed cases (1971-72 Cloud Catcher data). Regression line which fits all the data is shown.

Table 2

RESULTS OF COVARIANCE ANALYSIS OF CUBE ROOT OF ESTIMATED CONDENSED WATER VERSUS THE CUBE ROOT OF RADAR ESTIMATED RAINFALL FROM PROJECT CLOUD CATCHER

$X = (\text{condensed water})^{1/3}$
$Y = (\text{rainfall})^{1/3}$

	F(means)	F(one line)	F(same slope)
		1969-1970	
AGI-NO SEED	F(1,48) = 0.18	F(2,47) = 1.65	F(1,47) = 3.11*
SALT-NO SEED	F(1,59) = 5.70**	F(2,58) = 4.77**	F(1,58) = 3.59*
AGI-SALT	F(1,44) = 1.20	F(2,43) = 7.78***	F(1,43) = 14.01***
SEED-NO SEED	F(1,77) = 2.52	F(2,76) = 1.34	F(1,76) = 0.19
		1971-1972	
AGI-NO SEED	F(1,18) = 1.16	F(2,17) = 1.53	F(1,17) = 1.85
SALT-NO SEED	F(1,31) = 0.0	F(2,30) = 0.43	F(1,30) = 0.86
AGI-SALT	F(1,26) = 0.62	F(2,25) = 0.83	F(1,25) = 1.04
SEED-NO SEED	F(1,39) = 0.13	F(2,38) = 1.03	F(1,38) = 1.92
		1969-1972	
AGI-NO SEED	F(1,69) = 0.04	F(2,68) = 0.70	F(1,68) = 1.36
SALT-NO SEED	F(1,93) = 3.49*	F(2,92) = 2.75*	F(1,92) = 1.99
AGI-SALT	F(1,73) = 2.36	F(2,72) = 4.99***	F(1,72) = 7.40***
SEED-NO SEED	F(1,119) = 1.70	F(2,118) = 0.93	F(1,118) = 0.16

*10 percent significance level exceeded.
**2.5 percent significance level exceeded.
***1 percent significance level exceeded.

FIGURE 1

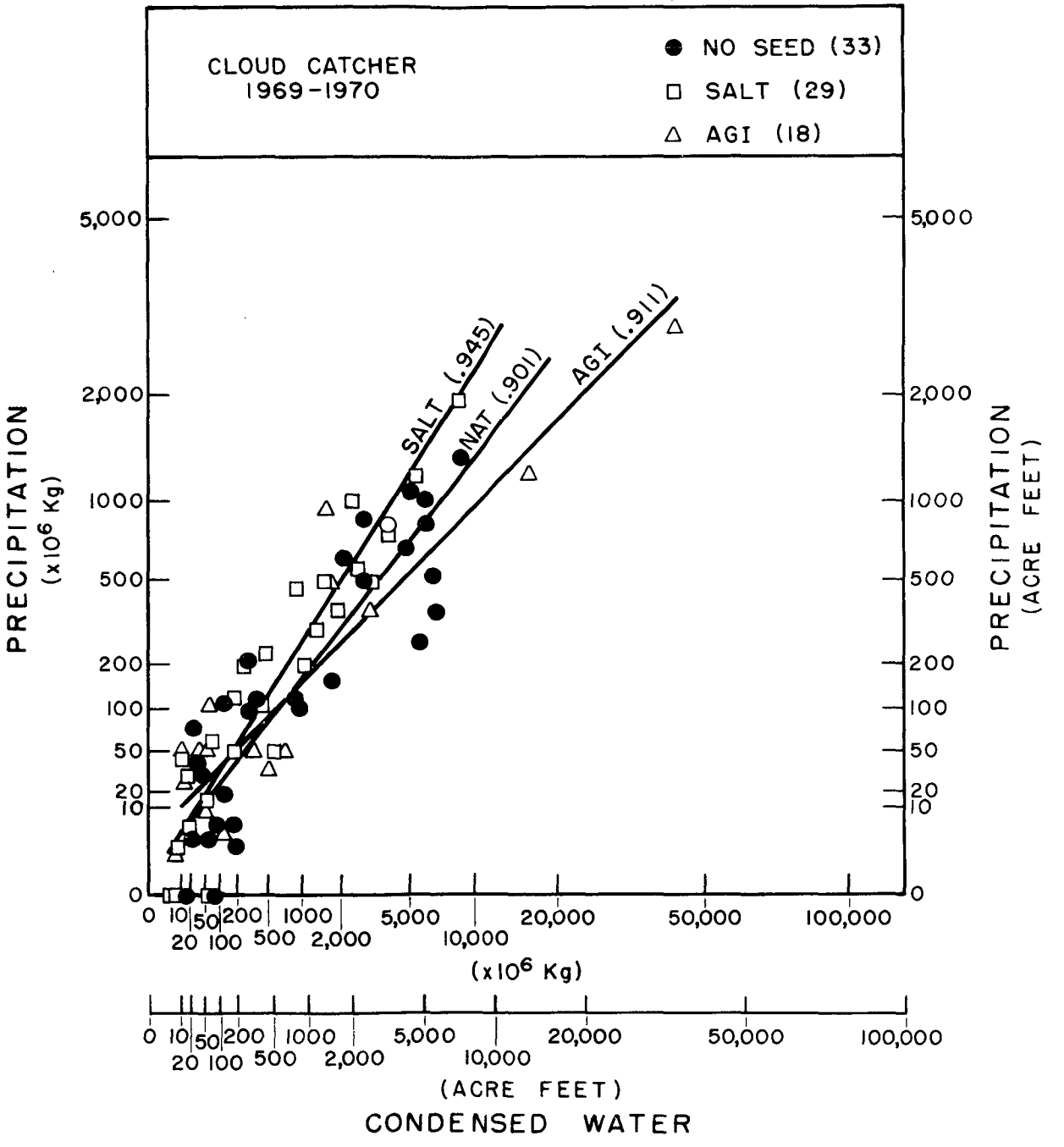

CLOUD CATCHER
1969-1970
NO SEED (33)
SALT (29)
AGI (18)
SALT (.945)
NAT (.901)
AGI (.911)
PRECIPITATION
(x10⁶ Kg)
PRECIPITATION
(ACRE FEET)
5,000
2,000
1000
500
200
100
50
20
10
0
0 10 50 200 1000 5,000 20,000 50,000 100,000
20 100 500 2,000 10,000
(x10⁶ Kg)
0 10 50 200 1000 5,000 20,000 50,000 100,000
20 100 500 2,000 10,000
(ACRE FEET)
CONDENSED WATER

FIGURE 2

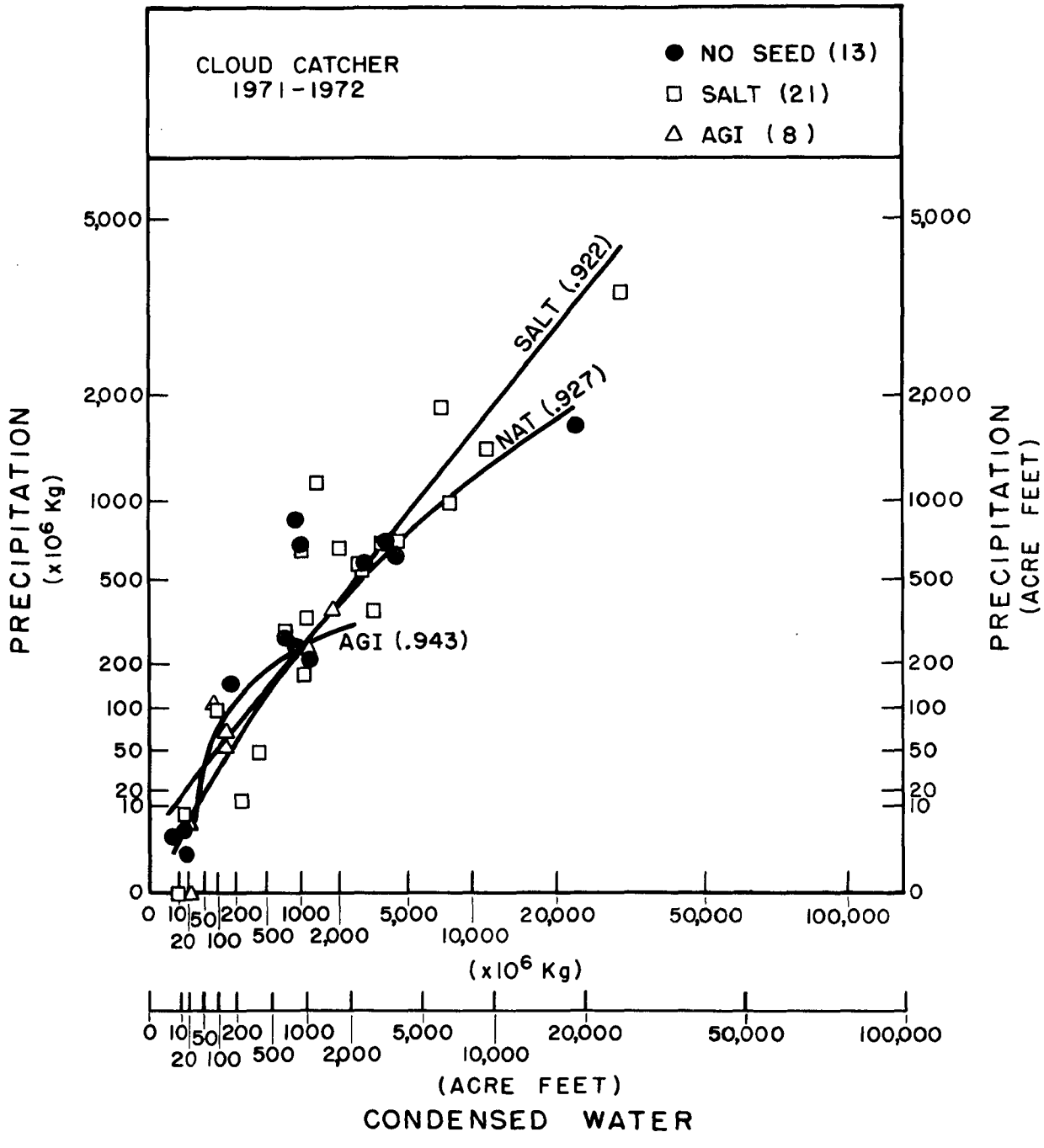

CLOUD CATCHER
1971-1972
NO SEED (13)
SALT (21)
AGI (8)
SALT (.922)
NAT (.927)
AGI (.943)
PRECIPITATION (x10⁶ Kg)
PRECIPITATION (ACRE FEET)
5,000
2,000
1000
500
200
100
50
20
10
0
0 10 20 50 100 200 500 1000 2,000 5,000 10,000 20,000 50,000 100,000
(x10⁶ Kg)
0 10 20 50 100 200 500 1000 2,000 5,000 10,000 20,000 50,000 100,000
(ACRE FEET)
CONDENSED WATER

FIGURE 3

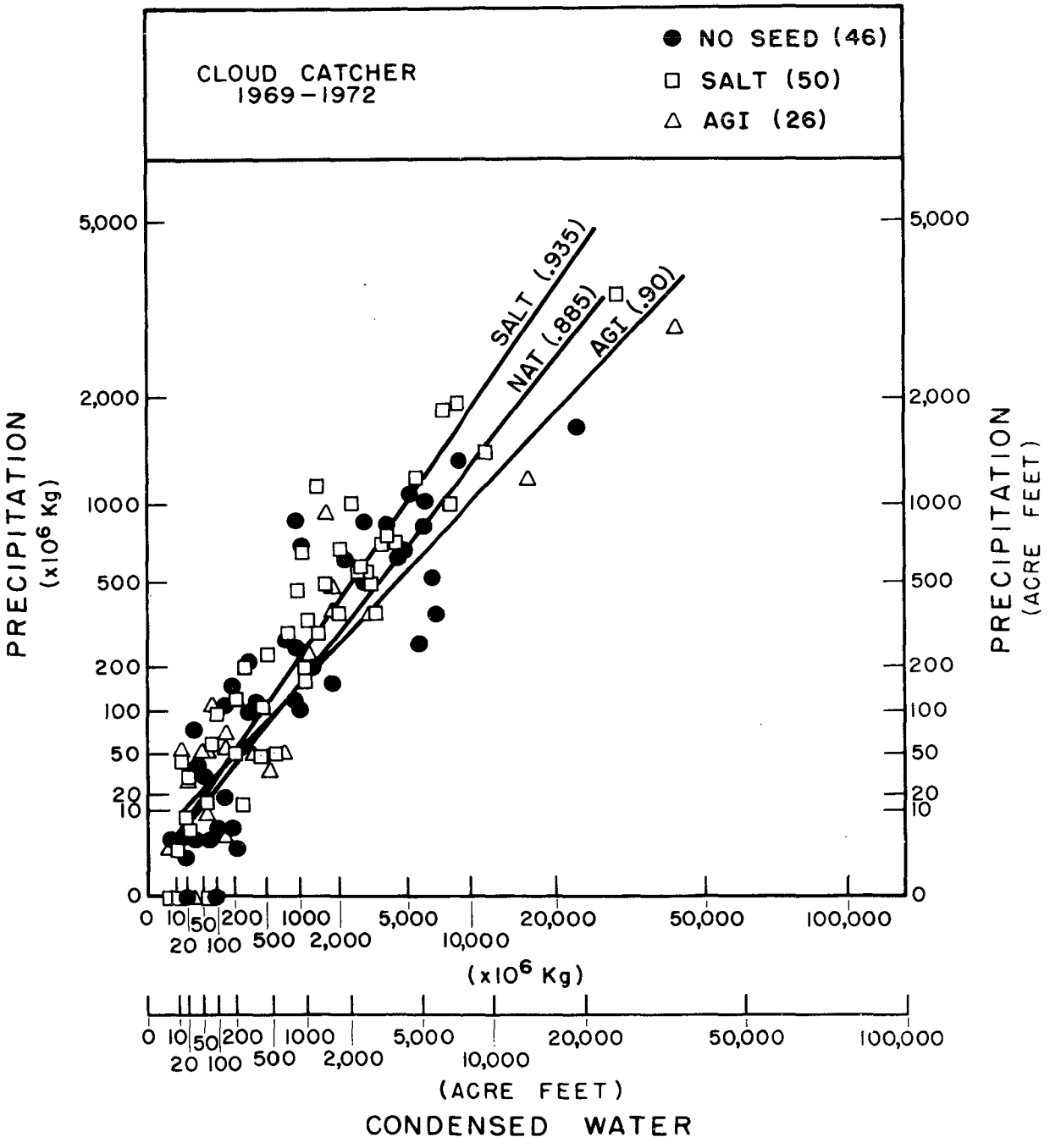

CLOUD CATCHER
1969–1972
NO SEED (46)
SALT (50)
AGI (26)
SALT (.935)
NAT (.885)
AGI (.90)
PRECIPITATION
(x10⁶ Kg)
PRECIPITATION
(ACRE FEET)
5,000
2,000
1000
500
200
100
50
20
10
0
0 10 50 200 1000 5,000 20,000 50,000 100,000
20 100 500 2,000 10,000
(x10⁶ Kg)
0 10 50 200 1000 5,000 20,000 50,000 100,000
20 100 500 2,000 10,000
(ACRE FEET)
CONDENSED WATER

FIGURE 4

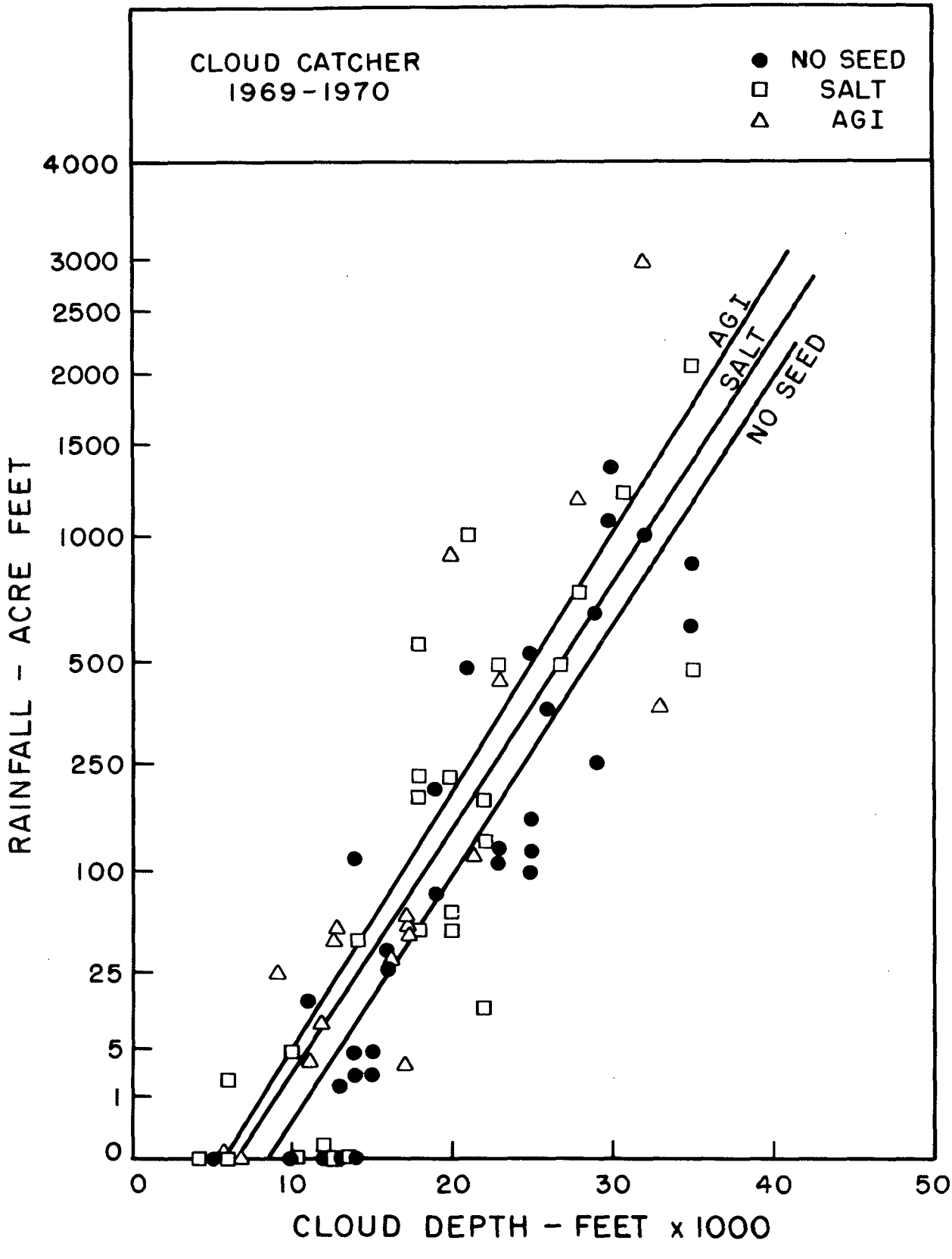
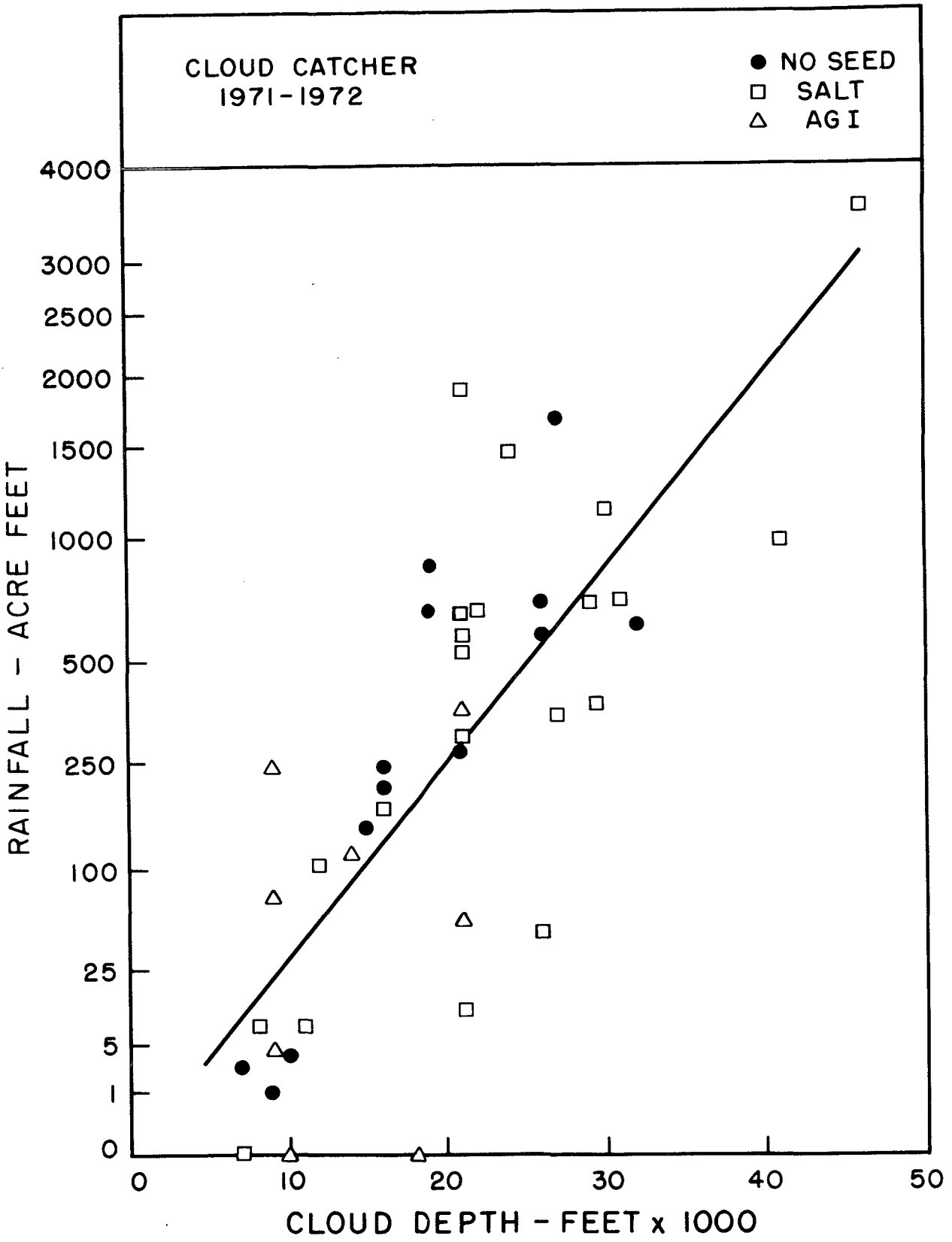

CLOUD CATCHER
1969-1970
NO SEED
SALT
AGI
4000
3000
2500
2000
1500
1000
500
250
100
25
5
1
0
RAINFALL - ACRE FEET
AGI
SALT
NO SEED
0
10
20
30
40
50
CLOUD DEPTH - FEET x 1000

FIGURE 5


CLOUD CATCHER
1971-1972
NO SEED
SALT
AG I
RAINFALL - ACRE FEET
4000
3000
2500
2000
1500
1000
500
250
100
25
5
1
0
0
10
20
30
40
50
CLOUD DEPTH - FEET x 1000

PRACTICAL USE OF TIME-LAPSE PICTURES OF RADAR ECHOES TO ESTIMATE AREAS AFFECTED BY SEEDED CLOUDS

Ray T. Telfer
Bureau of Reclamation
Denver, Colorado

On any cloud seeding project, it is rather difficult to determine precisely the areas or rain gages over which rain from seeded clouds has fallen. However, time-lapse photographs of the movement of cloud echoes on a radar scope offer a convenient means for making the determination. The following discussion describes how time-lapse photographs of radar echoes were used to determine areas and rain gages over which seeded clouds traversed on seeded days during the summer of the 1973 Kansas Cumulus Project (KANCUP '73).

The seeding aircraft used on KANCUP '73 was equipped with a transponder. Therefore, its seeding track could be followed accurately on and photographed from a 3 cm radar scope. A real-time clock was mounted on the outer edge of the radar scope (see Figures 1 and 2) so the exact times at which the aircraft or any cloud echo was over a particular geographical position could be accurately determined. All cloud echoes that were present just before or developed during or after the seeding operations were photographed once on every sweep on the scope. The pictures of these cloud echoes, together with those of the aircraft movements, were later projected onto a map such as the one depicted in Figure 3.

When the seeding tracks and estimated active plume positions were plotted and annotated with respect to time on the map, the radar filmstrip was rewound, and a second slow projection onto the map was performed. On this projection, cloud echoes present just prior to or developing during seeding times were colored in red on the map. These clouds continued to be colored in red as their positions changed when successive frames of film were projected onto the map. Echoes from clouds which were present at or in close proximity to the aircraft track when seeding was underway were assumed to be seeded if their drift coincided with the drift of the seed plume to locations where the seed was calculated to be active. However, projections of these cloud echoes were colored in red as though they were unseeded until they reached the active plume positions. Thereafter, their successive positions were colored in green. Those cloud echoes which first appeared on the scope at or near the plume positions at those times when the plumes were calculated to be active were assumed to be first echoes and were annotated accordingly. They were colored in green when they first appeared, and their projections continued to be colored in green until they dissipated.

The resulting red and green colorations on the map were assumed to represent the cloud footprints on the ground. A reprojection of the radar film at full speed over the colored footprints provided a colorful, life-like depection of the developments, movements, or dissipations of seeded

and unseeded clouds alike, together with the movements of the cloud seeding aircraft along its track. This enabled one to isolate and visualize the behavior of seeded clouds and the probable areas they affected despite the coexistance of a multitude of unevenly distributed unseeded clouds. The vivid color projection proved not only to be an effective analytical tool, but an impressionable presentation aid for demonstrating to interested or concerned groups the probable regions affected at specific times during KANCUP '73 cloud seeding experimentations.

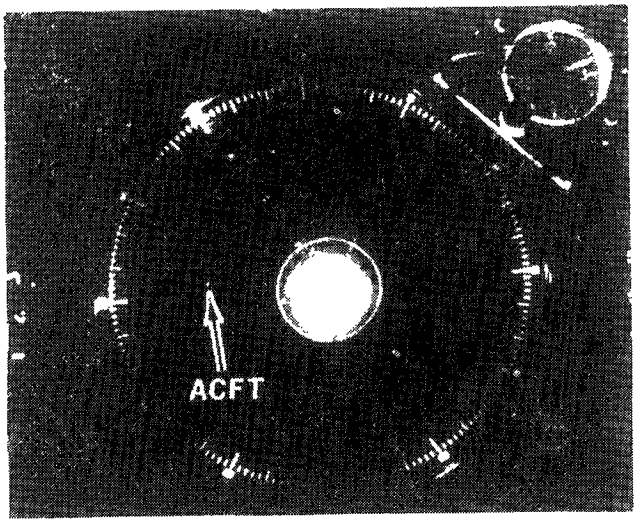
In the above explained analysis scheme, rain on the ground in areas covered by green footprints as depicted in Figure 3 was assumed to have fallen from seeded clouds. Accordingly, the rain gages within these areas were assumed to be measuring rain from seeded clouds. Likewise, any rain in gages within areas covered by red footprints was assumed to be from unseeded clouds.

The cited rain gage measurements were contoured (see Figure 4). Comparisons were then made of rainfall amounts in areas covered by seeded (green) cloud footprints and areas covered by unseeded (red) cloud footprints. In Figure 3 the seeded cloud footprints are depicted with dotted areas and unseeded cloud footprints are depicted by dashed line areas. Those areas traversed by both seeded and unseeded clouds are depicted by both dots and dashed lines. Figure 5 depicts an isolation of those areas over which some rain had fallen from seeded clouds as determined from Figure 3 for August 30, 1973. This particular example was selected for illustration because on this day numerous cumulus cells existed over the KANCUP '73 experimental area. Many of these clouds' footprints, seeded and unseeded alike, traversed a dense network of rain gages whose locations are pinpointed by small dots in Figure 5.

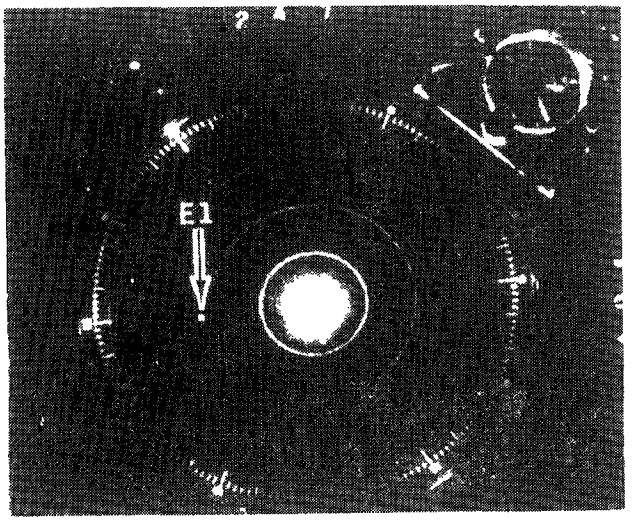
In conclusion, this discussion is intended to present an example of how time-lapse radar photographs, which are inexpensive and easily collected, can be of considerable assistance in reducing many of the uncertainties that always exist as to whether or not rain gages (regardless of the number or their distribution) receive rain from seeded or unseeded clouds. In essence, the example also introduces a practical evaluation procedure which can be useful to any cloud seeding endeavor - experimental or operational. It could be especially useful to the commercial operator who is often obligated to provide his clients with a rapid and reasonably reliable evaluation as to the effectiveness of his efforts.

LIST OF FIGURES

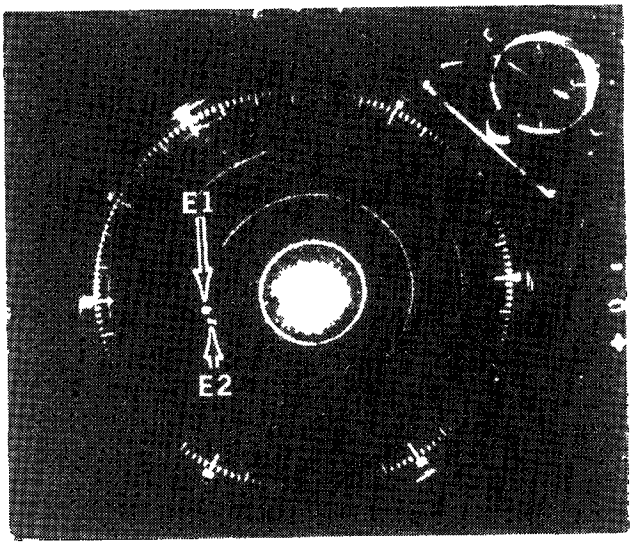
Figure: 1. Evaluation of August 30, 1973 cloud seeding effects on Project KANCUP'73.
2. Areas over which seeded clouds produced radar echoes, Aug. 30, 1973, 1500-2100.
3. Radar photograph sequence, Aug. 30, 1973.
4. Radar photograph sequence, Sept. 4, 1973.
5. Precipitation for 24 hours ending 0700, Aug. 31, 1973.



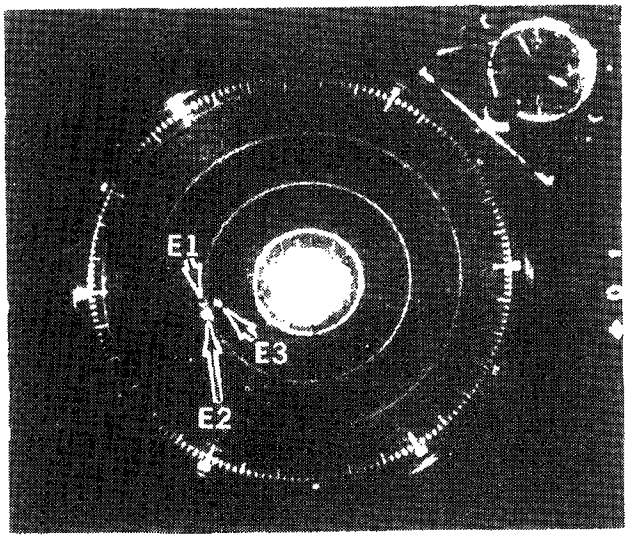
2:11 P.M. Aircraft identification beacon visible during seeding.



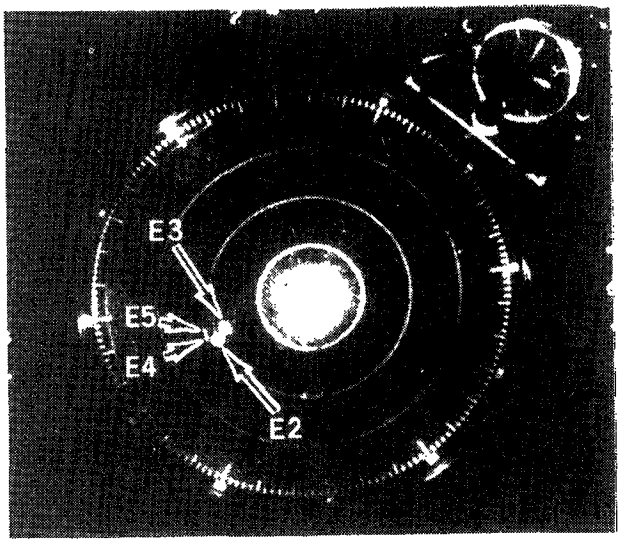
3:27 P.M. Event 1 "first echo".



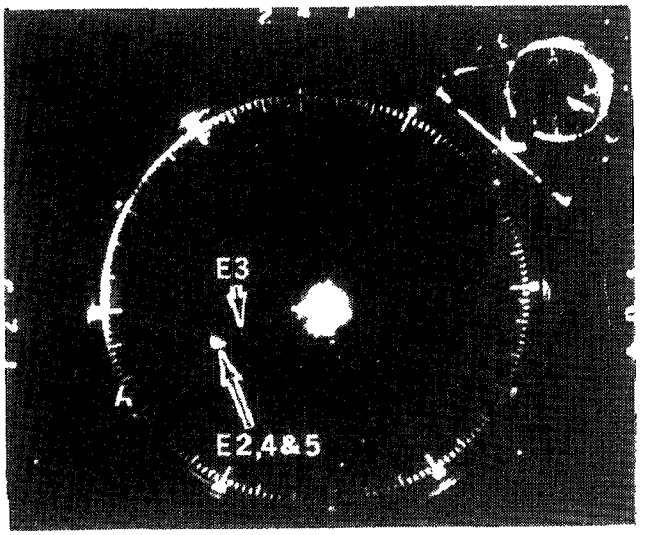
3:51 P.M. Event 2 "first echo".



3:56 P.M. Event 3 "first echo". Event 1 has nearly dissipated

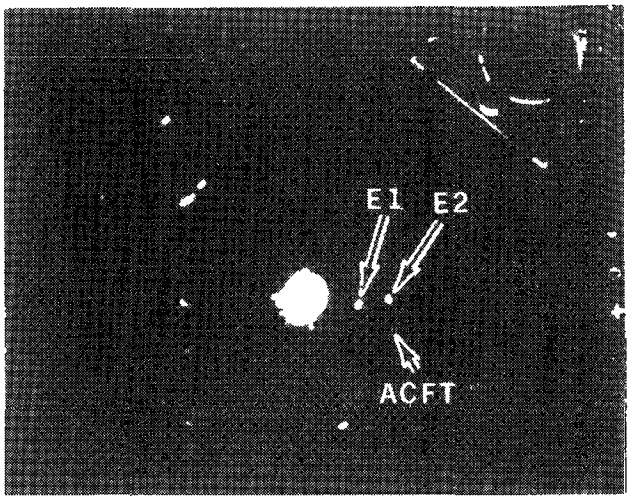


4:06 P.M. Events 4 and 5 showed echoes simultaneously.

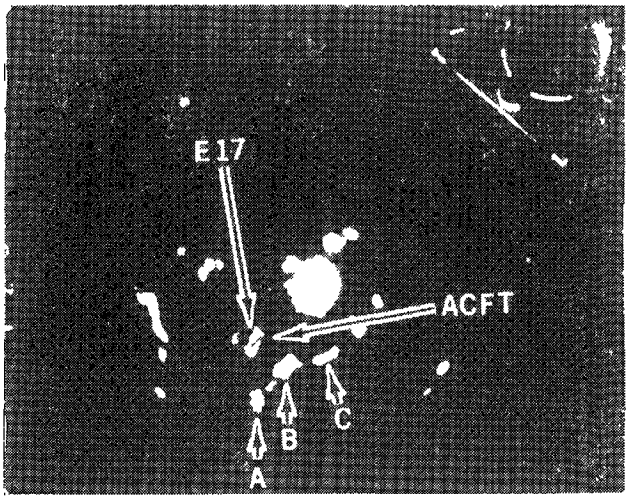


4:20 P.M. Events 2, 4 and 5 merged. Event 3 dissipating.

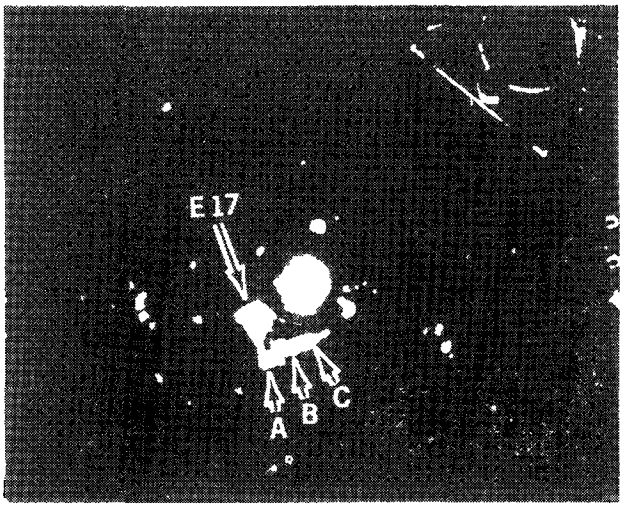
Figure 1. Radar photo sequence, September 4, 1973.



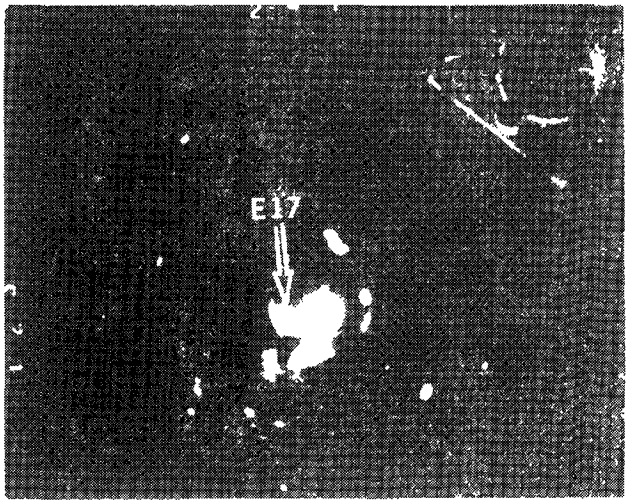
3:26 P.M. Fifteen minutes after seeding Event 1 and 9 minutes after seeding Event 2. Aircraft identification beacon is also visible on the scope.



5:37 P.M. Event 17 is being seeded. Echoes A, B and C are also seeded cells.



5:52 P.M. Fifteen minutes after seeding, Event 17 noticeably brightens. Note that echoes A, B and C have merged into a line.



6:15 P.M. Event 17 persisting 38 minutes after seeding.

Figure 2. Radar photo sequence, August 30, 1973.

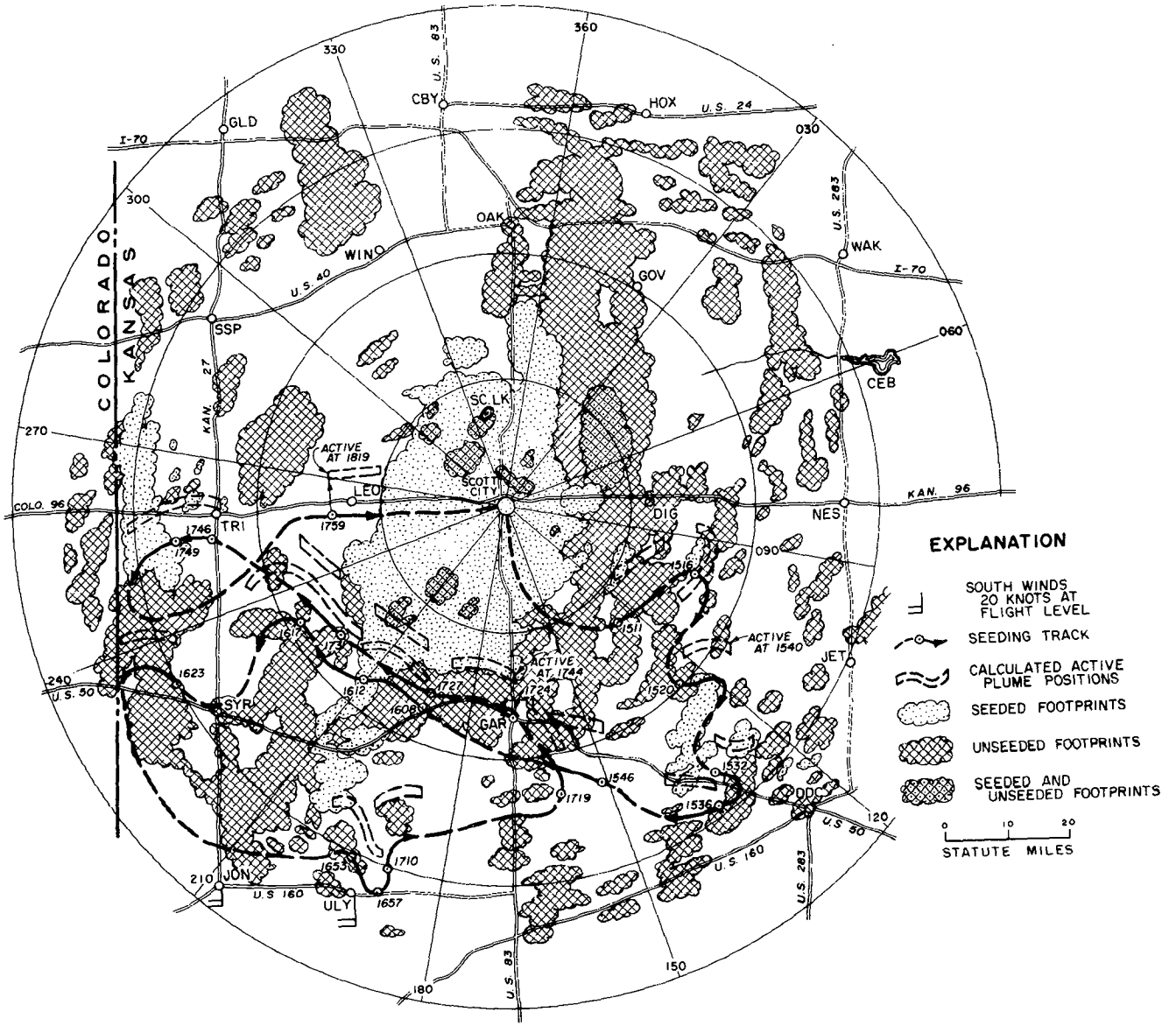


Figure 3. Evaluation of August 30, 1973 cloud seeding effects on Project Kancup

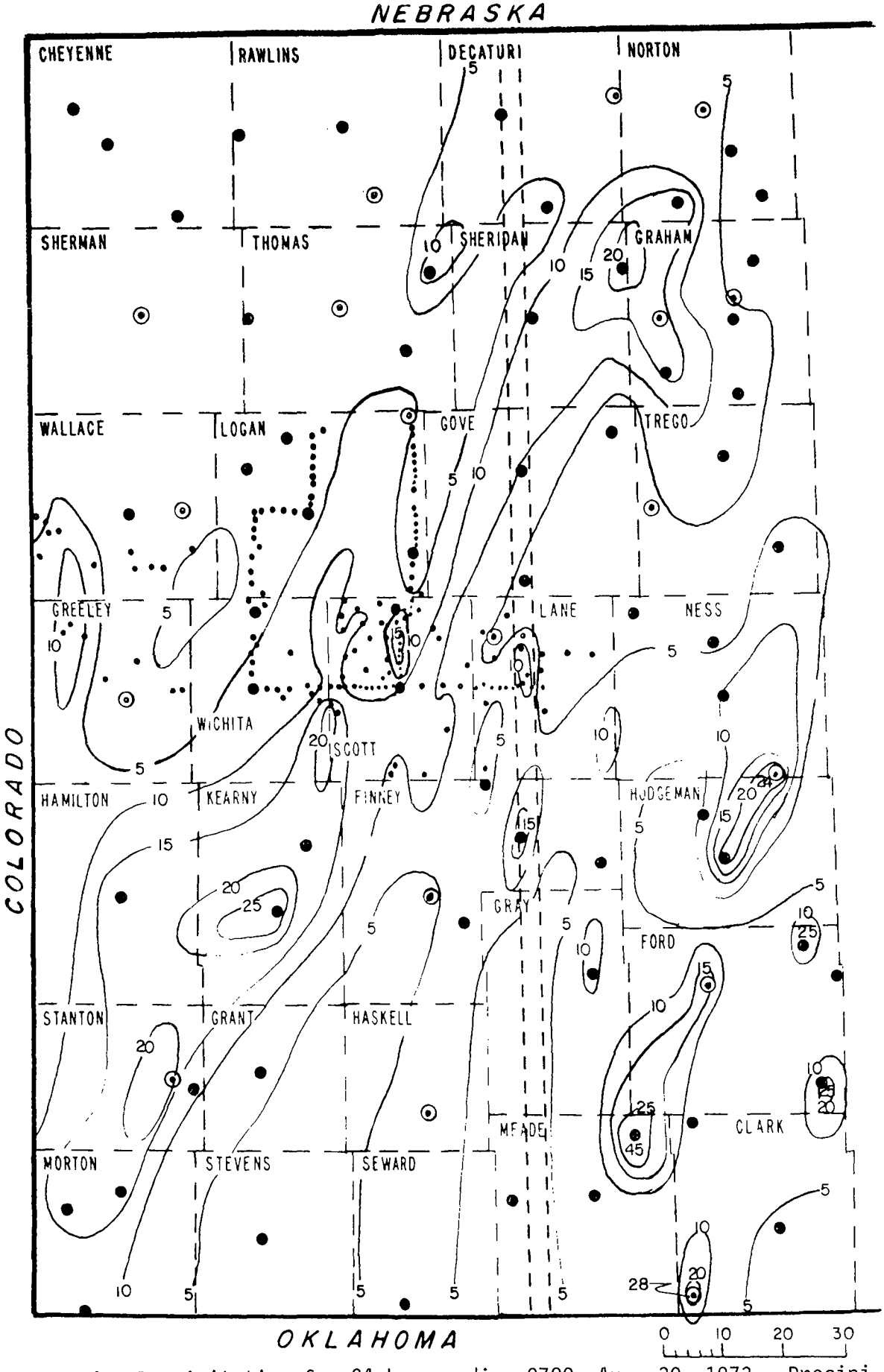


FIGURE 4: Precipitation for 24 hrs. ending 0700, Aug. 30, 1973. Precipitation to the east of the double dashed vertical line was due to an unseeded mid-morning squall line. Precipitation to the west of this line was due to afternoon convective clouds.

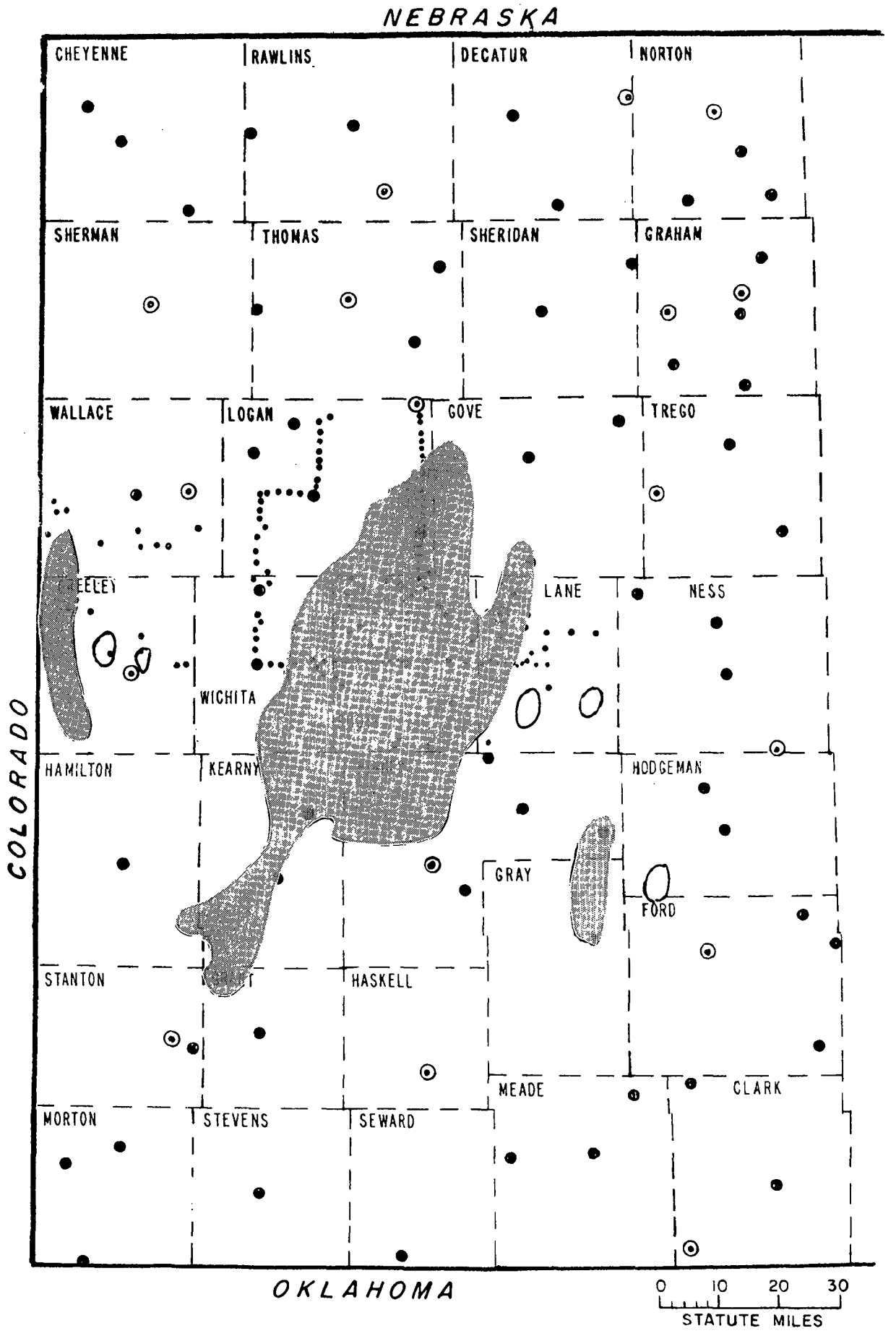


Figure 5. Areas over which seeded clouds produced radar echoes, August 30, 1973, 1500-2100.

MODIFICATION OF SUBTROPICAL WINTER CUMULUS CLOUDS - CLOUD SEEDING AND CLOUD PHYSICS IN ISRAEL*

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The Hebrew University of Jerusalem-Israel
Department of Atmospheric Sciences

1. INTRODUCTION

The first Israeli randomized cloud-seeding experiment took place in the years 1961-67. It was a cross-over experiment involving two areas, one of which on any given day served as an experiment area while the other one acted, on the same day, as a control. The roles of the two were interchanged according to a random scheme. The statistical results were examined by several investigators (Gabriel, 1970; Wurtele, 1971; and, most recently, Mielke, 1973). All these investigators found that there was an increase of rain on days of seeding, the apparent increase being about 15% or so, and the statistical significance of that result was deemed significant to very highly significant, depending on the method applied. The seeding project was accompanied by a program in cloud physics and by some relevant statistical research. As the years progressed, the research activities, especially those in cloud physics, intensified. A presentation of the statistical results will be found in a report by Gabriel (1970), while a review of the results in cloud physics and their meaning for the seeding project as well as a renewed examination of the statistical results are to be found in a paper by Gagin and Neumann (1973).

While the principal objective of Experiment I (Exp. I) was to explore the possibilities of rain enhancement in areas which were not selected for some specific reason, Exp. II was launched in 1969 with the specific purpose of studying the possibilities of rainfall augmentation over the catchment area of Lake Tiberias (Lake, or Sea, of Galilee). This lake is the source of water for Israel's National Water Carrier which transports water from the comparatively rainy (rainy in winter) north to the more arid, or arid, south. The importance of the objective is seen in that the Lake supplies - through the Carrier - about 1/4 of Israel's water consumption. Without its waters the cultivation of the more southern areas of the country would be impossible.

We note that the cloud seeding experiments conducted by the NOAA Experimental Meteorology Laboratory in Florida (see paper by Joanne Simpson et al., 1973, at this symposium) and those of our Group rely on different physical principles. The former endeavors to enhance rainfall through the release of large amounts of 'latent' heat designed to lead to a rapid growth of cumulus clouds, the latent heat deriving from the administration of massive doses of silver iodide particles to individual

*Reprinted from the Proceedings of the International Tropical Meteorology Meeting, Jan. 1 - Feb. 7, 1974, Nairobi, Kenya

cumulus clouds or to systems of cumulus clouds. The Israeli experiment, on the other hand, aims primarily at changing the microphysical properties of cumulus clouds, or, more specifically, at modifying their large-hydrometeor properties. Hence, the seeding is directed at affecting clouds of a relatively large area lying downwind from a line of seeding by aircraft.

2. PRELIMINARY RESULTS OF EXPERIMENT II

Exp. II was designed (and begun) in 1969 with the participation of K. R. Gabriel, Dept. of Statistics, The Hebrew University of Jerusalem. With the 24-hr day as our fundamental 'time unit', and assuming, on the basis of Exp. I, a possible increase under seeding of 15% to 20%, we estimated that in order to reach a significance level of 5% or better, on a 'power-of-test' of 75% and a correlation coefficient (between control and target in the North) of 0.88, we shall need 7.3 to 4.2 years of experimentation, respectively. At the time of writing this paper (Sept., 1973) we have completed but four years of Exp. II and, thus, the results are preliminary.

In Exp. II, we again have two experiment areas, though the areas are larger than those of Exp. I. In the southern experiment area of Exp. II, the rainfall is much more variable than in the northern one, and consequently, work will have to go on for a longer period in order to be able to identify effects, if any. Therefore, at the present time we will report results for the northern area alone, which includes the major part of the catchment area of Lake Tiberias. As was pointed out in Sec. 1, the principal aim of Exp. II is to enhance, if possible, rainfall over the catchment. One other feature of the present experiment in which it differs from Exp. I is in that we now have a control area (CA) for the northern experiment area (NEA). The CA lies to the west and southwest of the NEA. The correlation coefficient between the daily rainfalls of the two is 0.88, so that the two are very highly correlated, a fact which adds greatly to the usefulness of the CA.

Seeding in the NEA is done on randomly allocated days by aircraft flying at cloud-base level to the west of the area (on most rain days, winds have a westerly component) and by ground generators placed in locations where the orography should help the particles reach the clouds. The effect of seeding is estimated through the ratio (DR=Double Ratio)*

$$DR = \frac{E_S}{E_N}\,\frac{C_N}{C_S} = \frac{E_S}{C_S}\,\frac{C_N}{E_N}\ , \qquad (1)$$

where E stands, for short, for the average daily rainfall for the experiment area, C for the parallel average for the control area and the subscripts

*It will be noted that the DR is not identical with the Root Double Ratio which can be used in the case of a cross-over experiment such as our Exp. I.

S and N denote days allocated, respectively, to seeding and to no-seeding. As in Exp. I (a) a day allocated to seeding, but not actually seeded (no clouds, or, cloud tops warmer than -5C), counts as seeded; (b) the Buffer Area (BA), which is not seeded, serves as an objective indicator of 'natural' conditions: days when no measurable amounts of rain occur in the BA, are excluded from the experiment.

If (a) the experiment comprises a large number of experiment time units, and (b) the CA is not affected by seeding the EA (Experiment area), the expectation is that C_S should closely equal C_N, so that DR $\approx E_S/E_N$ and then the excess of E_S over E_N, whether positive or negative, should provide an indication of the effect of seeding*. The variability of rainfall is, however, so great, that in practice, C_S is not always closely equal to C_N even for a period extending over several years, despite the random allocation of days to seeding. Nevertheless, the high correlation between the EA and the CA will tend to reduce the misleading effects of natural fluctuations in rainfall. For when there is a large natural fluctuation in rainfall on any day in the EA, there will be, on most occasions, a more or less similar fluctuation in the CA on the same day (the correlation coefficient is positive and large); that is, a large 'natural' contribution to, say E_S, will be compensated to an extent by a large contribution in C_S, in view of the fact that C_S appears in the denominator of (1).

The statistical significance of (1) is estimated from randomized computer experiments in which the actual rainfall data are permuted a large number of times (approximately 1000 times).

The statistical results of the first four years of Exp. II are listed in Table 1. For comparison, we have added the figures describing the situation at the end of the third year.

It is seen in Table 1 that while the figures for the apparent increase for days of seeding remained approximately the same (actually an increase of 1% took place), the significance figures have improved substantially. If the past trend in the rise of significance levels continues, we can expect that by the end of the fifth season, the level will be close to 5%.

*Ratio estimates are subject to bias (Flueck, 1973). Estimators of the type of (1) tend to overestimate the effects. Our computer experiments indicate, however, that as the sample size (number of experiment time units) is increased, the bias becomes small, something like 1 to 2%. That is, in Table 1, the 15% indicated increase might in fact be only 13% or perhaps 14%.

TABLE 1

Preliminary results of the Second
Israeli Randomized Cloud-Seeding Experiment
(DR = Double Ratio, e.g. (1) above)

		North Experiment Area (NEA)	Catchment Area of Lake Tiberias (part of NEA)
A.	1969/70-1972-73 (four years)		
	(DR-1) X 100	11%	15%
	Statistical significance level	9%	8%
B.	1969/70-1971-72 (Three years)		
	DR-1) X 100	10%	14%
	Statistical significance level	12%	13%

3. STATISTICAL - PHYSICAL STUDIES

In recent years we have endeavored to introduce some relevant physical factors into the evaluation process. It is to be expected that this procedure will enhance the significance of results and 'infuse' into us more confidence in the meaning and physical significance of the statistical results.

Our cloud physics studies over the years have led us to the expectation that super-cooled cumuli having a cloud-top temperature between about -15° and -20°C should be most responsive to seeding by potential ice nuclei. Ice-crystal growth is particularly rapid at about -15°C when the crystals, if any, are in the stellar, dendritic, form (the dendrites have the highest collection efficiency of all crystal forms). On the other hand, such stellar crystals can easily grow into graupels and grow fast through riming. We find that with the use of the above stated seeding technique there is little point in seeding clouds having tops colder than about -20°C: our atmosphere has high concentrations of potential ice nuclei which become active at temperatures below -20°C, Gagin and Steinhorn (1973).

Setting out from the above physical considerations, E. Shimbursky of our Department has developed a new statistical-physical technique for the estimation of the temperature range most amenable to seeding. On this technique, additionally to rainfall data, use is made of radar observations of cloud-echo top heights. The height data are turned into temperatures by reference to radiosonde measurements of the Israel Meteorological Service.

In the first three years of Exp. II we have just over 180 days allocated to seeding for which radar observations are available, as obtained by the 3-cm weather radar of the Meteorological Service. For each such day there is a more or less large number of cloud-top readings, and for each day the distribution of cloud-top temperature frequencies is

plotted. The days are then classified in three groups, according to the location of the mode and the number of observations in the low-temperature 'tail' of the distribution. The temperature intervals adopted are: > -15°C, -15 to -20°C, and < -20°C. We have felt that it is not satisfactory to classify the days according to the location of the mode alone. On many occasions the distribution is rather flat and even though the mode may reside in, say, the -15 to -20°C interval, the number of cases in the range <-20°C may be large so that cold clouds predominate in such a situation. As pointed out above, we expect little effect of seeding in the case of 'cold' clouds. In each of the three classes, we have about the same number of cases.

For each of three classes, the differences in rainfall between a subarea* of the NEA and the CA are listed in order to magnitude, according to a procedure worked out by Wilcoxon (1947) and frequently referred to as the Wilcoxon-Mann-Whitney or the Two-sample rank test (Brownlee, 1967, pp. 251-253). If the seeding had no effect, we sould expect the differences to be distributed normally with a zero mean. The test, as adapted by Shimbursky, examines the deviations of the distribution of the observed differences from normal for each of the three classes. We find for the first three years the following results:

Table 2

Two-sample rank test (Wilcoxon-Mann-Whitney) applied to daily rainfall differences between a subarea of the NEA and the CA, 1969/70-1971/72, based on 180 experiment days for which cloud-top data are available

(Test statistic=standardized rank sum variate, eq. (5.7) in Brownlee, 1967, p. 253)

Cloud top Temperatures	Value of test statistic	Statistical significance
-15°C	0.6	not significant
-15° to -20°C	1.9	2.9%
-25°C	1.1	13.6%

We note the comparatively high value of the statistic for the -15 to -20°C interval and its relatively high statistical significance. Thus, this statistical test bears out our physical reasoning and points to the effectiveness of seeding of continental type cumulus clouds with tops in the -15° to -20°C range.

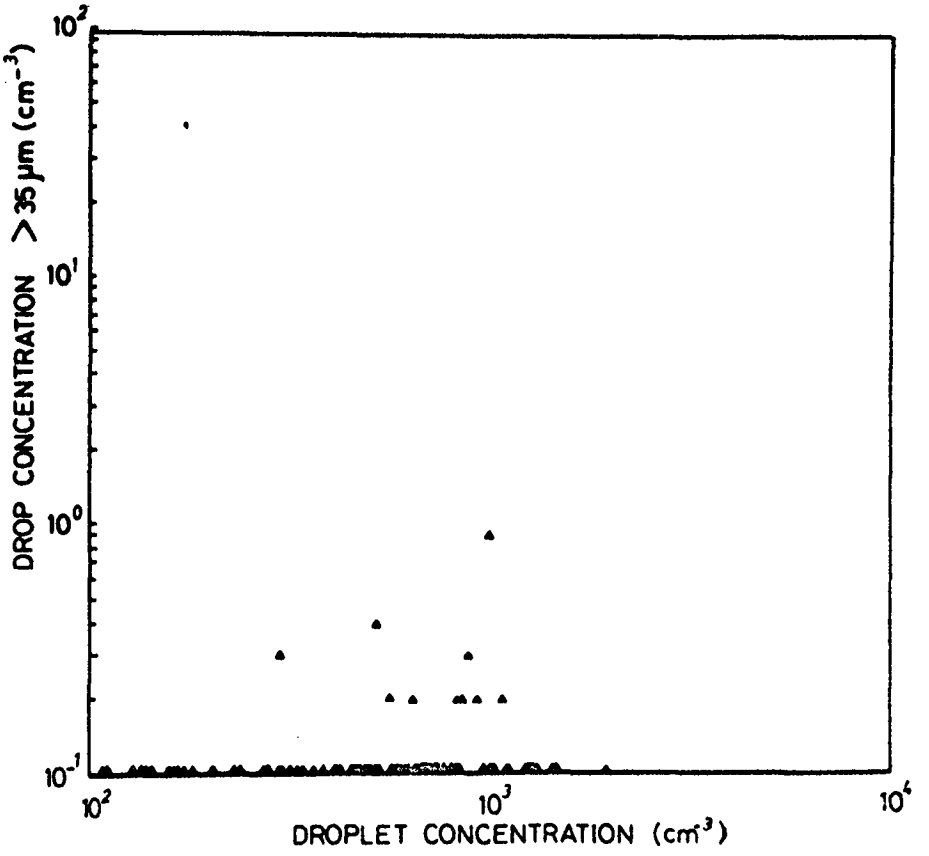
*This subarea was chosen in view of the large apparent increase under seeding exhibited by it.

4. MECHANISM OF RAIN FORMATION

In order to study the physics of our cumulus clouds, we have measured, in cloud and at cloud base, a number of factors such as cloud-condensation nuclei, droplet distributions, large cloud particles, ice-nuclei and ice-crystal concentrations, temperatures, (environmental) humidity, liquid-water content and radar echoes. The cloud measurements were (and are) accompanied by laboratory experimental investigations and by studies of a theoretical nature. The central problems of these investigations have been: How do our winter cumulus clouds form their precipitation? Is the seeding of these clouds by silver iodide justified? If it is, is it done in a rational manner? Is not the collision-coalescence process in our clouds more powerful than the ice-crystal mechanism? The truth is that seeding was begun (in 1961) years before we were able to obtain or to develop the instrumentation or measuring methods.

FIGURE 1

Concentration of droplets with diameters greater than 35μm.



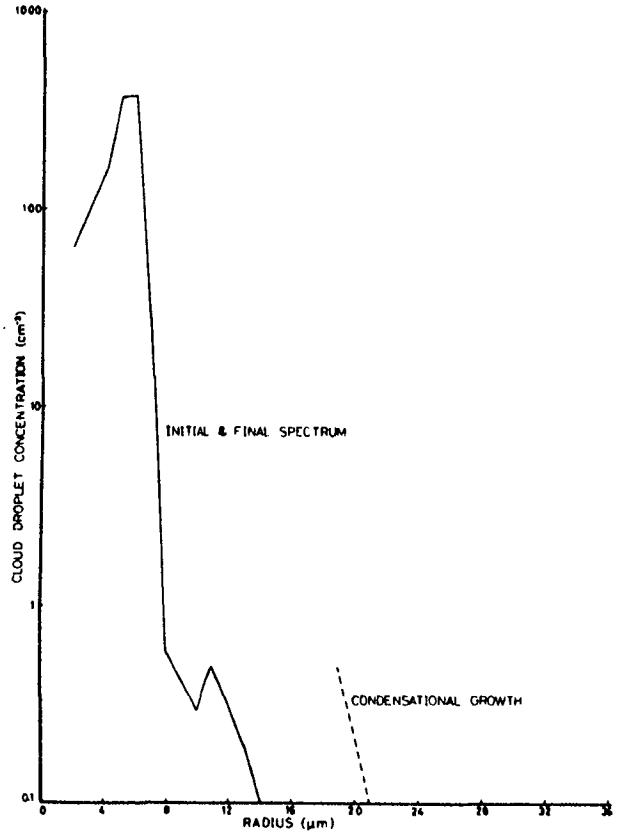
Perhaps one of our more important findings was that Israel's winter cumulus clouds are of a 'continental'character. The droplet concentration is very high, something like 500-1200 cm^{-3} while the width of the (size) spectrum is narrow. Droplets of diameters larger than about 40 m are scarce. Apparently, at cloud-top temperatures >-12.5°C large drops (diameter $\geqslant$ 250 m) do not develop. In colder clouds, with tops in the range -12.5 to -23°C, the concentration of such drops is less than 0.10 $liter^{-1}$. In contrast, in maritime, or maritime-like clouds, Koenig (1963) and Mossop (1968, 1970) find large drops in concentrations of a few hundred $liter^{-1}$.

Gagin (1971) has shown, on the basis of calculations for a 'continuous' cloud model and using an equation due to Bartlett (1970) that in the case of our observed cloud-droplet spectra, the time elapsing before the first collision takes place between the largest drop and a drop half its size (Bartlett shows that collision rate is highest for this case), is almost always longer than the lifetime of clouds. The Bartlett formulation assumes a uniform distribution of droplets in the cloud. Recently, however, a stochastic formulation was considered (by N. Chodes of our department) of cloud processes, the droplet positions taken to be random. Taking again our observed spectra, we find that the collision rate is higher. Nevertheless, even this modification is unable to produce precipitation elements (diameter $\approx$ 100 m) within cloud lifetime. In another numerical experiment we have added a 'tail' to the spectra observed at cloud base and at a level 2 km above base, the 'tail' being that observed in droplet spectra for near cloud-top altitudes. Again, the existing collision-coalescence theories do not predict the formation of large drops occur in very low concentration is, in a way, in a qualitative agreement with the above computational results.

If we approach the problem of droplet growth via condensation processes, we find (Gagin and Neumann, 1973) that the droplets of our spectra can grow, within reasonable time, to sizes which are larger than the sizes predicted by current collision-coalescence theories. Figure 2 depicts the results for a typical cloud base-level spectrum. Again, the sizes are far too small to explain the formation of precipitation elements. Thus, neither latter-day collision-coalescence theories nor condensation processes can account for the formation of rain in our winter cumulus clouds.

An examination of results of our measurements in clouds shows a marked correspondence between ice-nuclei concentrations in our atmosphere and ice-crystal concentration in clouds in the temperature range -5 to -25°C (Gagin, 1971); our cumulus clouds do not develop the process referred to as ice-crystal multiplication. Since the concentration of ice nuclei has a pronounced, well-known, dependence on temperature, it is obvious that clouds warmer than about -14°C will, in general, be deficient of ice-crystal concentrations deemed sufficient for an efficient production of rain through the ice-crystal process. In fact, in clouds warmer than -10°C, we could not detect ice crystals (lower limit of detectability is about 0.01 $liter^{-1}$). It can be seen in Figure 3, on the other hand, that graupel particles (1 mm) can be found only in clouds colder than -15°C and this suggests that, in general, the comparatively rapid

FIGURE 2



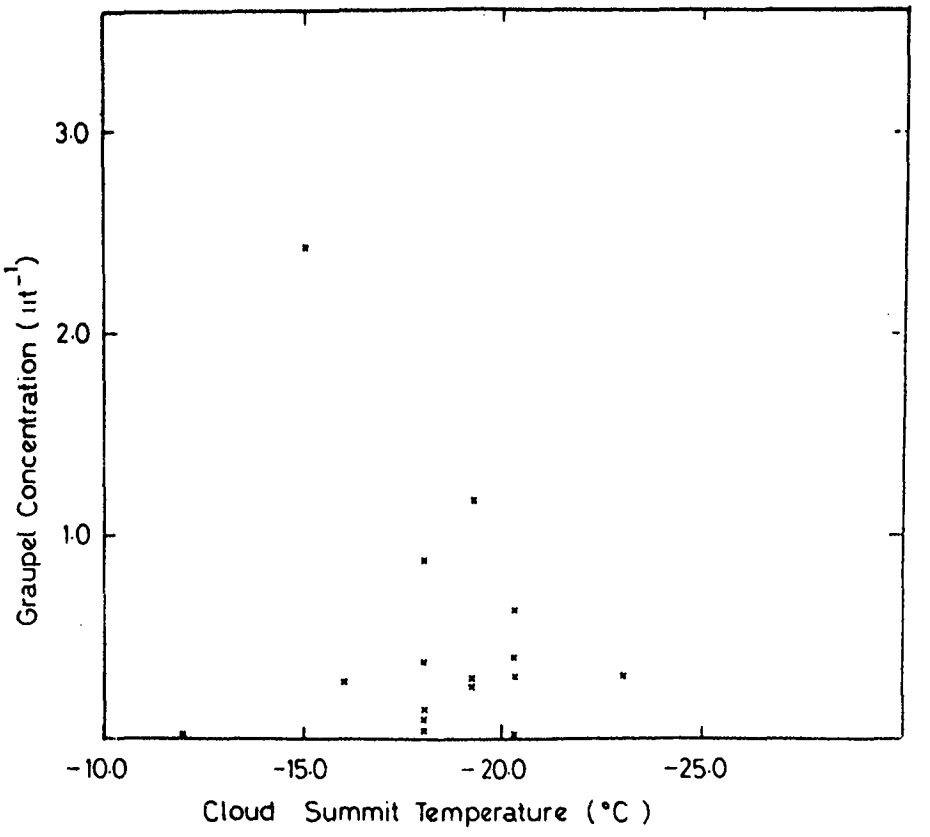
The observed cloudbase level spectra undergo virtually no change in 1000 sec. as a result of collision-coalescence processes. The condensation is somewhat more effective for droplet growth but neither process is capable of producing 'large' drops within reasonable time.

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growth rates of ice crystals at about -15°C, where the crystals are mostly of the dendritic type, are essential for the formation of graupels. From Jayaweera's (1971) calculations of ice-crystal growth rates as a function of time and temperature, one is led to the conclusion that, in the absence of a sufficiently large concentration of ice crystals that may enjoy the rapid growth domain at -5°C, early in the life cycle of the clouds, the rapid growth from the vapour, at -15°C, is likely to be achieved only by crystals that formed earlier, namely at about -10 to -12°C. But since our clouds show a dearth of ice nuclei at that temperature, the artificial addition of ice nuclei active at these heights and temperatures (a domain which is often associated with a liquid-water content higher than at lower altitudes), may lead to an increase of precipitation efficiency through the promotion of graupel formation and growth: First through the deposition of vapor and, subsequently, through the powerful accretion process of riming. "Spherical", or near-spherical graupels have a high collection efficiency (see, e.g., Mason, 1971, p. 580, for 'collision' efficiencies of large drops).

FIGURE 3

Concentration of graupels as a function of cloud-top temperature. Graupels have been observed mostly at temperatures of -15°C and below.



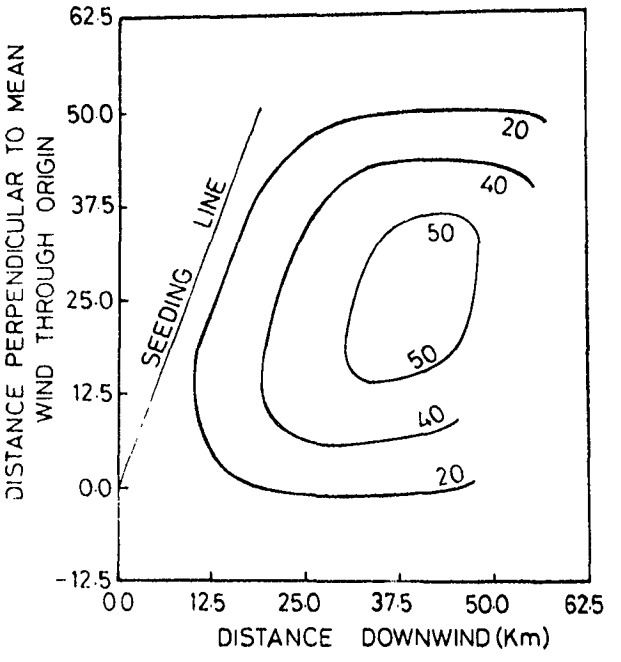
5. SOME DIFFUSION CALCULATIONS AND LOCATION OF MAXIMUM APPARENT INCREASES UNDER SEEDING

In recent months, M. Aroyo of our Department has carried out calculations of the diffusion of small particles dispensed from an aircraft (Cessna 337) flying back and forth along a line forming an angle of 70° with the mean wind. These conditions simulate the conditions under which the burners of the seeding aircraft release silver-iodide particles. The plane flies a few kilometers offshore parallel with Israel's Mediterranean coast, which typically, subtends an angle of about 70° with the mean wind at cloud base altitudes (700 to 1000 m) on cloudy, rainy days. The plane flies at a speed of 50 m sec^{-1} and releases 550 g silver iodide hr^{-1}; the mean wind was taken 10 m sec^{-1}. The starting point for the diffusion calculations is eq. (3.154) in "Meteorology and Atomic Energy, 1968"

Slade (editor), 1968, see p. 115 , which represents a Gaussian model. The seeding plane is a moving instantaneous point source. In the numerical calculations we have assumed that we are dealing with a succession of 2.5 km long segments of instantaneous line sources.

The principal purpose of the above calculations was to see if the rate of release is adequate to affect an area extending about 50 km downwind. We have assumed that a concentration of $\geq$10 liter^{-1} is an 'adequate' concentration. Figure 4 shows the results for the percentage of time that the concentration is $\geq$10 liter^{-1}, taken that the plane flies back and forth constantly along a line 55 km long. A potentially serious

FIGURE 4



Percentage (calculated) of time that the concentration of silver-iodide particles is $\geq$10 liter^{-1}. These diffusion calculations assume that the particles are released from the burners of a single seeding plane which flies back and forth along a line ca. 55 km long, parallel with Israel's Mediterranean coast, at a speed of 50 m sec^{-1} at cloud-base height (700 to 1000 m). The direction of the mean wind at cloud-base level has been so chosen that the mean wind at these heights is parallel with abscissa and is directed from left to right, its speed being taken as 10 m sec^{-1}. Rate of release of silver-iodide is 550 g hr^{-1}. Note maximum coverage at distances from about 20 to 40 km.

shortcoming of the calculations is that we do not know how to take account of the deformation and changing patterns of deformation of the flow field in an atmosphere in which clouds and cloud circulations grow and decay and of the effect of all these factors on diffusion.

Nonetheless, the calculations, and, in particular, Figure 4 seem to bear a possibly significant relationship to our experience with apparent rainfall increases under seeding. It has been observed both in Exp. I and in the current experiment that there is a maximum of apparent increase some 20 to 45 km downwind of the seeding line (see discussion of 'interior areas' in Gabriel, 1970, pp. 16-17 and Tables 3 through 5; the 'interior areas' indicate an apparent increase over 20% against the overall average apparent increase of 15% for the entirety of the experiment area). A conjecture raised by Figure 4 is that the above maximum of apparent enhancement might be due to the maximum time coverage indicated for distances of 25 to 45 km by the diffusion computations.

Some experimental work has been done by our Group to measure ice-crystals concentrations at tops of clouds, using our instrumented research aircraft (Aerocommander 680 FL) flying in the area downwind from the seeding line. The number of hours of such measurements is small to date. The results exhibit appreciable fluctuations in concentrations. Some clouds showed no detectable concentrations as is typical to natural, unseeded, clouds at these temperatures; others, at about the same distance and temperature, demonstrated 30 crystals liter^{-1}. Clouds possessing a maximum concentration, of the order of 100 liter^{-1}, were located at a distance of 20-25 km downwind, in fair agreement with the location of the maximum time coverage in Figure 4.

The results of the diffusion calculations raise the desirability of introducing some changes in the seeding pattern in order to ensure a better time 'coverage' of the experiment area.

6. OUTLOOK TO TROPICAL AREAS

Many of our problems, whether physical-meteorological, statistical or organizational, are common with those of countries in the tropics. The one problem where major differences are likely is the problem of mechanism of precipitation formation. Foreign experts can help research and operations, but an exploration of the physics of local clouds and a convincing verification whether cloud-seeding is effective or not, are activities requiring in all probability years of work and, hence, they require the building up of understanding and capabilities by people, scientists, engineers, technicians, living *in situ*.

ACKNOWLEDGEMENTS

The authors are indebted to (a) M. Aroyo, N. Chodes and E. Shimbursky, of the Hebrew University Department of Atmospheric Sciences, for their able assistance and participation in our research activities, (b) the Israel Meteorological Service for the use of its

weather-radar facility and for its rainfall data, and (c) the Mekorot Water Co., and its subsidiary Electrical and Mechanical Services, Ltd. for their financial and moral support of the project. Finally, we thank the Israel National Council for Research and Development for their interest and encouragement.

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THE ROLE OF SOLID PRECIPITATION ELEMENTS IN NATURAL AND ARTIFICIAL PRODUCTION OF RAIN IN ISRAEL

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1. INTRODUCTION

The rainbearing, wintertime, subtropical cumuli of Israel, are predominantly mixed clouds. Their modal cloud-top temperature is -20C whereas cloud base temperatures are, on the average, at +9C. Consequently values of maximum liquid water contents (LWC), in the upper parts of each of these clouds, were found to be normally in the range of 0.7 - 1.5 gm^{-3}, depending on the size of the clouds. Extensive measurements of ice crystal (I.C.) concentrations, in the vicinity of cloud tops, indicate that these concentrations correspond to the ice nuclei (I.N.) concentrations active at the same temperatures and are thus clearly temperature dependent, Gagin (1971). Furthermore, equally extensive measurements of the cloud droplet characteristics, at all levels in these clouds, suggest that the relatively high droplet concentrations, averaging around 800 cm^{-3}, and their narrow size distributions render the microstructure of these clouds typically continental in nature, Gagin (1971). This latter conclusion has been arrived at, earlier, through an extensive survey of the cloud condensation nuclei (CCN) properties of the local wintertime air masses, Terliuc and Gagin (1971).

These findings led us to conclude, Gagin (1971), that the local wintertime cumuli have a marked colloidal stability and therefore provide an exceptionally suitable opportunity for rainfall enhancement. Indeed, in both the 1960-67 and the presently continuing (begun in 1969) cloud seeding experiments, highly significant results of positive effects have been obtained. Thus for the already completed 1960-67 experiment, these results suggest increases of the order of 15-22%, at one tailed significance levels of 0.9-0.2% respectively, Gabriel (1970), Gagin and Neumann (1972).

As in many other experiments, the working assumption underlying this seeding technique, rests on the theory requiring that, in the absence of alternative rainforming mechanisms, an efficient rain process can be initiated in clouds through the formation of ice crystals, if the following two basic conditions are fulfilled:

a) A necessary condition, requiring the existence of sufficient concentrations of ice crystals;

b) A sufficient condition, requiring the existence of conditions in the clouds, favouring a fast and efficient growth of these ice crystals.

In an analysis of the evolution with height or time, of the cloud droplet spectra of the local continental cumuli, Gagin (1971) has shown, on the basis of calculations of the collision frequencies, that in medium sized, 4 km deep "homogenous clouds", the times for the first collision, frequently exceeds the lifetime of the clouds. Alternatively, making use of the stochastic formulation of the coalescence process, with the same sets of observed cloud droplet spectra and in equally deep clouds, it was found that the overall numbers of collisions, within a period of 1000 sec, was certainly insufficient to initiate the formation of precipitation elements.

The lack, in the clouds in question, of the well documented natural ice-crystal enhancing mechanism found in maritime cumuli, Mossop (1970), results in the common observation that clouds having tops warmer than -14C have I.C. concentrations that are lower than 1 lit.$^{-1}$. In fact clouds warmer than -10C were not found to have detectable concentrations of I.C. Radar observations of echo-top altitudes in rain days suggest that a substantial fraction, i.e. about 35% of the total number of the clouds on any rain day, have echo-top temperatures of about -14C or warmer, Gagin and Neumann (1972).

Thus, if our understanding of the collision-coalescence processes is correct, both the inefficiency of such processes and the relative scarcity of ice crystals suggest that the above mentioned necessary conditions do not exist in a substantial fraction of the total number of clouds on any given rain day. However, with the aim of further explaining the adequacy of the above mentioned theory of cloud seeding and more specifically, in order to define the properties of clouds that provide the required sufficient conditions, once seeding satisfies the necessary conditions, an attempt was made to calculate the growth of solid precipitation particles in a variety of cloud conditions that are derived from actual measurements.

It is the purpose of this report to assess the physical plausibility of the statistically significant, positive effects, that were obtained in both the Israeli first, and continuing, second cloud seeding experiments.

2. COMPUTATIONS OF THE GROWTH OF SOLID PRECIPITATION ELEMENTS

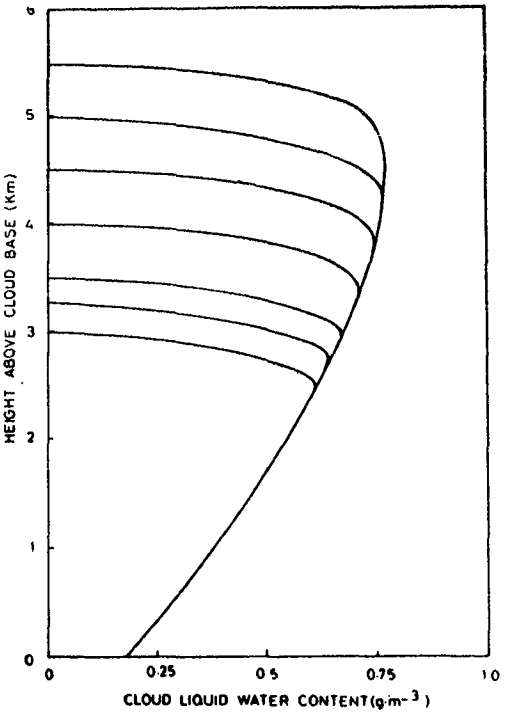
a. The variation, with height, of LWC, T, U and I.N.

In the following computations, the model clouds are assumed to be steady state and one dimensional. The variation with height of temperature and LWC were obtained from averages of actual measurements taken with our instrumented research aircraft, Gagin and Neumann (1972).

In view of the well documented observations of the fluctuations of LWC, at any horizontal traverse in the clouds, Warner (1955), the maximum values, for each of these horizontal crossections, were assumed to be representative for the computations of the ratio of the observed (w) to the adiabatic (w_a) values of LWC. The variation with height, in our clouds of this ratio across the first 2 km above cloud base, was found to be

quite similar to that of Warner (1970). Consequently, the vertical profiles of LWC were computed on the basis of this variation. At altitudes greater than 2 km w/W_a was assumed to be a constant equal to 0.15. LWC was assumed also to diminish gradually to zero within a depth of 0.5 km just below cloud top. Figure (1) displays the variation of LWC values, within clouds of different depths. The variation of temperature with height is given in Figure (2).

FIGURE 1



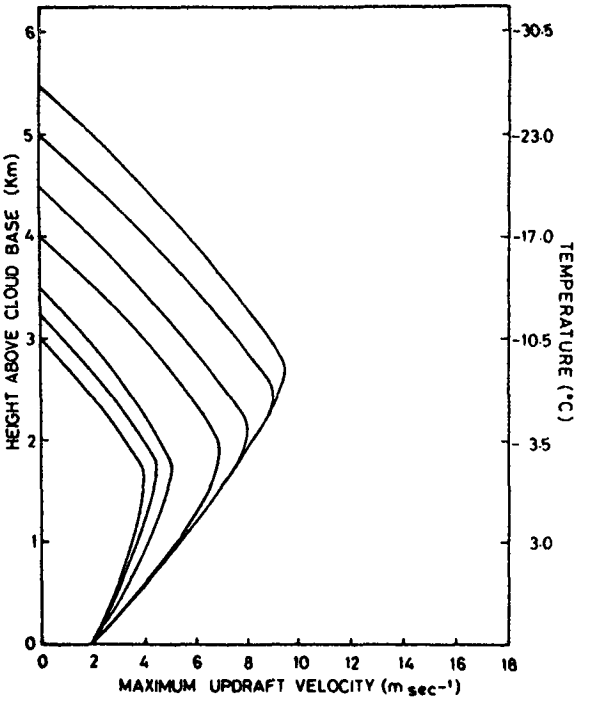
The variation of Liquid Water Content (LWC) with height for different cloud depths.

A crucial factor in the computations of the growth of precipitation particles, is the updraft velocity (U) structure, along both the horizontal and vertical axes of the clouds in question. The magnitude and the duration of the updrafts, determine quite decisively such important characteristics of precipitation as rainfall intensity, its duration and the size distribution of the precipitation particles.

In adopting the available measurements of updrafts in cumuli, a serious problem emerges from the fact, that such clouds are no other than a turbulent entity. Warner's (1970) measurements suggest that the fluctuating nature of the updrafts, makes the concept of a horizontal average, for a given altitude in a cloud, absolutely meaningless. As in the case of LWC, it would be a gross overestimate to use also maximum values of

U. Sulakvelidze et al. (1967) published U velocity data, obtained by using a 3.2 cm radar, for the location of no-lift balloons at known intervals of time. This method, should, in principle, yield updraft profiles that are relevant to the above mentioned studies. An interesting feature of these measurements, is that the maximum of U seems to be located, on the average, at a distance midway between cloud base and cloud top. In conclusion although we feel that the problem of averaging U is still unsolved, we have decided to adopt the data of Sulakvelidze et al. (1967), as far as the general shape of the profiles is concerned, together with a not unreasonable assumption, that rests on their findings, that the maximum of U, along the vertical axis of the cloud, increases linearly with the depth of the cloud. Figure (2) displays the variation with height of U in the different cloud depths under investigation.

FIGURE 2



The variation of maximum updraft velocity with height for different cloud depths.

The variation of temperature with height is given on the right ordinate.

It is appropriate to emphasize at this point, that such assumptions can be made only if the results of the calculations can be tested for their validity, against direct observations of parameters that are the end products of the investigated processes.

As stated above, since I.C. concentrations were found to depend on temperature as natural I.N., the initial stratification of their concentrations in the clouds, can readily be specified. Figure (3) gives the temperature spectrum of natural I.N. In this figure the plotted concentrations have been corrected for the lower retention efficiency of 0.45μm filters as compared to that of 0.05μm filters, Gagin, (1973). Thus once we assume that the cloud is saturated with respect to water, the vertical distributions of LWC, U, T and I.N. can be used to compute the mass of the ice particles as a function of height above cloud base.

b. Physical properties of ice particles

Ice crystal growth was computed on the basis of Jayaweera's (1971) findings on the mass rate of growth of ice crystals from the vapour, as a function to temperature and time. Crystal growth habits, as a function of temperature, were assumed to follow the classification of Magono and Lee (1966). Crystal dimensions and axis ratios were computed with the use of Raynolds' (1957) and Ono's (1969)(1970) formulations.

In unseeded clouds, because of the lack of detectable concentrations at temperatures warmer than -10C, the only crystal forms considered were those of plates and stellar crystals. When seeded clouds were investigated, use was made of Jayaweera's (1971) findings, that in the first 300 seconds of the lifetime of ice crystals, their mass rate of growth is equivalent to that of spheres of the same dimensions. Thus in view of the extremely short time spent between -6C to -10C levels, crystals forming at -5C had no opportunity of enjoying the faster rates of growth at -6C. In fact it made little difference if their forms at -10C were taken as small thick columns or thick plates (initial thickness of 60 μm).

Riming was assumed to be of significance only after the largest crystal dimension exceeded that of 200μm. If however riming was assumed to start earlier when the crystals were much smaller, the contribution to the total mass from this additional growth stage, was found to be negligible. Actually, growth by vapour deposition for crystals smaller than 200 μm was found to be, by far, excessive to riming. In the absence of reliable information on the collection efficiency of ice crystals and in view of the qualitative difference in the collection efficiency between plate and stellar sryctals, Weickmann (1957), the common assumption was made that plates and stellars have collection efficiencies of 0.5 and 1 respectively, Jiusto (1971). However, their area cross sections, for the computation of the volume swept by them, as they fall, were taken to be 1 and 0.5 of the area of a disc having the same diameter. For the computation of the mass-size relationships, three growth domains were defined:

a) Crystals alone exist in sizes d<200 μm where d is the crystal diameter;
b) Crystals with drops exist in the range 200 μm<d<500 μm;
c) Quasi-spherical graupels exist in sizes when d$\geq$500 m.

For domains (a) and (b) crystal sizes were attributed to the growth by deposition. Graupel's dimensions fall velocities and densities were

estimated on the basis of Zigmunda and Vali's (1972) measurements. The collection efficiency of graupels, for the modal value of the local cloud droplet spectra, Gagin (1971), was taken from Mason's (1971) data for spherical particles.

c. Ice particles' growth: Procedure of calculations

Equation (1) was used to calculate the growth of the particles.

$$m_z = m_o + \left(\frac{dm}{dt}\right)_{dep} + A_c V_c \overline{W}.E \quad \frac{\Delta z}{(\overline{U} - V_c)} \ldots \qquad (1)$$

$\left(\frac{dm}{dt}\right)_{dep}$ is the growth rate by deposition, m_o and m_z are the initial mass and the mass at the upper boundary of the layer Δz, normally 50 m thick, for which $\overline{W}$ is the average LWC. T is the temperature and $\overline{U}$ the updraft belocity, as given in Figures (1) and (2). A_c, the effective area for collection of the particles and E its collection efficiency, are calculated from the various mass-size relationships mentioned above. For particles larger than 1000 μm the size was computed through the use of Macklin's (1962) method of computation for the density of riming particles. V_c, the particles' fall velocities for the various growth domains, are computed according to the following relationships:

for domain a: V_c = const = 10.7 cm sec^{-1} - Yagi (1970)

for domain b: $V_c = 199 + 85 \log_{10} d$ - Zigmunda and Vali (1972)

for domain c: 1) for Graupels in the range 500 μm<d<1000 μm
$V_c = 285 + 138 \log_{10} d$ - Zigmunda and Vali (1972)

2) for Graupels in size d>1000 μm

$$V_c = \left(\frac{8dSG}{6C_D S_a}\right)^{1/2}$$ - Mason (1971)

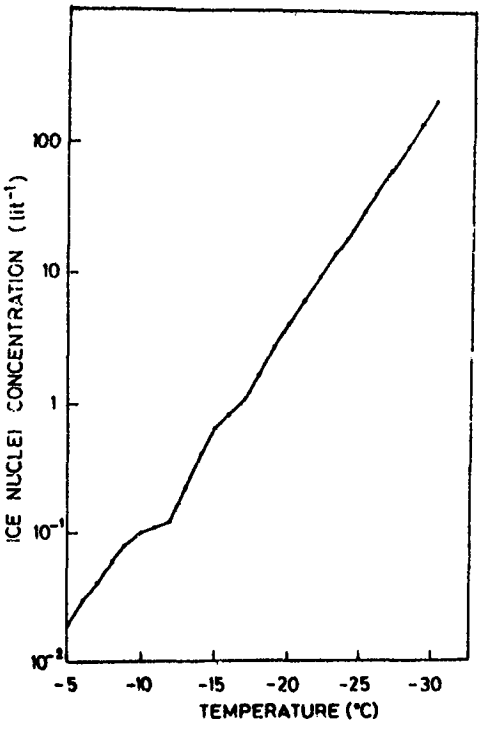
where d is the diameter of the particles, S their density, C_D their drag coefficient, and S_a the density of the air.

In conclusion, the masses and size of the particles, formed at the various levels and temperatures in the cloud, are computed as they ascend, or descend in the cloud according to whether the difference $(U - V_c)$ is positive or negative. The total mass contained by all the particles at any given level in the cloud, has also been computed and compared to the total LWC at this particular level.

c. Results

In the absence of suitable data on the interrelation between the magnitude of the updraft maximum (U_{max}) along the vertical axis of the cloud and cloud depth, the computational model was first tested for its sensitivity to U_{max}. Furthermore, since LWC values are deduced on the basis of maximum values and in view of our intention to present average processes, the actual values of LWC were assumed to be always one half

FIGURE 3

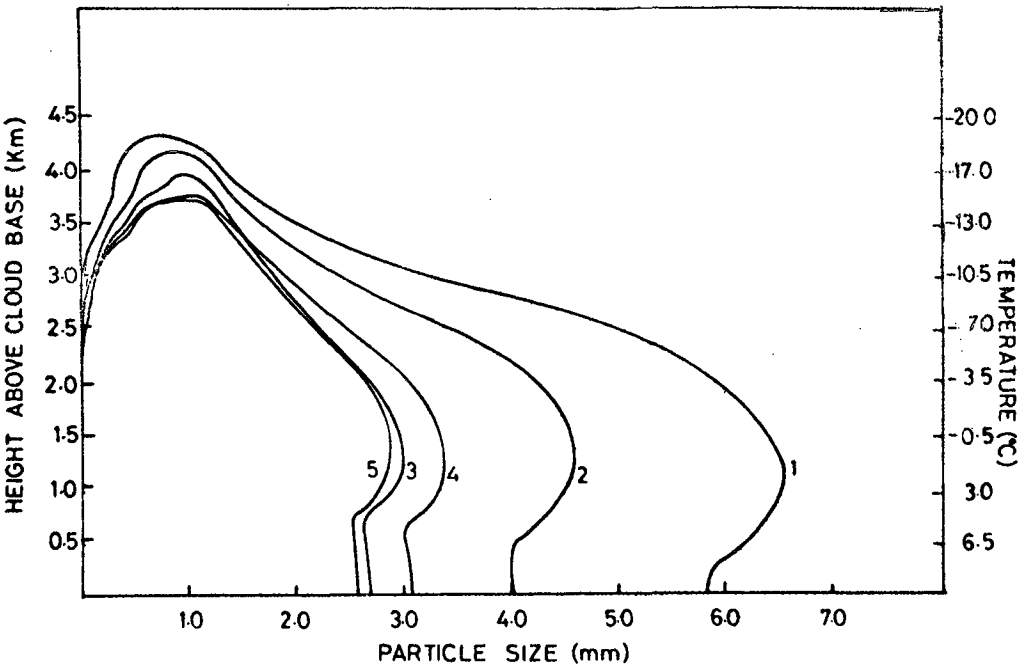


The dependence of ice nuclei concentration on temperature

of these maximum values. Therefore, Figure (1) presents this corrected stratification of LWC.

Figure (4) displays the results obtained for a variety of $\overline{U}_{max}$ values, assumed to be representative for the average maximum of a 4.5 km deep cloud having a U_{max} = 8 m sec^{-1}. Sulakvelidze et al. (1967) estimated the average of U_{max} = 12 m sec^{-1}, for a 4 km deep cumulus congestus cloud. As is immediately seen, in this figure and in table 1, the assumption of a maximum value of "only" $\overline{U}_{max} = U_{max}$ = 8 m sec^{-1}, results in anomalous raindrop sizes at cloud base, totally unreasonable times for rain-drop formation and, unrealistic ice particle size spectra near cloud top. Measurements of raindrop size spectra on the ground, using a dyed filter paper continuous sampler for the last three years, accompanied by simultaneous measurements of scho-top height, suggest a mean raindrop size of 2.5 mm for clouds of comparable depth. Furthermore, radar observations of the duration of rain, Battan (1959), assumed to be comparable to the time it takes a precipitation element to form, grow and fall from cloud base, suggest that 2000 seconds is a more reasonable period for such clouds. Moreover, from Table 1 it seems that the time of 955 seconds that it takes a particle, that formed at -10C to reach its maximum height in the cloud is comparable to radar measurements of the time required for the echo to reach its maximum size in similarly deep clouds; Battan (1959).

FIGURE 4



The size of precipitation particles as a function of height for a 4.5 km deep cloud, having different updraft profiles. Curve numbers correspond to those of Table 1.

Table 1 summarizes the results obtained with the various properties of the clouds as specified. U_{max} and $\overline{U}_{max}$ are the "absolute" and "average" vertical velocity maxima of the cloud. LWC is the maximum at 0.5 km below cloud top. The results give details of the lowest temperature (T_{min}) at which ice particles form, and are capable of becoming precipitation elements. Their concentration (C), size range at the top (R_{top}) and at cloud base (D) (as raindrops) are also specified. The time taken for the largest particle in 10 liters of air as it ascends to the top (T_{top}) and the total time for its formation as a raindrop (t_{tot}) are given in the last two columns.

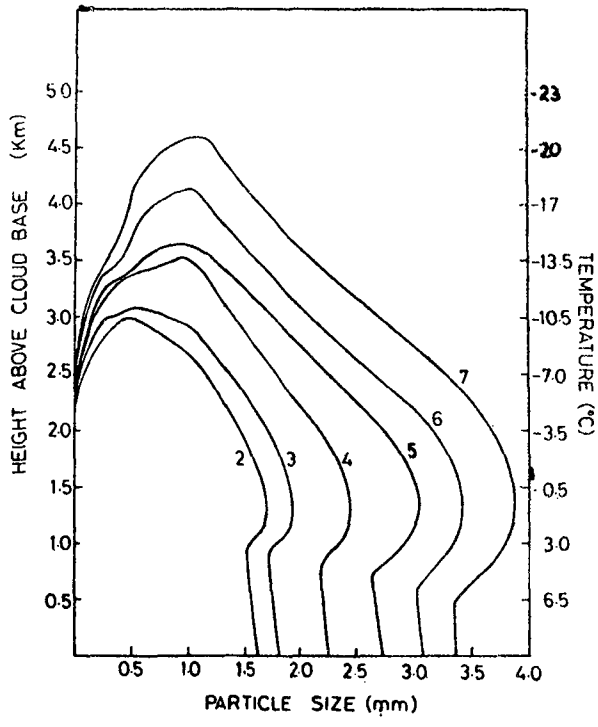
TABLE 1

No.	Depth km	Top temp. °C	LWC g.m^{-3}	U_{max} m.sec^{-1}	$\overline{U}_{max}$ m.sec^{-1}	T_{min} °C	C lit^{-}	R_{top} mm	D mm	t_{top} sec	t_{tot} sec
	Cloud Properties							Precipitation elements			
1	4.50	-20	0.75	8	8	-17	1	0.05-0.51	5.6	602	4495
2	4.50	-20	0.75	8	6	-15	0.6	0.05-0.68	4.0	921	3465
3	4.50	-20	0.75	8	4	-17	1	0.05-1.2	2.7	955	2124
4	4.50	-20	1.0	8	4	-17	1	0.05-1.2	3.2	852	1996
5	4.50	-20	0.75	8	3.5	-17	1	0.05-1.1	2.5	1038	2345

Size distributions of graupel particles in such clouds, have been obtained from our replicator data and give evidence of the existence of particles 1 - 1.5 mm in diameter in concentrations of around 1 - 2 lit^{-1}. Such values are given by the computations for a cloud in which $\overline{U}_{max} = \frac{U_{max}}{2}$ approximately. It is also obvious that the results for a cloud in which $\overline{U}_{max}$ = 6 m sec^{-1} are still quite unrealistic. It is of interest to note that an increase of LWC to a maximum of 1.0 gm^{-3} does not produce a drastic change in the results. Moreover, another point of interest is the fact that while at cloud top, the particles are shown to have a size distribution, the assumption that the updraft is uniform, along any horizontal crossection, yields a monodisperse spectrum of raindrops at cloud base. Thus the computation of rainfall intensity in such a model yields unrealistically high rates. It now seems that in order to produce a more realistic distribution of raindrops, at cloud base, one must specify a cloud in which U fluctuates in size and also in direction, at any given level. The problem we face here is analogous to that of explaining the evolution of the cloud droplet spectrum, and requires a treatment of clouds as a turbulent entity. In any case, in view of the reasonable distributions of precipitation elements at cloud top, their mean at cloud base and the realistic times for their formation, we tend to conclude that in order to obtain physically sound results, one must assume average values of LWC and U which can be derived by multiplying the observed maxima by about a factor of 0.5.

Figure (5) displays the results that were obtained for a variety of cloud depths. The updraft values are 0.5 of the maximum values presented in Figure (2). Table 2 gives some details of these computations. It should be noted that Figures 4 and 5 display the trajectories of the particles that formed at -5C, considered to be the warmest temperature at which AgI nuclei can be activated. However, the corresponding trajectories for all other particles, that formed at lower temperatures, were also obtained. The total concentration of precipitation elements was obtained by determining the lowest temperature at which ice particles formed that were capable of growing to a size which enabled them to fall through the cloud and emerge as raindrops after melting.

FIGURE 5



The size of precipitation particles as a function of height for different cloud depths as specified in Figs. 1, 2 and Table 2.

Table 2 gives a summary of the results of these computations. The symbols are as in Table 1 but for clouds of different depths. The last column F_{pr} gives the percentage of the total LWC, occupied by all ice particles at cloud top.

TABLE 2

	Cloud Properties					Precipitation Particles						
No.	Depth km	top temp. °C	LWC gm^{-3}	U_{max} m sec^{-1}	$\overline{U}_{max}$ m sec^{-1}	T_{min} °C	C lit^{-1}	R_{top} mm	D mm	t_{top} sec	t_{tot}	F_{pr} %
1	3.00	-10.5	0.62	4.0	2.0	-	-	0.2	-	-	-	0.1
2	3.25	-12.0	0.65	4.6	2.3	-5	2.10^{-2}	0.3-0.48	1.6	-	-	0.15
3	3.50	-13.5	0.68	5.0	2.5	-10	10^{-1}	0.03-0.50	1.8	600	2057	0.2
4	4.00	-17.0	0.72	7.0	3.5	-15	6.10^{-1}	0.05-1.0	2.3	1014	2261	7.2
5	4.50	-20.0	0.75	8.0	4.0	-17	1	0.05-1.2	2.7	1027	2324	8.0
6	5.00	-24.0	0.78	9.0	4.5	-19	2.6	0.05-1.2	3.0	1059	2572	10.0
7	5.50	-27.5	0.78	10.0	5.0	-20	4.0	0.05-1.2	3.4	1242	2741	61.0

3. CONCLUSIONS AND DISCUSSIONS

On the basis of this simple computational scheme and with the use of the above mentioned measurements and assumptions of the various Cu cloud properties, one can draw the following conclusions regarding the efficiency of, naturally or artificially induced, precipitation forming processes:

1. In the absence of an alternative rain-forming process, normal ice crystal formation and its subsequent growth by accretion is shown to be capable of producing precipitation sized particles in Cu clouds that have top temperatures colder than -12C (equivalent to a cloud 3.25 km deep).

2. The size and concentration of precipitation elements in the various clouds are proportional to the depth of the clouds, and their top temperatures. As evident from Table 2, the shallowest Cu cloud, that is capable of producing precipitation sized elements, will produce raindrops of a diameter of 1.6 mm, at concentrations of only 0.02 lit^{-1}. Whereas a cloud having a top temperature of -14C may already provide the necessary and sufficient conditions, for the "natural" production of raindrops, 1.8 mm in diameter and at concentrations of about 0.1 lit^{-1}. The latter values are indeed quite common for normally precipitating clouds. The coldest cloud studied, i.e., having a top temperature of -27.5 and depth of 5.5 km will produce 3.4 mm raindrops at a concentration of 4.0 lit^{-1}.

3. The computed values of the duration of precipitation and the time for its full development are in a good agreement with the corresponding values observed by radar.

4. Due to their lower density, graupel particles attain just above the $0^{o}C$ level stable sizes that can be larger by even 0.5 mm than the raindrops emerging from cloud base. This difference in size and the vertical extent for complete melting depend clearly on depth of the clouds.

5. Modelling of precipitation growth in a cumulus cloud lacks in such important details as size distribution of raindrops or precipitation intensity if due consideration is not given to the fluctuating nature of the updrafts in the turbulent Cu clouds. Realistic results can be obtained only if a fraction of the measured maximum LWC at the various altitudes of the cloud are considered. In fact it seems that for both LWC and the updraft velocities, reduction of the maximum values by a factor of about 0.5 seems to yield physically plausible results. Under such conditions the size distributions of cloud particles near the tops of the clouds are comparable to observed values.

Bearing in mind that the above conclusions apply to naturally precipitating continental Cu clouds, where the collision coalescence processes seem to be incapable of alternatively producing precipitation elements, the following conclusions can be drawn as to the effect of seeding such clouds with ice forming nuclei:

1. Clouds having top temperatures warmer than -12C are unlikely to be affected by seeding with AgI particles having a threshold activation

temperature of -5C.

2. If a concentration of precipitation elements of the order 1 lit^{-1} is assumed to be a necessary minimum for an efficient rain process, then Cu clouds having top temperatures in the range of -12C to -20C seem to be mostly favourable to the type of seeding discussed above. In fact, within this temperature range, seeding can be allowed to produce even higher concentrations than 1 lit^{-1} without completely glaciating the clouds. Table 2 suggests that natural glaciation will occur in clouds having only top temperatures colder than -27.5C.

As mentioned earlier, in a typical rain day in Israel a substantial fraction of the total daily cloud population is within this temperature range. Gagin and Neumann (1972). In a recent report, Gagin and Neumann (1973) have shown, on the basis of physical-statistical analyses that seeding seems to be exceptionally positive in the cloud-top temperature range of -15C to -20C. We suggest that although the rate of water consumption of the growing elements is far less than that of the rate of water generation within naturally seeded clouds, having top temperatures in the range of -12C to -15C, the lower output of our AgI generators in the temperature range of -5C to -10C prevents the potential seeding effects in these clouds from being realized and/or subsequently detected by our statistical analyses.

Thus in conclusion, we tend to propose that both the microstructural nature and the size distribution of the local continental cumulus clouds, on any rain day, provide both the necessary and sufficient conditions that are required for a successful cloud seeding operation. It seems also that, in the light of this conclusion, the positive and statistically significant results obtained in our large scale experiments may be regarded as physically plausible.

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CUMULUS CONGESTUS GROWTH DOWNWIND OF ST. LOUIS, MISSOURI: CASE STUDY

by

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The most comprehensive climatological investigations into precipitation anomalies associated with inadvertent weather modification by metropolitan areas have been presented by Huff and Changnon (1972a, 1972b) and Changnon (1973). The responsible mechanisms for these precipitation anomalies are merely speculative at this juncture. For example, both Landsberg (1964) and Huff and Changnon (1972a, 1972b) agree that the effect of the urban area in causing updrafts and increases in convection from added heat and urban turbulence are probably major factors in the urban precipitation anomaly. Prior to Project METROMEX (Changnon et al., 1971), there has been no direct field research conducted on the subject of urban influences on convective precipitation. The only studies of an associated nature were conducted by Atkinson (1970, 1971) wherein he investigated two cases of thunderstorms over the London area by examining recorded radar and surface network data. In order to generalize the application of the results from a field effort like Project METROMEX to other cities, it will be necessary to delineate the causes of the climatically observed precipitation anomalies associated with metropolitan areas. Recently, Grosh and Semonin (1973) provided a preliminary description of the moisture budget and air flow structure of two thunderstorm case studies in the Metropolitan St. Louis area.

This paper presents some preliminary results of analysis of both airborne and surface observations of meteorological parameters relevant to cumulus development, growth and modification obtained downwind of the urban area for a case study in METROMEX 1973.

CUMULUS STUDY OF 14 AUGUST 1973

One case study possibly documenting the effect of cumulus cloud development downwind from the St. Louis Metropolitan area occurred on 14 August 1973. A weak maritime cold front had passed through the metropolitan area approximately 15 hours prior to the case study, providing light to moderate northwesterly flow. The only convective cloud activity in the Metropolitan St. Louis area was limited to that observed in the downwind plume. Figure 1 shows a vertical profile of the Aitken nucleus concentrations and potential temperature upwind of the metropolitan area at 1320L. The top of the mixing layer, clearly limited by the frontal inversion, is identified at 1800 ft (550 m) MSL (by potential temperature) or 2200 ft (675 m) MSL (by Aitken nucleus concentration). At 1400L, a growing line of

cumulus congestus clouds in the downwind plume from the metropolitan area were investigated. These clouds were essentially over the Waterloo-Columbia-Millstadt (WLO-COL-MST), Illinois area (see Figure 3). Figure 2 shows the vertical profiles of Aitken nucleus concentrations and potential temperatures observed downwind of the Metropolitan St. Louis area (3 n mi south of Bi-State Airport at 1400L). The depth of the mixing layer downwind had increased such that the top of the mixing layer (as determined by both potential temperature and Aitken nucleus concentrations) lay near 2800 ft (850 m) MSL. In addition, there had been a warming of the well-mixed layer by 1.5 K as the air moved over the metropolitan area. The convective cloud bases in the downwind area were observed at 2500 ft (750 m) MSL (within the well-mixed layer) and maximum cloud tops were on the order of 9,000 ft MSL. Several penetrations (see Figure 3) at 7,000 ft (2150 m) MSL were conducted and cloud droplet and hydrometeor spectra were obtained, as shown in Figure 4.

Several interesting results of the four penetrations of a single cumulus congestus cloud are summarized in Table 1. It can be seen from Table 1 that evidence exists that urban effluent is being ingested by the downwind cumulus clouds since these clouds carry boundary layer signatures; i.e., odors from surface industries and values of Aitken nucleus concentrations found only within the downwind well-mixed layer (see Figure 2). Inaddition, during the second penetration at 1419, the maximum value of θ_e observed in the core of the cloud was 327K, a value later documented as the θ_e at cloud base.

Four minutes after the last penetration, at which time a hydrometeor sample was collected, the airborne 3-cm radar began to paint a threshold detection of the penetrated cloud at a range of 5 n mi. Characteristics of the airborne radar (RCA AVQ-55) are such that at this range the threshold reflectivity is 7.5 $mm^6\ m^{-3}$ (corresponding to a maximum hydrometeor diameter and concentration of 1.4 mm and 1 m^{-3}); it can be seen from Figure 4 that the largest hydrometeor encountered on the final penetration was 1.1 mm at a concentration of 1 m^{-3}.

Cloud motion was observed to be from 345° true at 15 kt. The initiation of these isolated convective clouds was observed to occur on a line from 3 n mi south-southwest of the Gateway Arch to the Jefferson Barracks Bridge. Thus, the cloud sampled developed precipitation size particles within 30 min of their initiation. Cloud top temperatures were not observed colder than +6.0C, suggesting coalescence as the mechanism of precipitation formation.

Figure 3 also shows an area of scattered coverage of minimally detectable 3-cm radar echoes as determined from the airborne radar and the Pere Marquette radar observer's comments between 1430-1435L. An interesting feature of this echo distribution is that it is parallel to but displaced 11 n mi downwind of the downtwon St. Louis-Granite City-Alton Industrial Complex line. The presence of these minimally detectable "first echoes" again corresponds to a cloud lifetime of approximately 30 min. Aviation weather reports filed at Scott Air Force Base (BLV) indicated that between 1500-1600L intermittent very light rain showers were recorded, presumably

from the scattered radar echoes shown in Figure 3 as these echoes moved south-southeastward in the next 30 min.

The possible extrapolation of the findings from this single case study of cumulus growth and development downwind of the St. Louis area should not be construed as even a partial explanation of the St. Louis precipitation anomaly. While other case studies of similar cumulus development have been recorded, the modification of cumulonimbus during passage over the metropolitan area (e.g., Boatman and Auer, 1974) must also be considered in explaining any urban precipitation anomaly.

ACKNOWLEDGMENTS

This research was supported under Grant GI-39212 to the University of Wyoming as a part of the research on METROMEX, sponsored by the Weather Modification Program, RANN, National Science Foundation. Our appreciation is also expressed to the Illinois State Water Survey for its assistance in providing radar information during the course of this case study.

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Figure 1. Vertical profiles of Aitken nucleus concentrations and potential temperatures upwind of the Metropolitan St. Louis area (over the St. Louis VORTAC) on 14 August 1973 at 1320L.

Figure 2. Vertical profiles of Aitken nucleus concentrations and potential temperatures downwind of the Metropolitan St. Louis area (3 mi south of Bi-state Airport) on 14 August 1973 at 1400L.

Figure 3. Portion of a flight path from 14 August 1973 showing penetrations of an element of a cumulus congestus line growing in the downwind plume from Metropolitan St. Louis. The symbol () indicates the penetrated cloud's boundaries. The hatching represents a scattered area of minimumly detectable 3-cm radar echoes as determined from airborne radar and PMQ radar observer's comments between 1430-1435L.

Figure 4. Cloud particle size distributions observed on a 7,000 ft MSL penetration of a cumulus congestus cloud in the vicinity of Columbia, Illinois, downwind of the Metropolitan St. Louis area on 14 August 1973.

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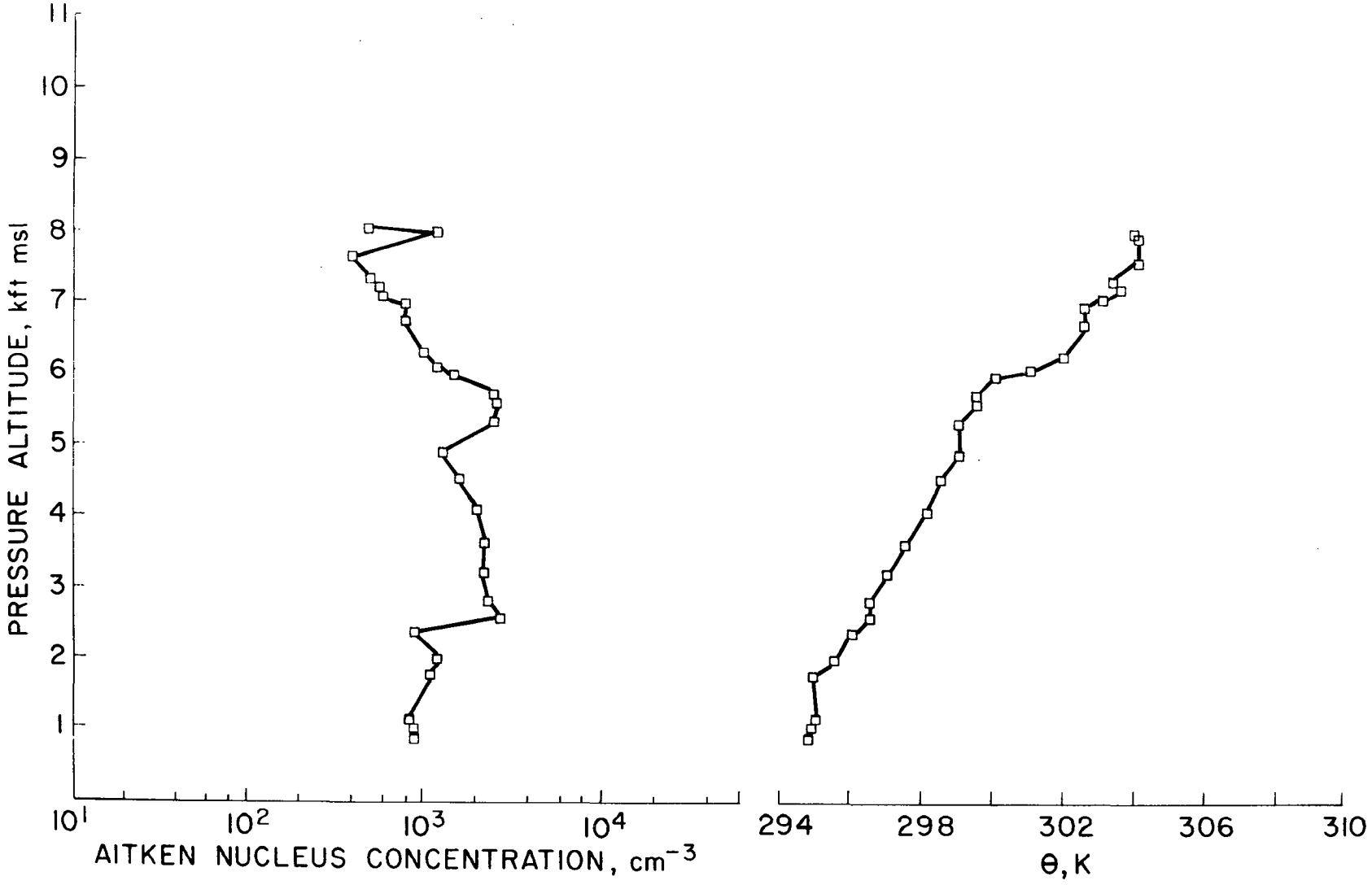


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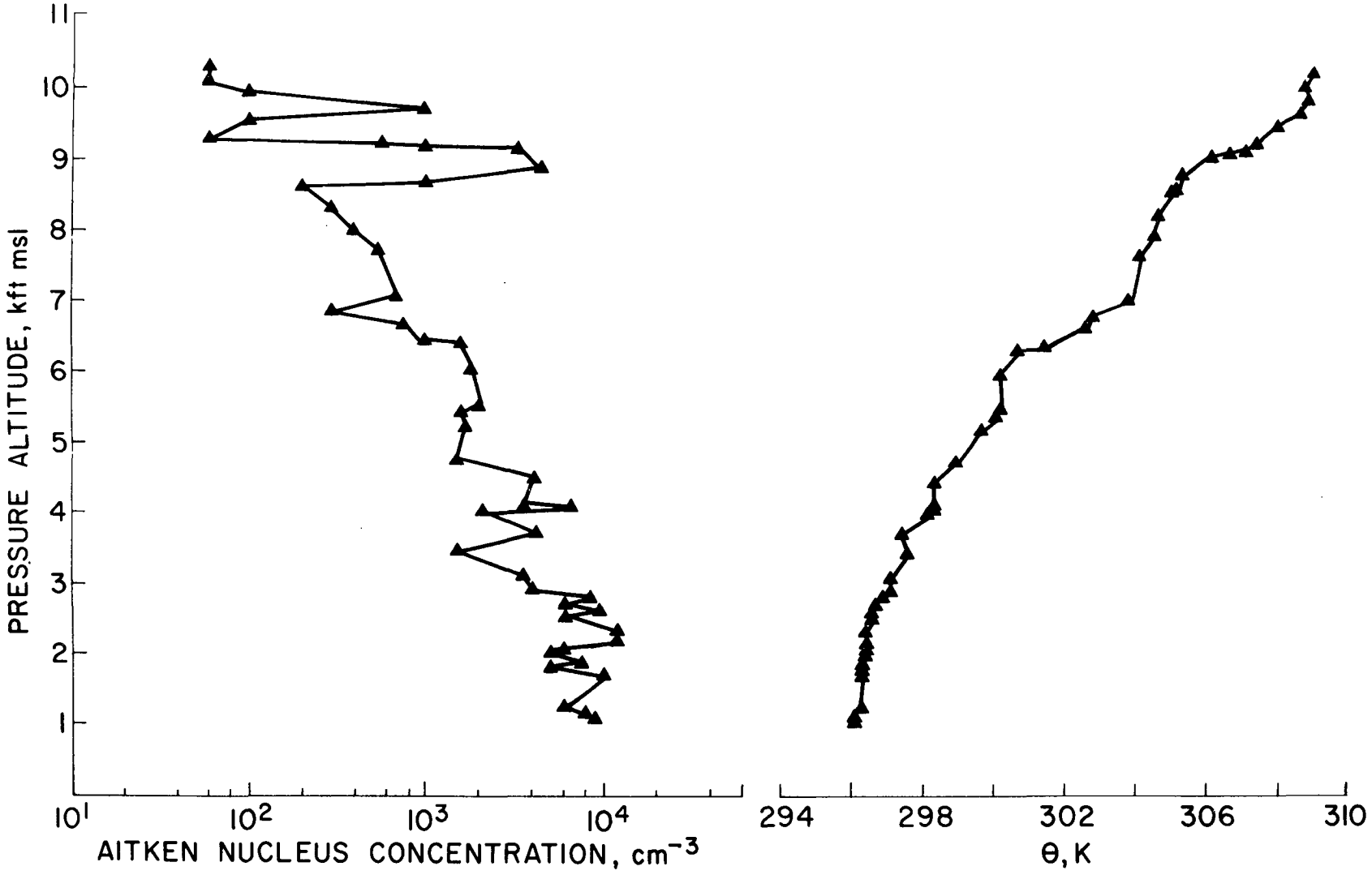


Figure 2. Vertical profiles of Aitken nucleus concentrations and potential temperatures downwind of the Metropolitan St. Louis area (3 mi south of Bi-State Airport) on 14 August 1973 at 1400L.

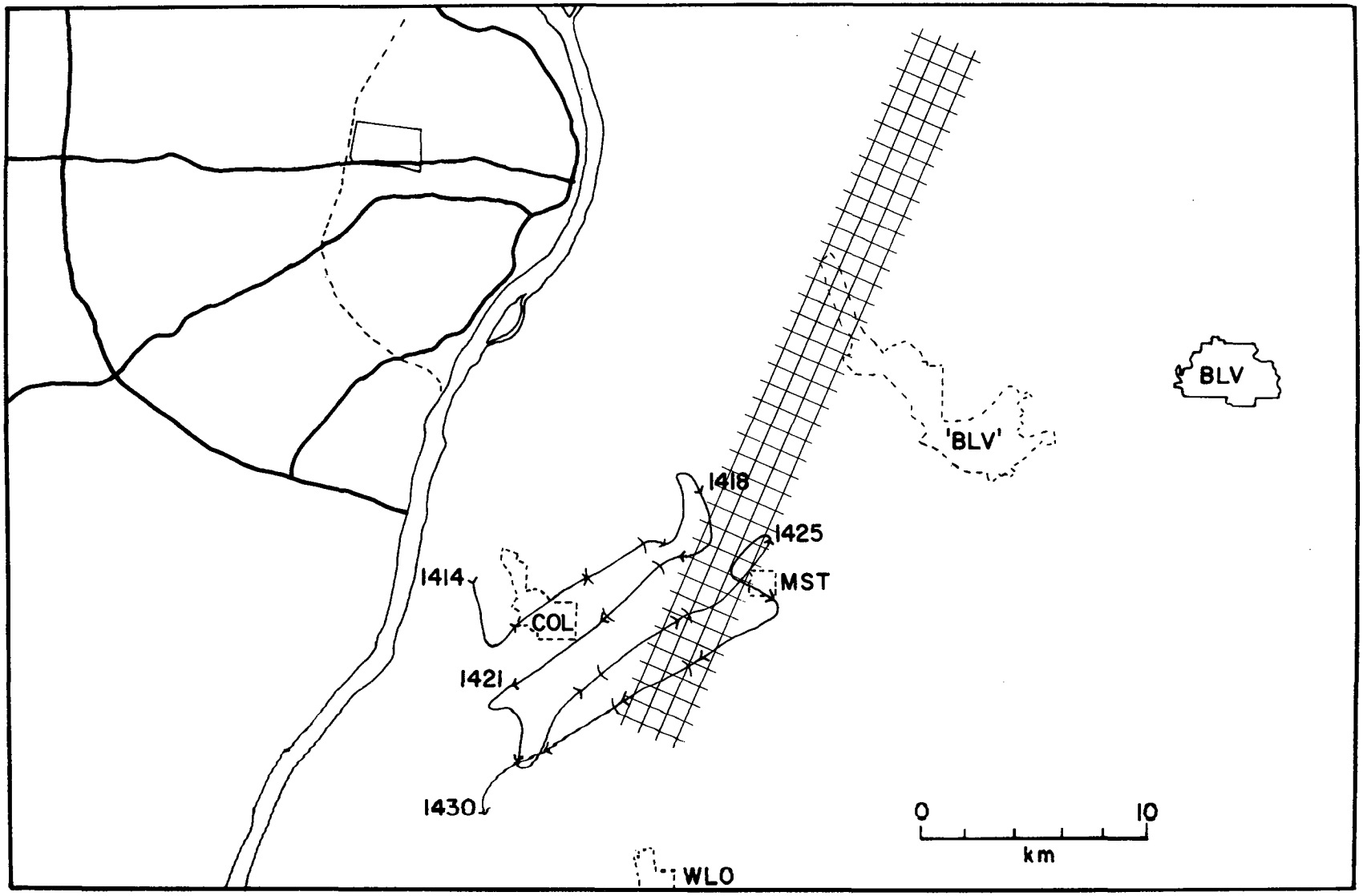


Figure 3. Portion of a flight path from 14 August 1973 showing penetrations of an element of a cumulus congestus line growing in the downwind plume from Metropolitan St. Louis. The symbol () indicates the penetrated cloud's boundaries. The hatching represents a scattered area of minimumly detectable 3-cm radar echoes as determined from airborne radar and PMQ radar observer's comments between 1430-1435L.

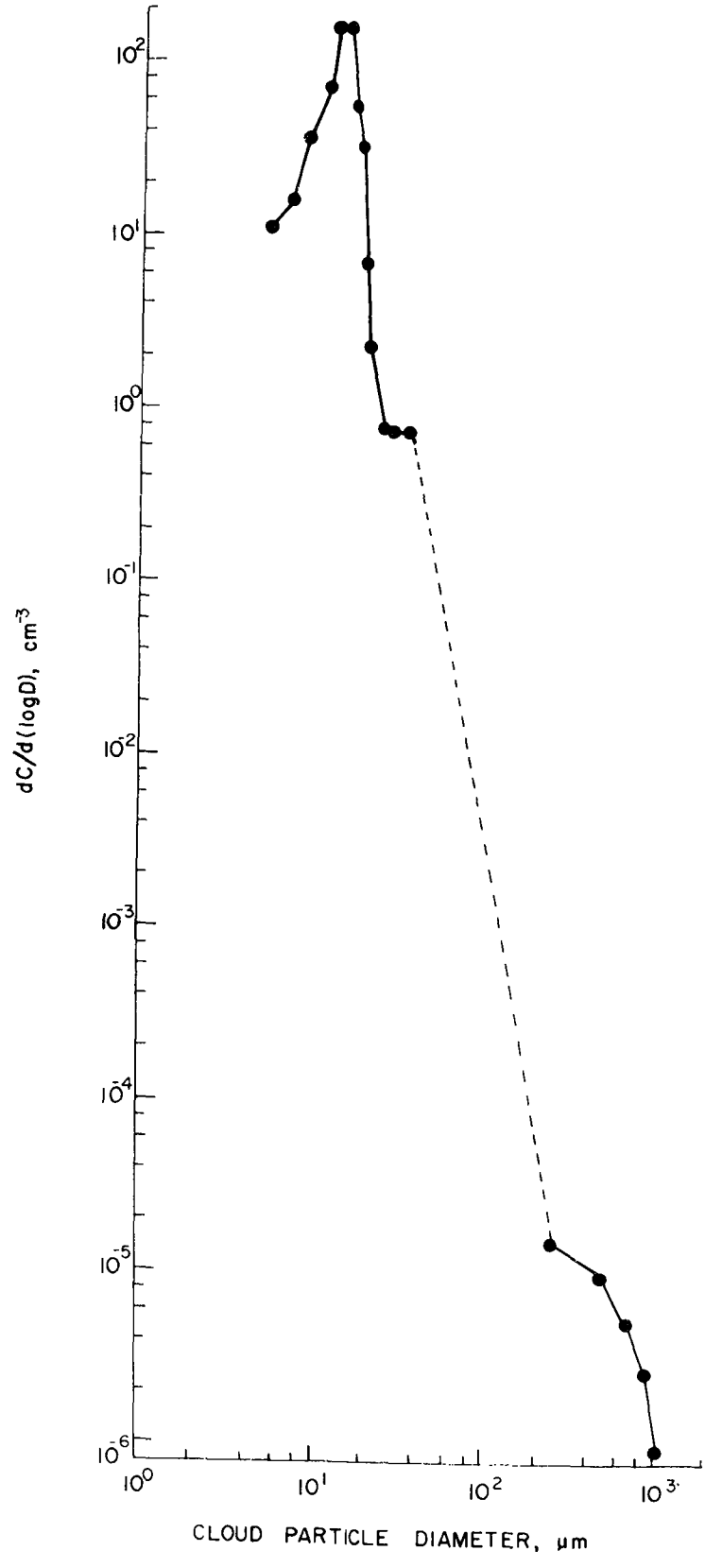


Figure 4. Cloud particle size distributions observed on a 7,000 ft MSL penetration of a cumulus congestus cloud in the vicinity of Columbia, Illinois, downwind of the Metropolitan St. Louis area on 14 August 1973.

TABLE 1

Summary of penetration data from downwind cumulus congestus cloud, 14 August 1973.

Time	Aitken Nucleus Concentrations (cm^{-3}) Outside Cloud	Inside Cloud	Updraft Velocity (mps)	Remarks
1416-1417	500	9,000	1.5	--
1419-1420	200	7,000	1.5	Strong chemical, industrial odor; cloud droplet sample
1423-1424	800	3,700	1.5	ISWS water sample*
1427-1428	400	8,500	0.5	Hydrometeor sample

*Periodically during cumulus cloud penetrations, cloud water samples were collected for the Illinois State Water Survey for chemical analysis.

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FLAME TEMPERATURE EFFECTS ON AgI NUCLEI PRODUCED FROM ACETONE GENERATORS

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ABSTRACT

AgI nuclei that are active at -2.5 to -3C can be produced from an acetone solution of AgI-NH_4I in a cloud seeding generator when airflow to the combustion chamber is properly regulated. An excess of air (stoichiometric ratio greater than two) must be used to produce these results. The flame temperature under these conditions is about 650C. If airflow to the combustion chambers is cut down using a stoichiometric ratio closer to one, the flame temperature rises to near 1200C and nuclei are produced that are active at only -6C and colder.

When an excess of air is used in the combustion chamber, particles are produced that are very slightly larger than those produced if the combustion supporting air is reduced. X-ray diffraction studies show the presence of a trace of NH_4I as an AgI-NH_4I complex when an excess of air is used, but this NH_4I disappears when the combustion supporting air is reduced.

INTRODUCTION

When a silver iodide generator is ignited and continues to burn, most operators assume it is operating properly as long as combustion takes place, and normally little thought is given to establishing optimum operating conditions.

A series of test have been conducted to determine the optimum operating conditions of a silver iodide burner to produce AgI ice nuclei that are active at the warmest possible cloud temperatures.

The test facility has been described in detail by Donnan and Wright (1969) and Blair, et. al., (1973). For these tests, the flame temperature of the silver iodide burner was controlled by varying the airflow to the combustion chamber of the burner while burning the acetone solution at a constant rate.

EXPERIMENTAL PROCEDURE

For all of the tests, a 5% (by weight) solution of AgI-NH_4I in acetone was used. Mole ratios of AgI to NH_4I were maintained at 2:1 and

content of the acetone solution was constant at 0.5% for one series and 10% for another series of tests.

The burner used to make these tests was a modified version of the Naval Weapons Center airborne jet seeder (Corroz and Durham, 1973). This burner was mounted in the wind tunnel in such a way that all the air from the wind tunnel blower was forced through and around the burner by the use of a cone adapter. Acetone solution is sprayed into the burn chamber through a Delevan No. 2.0 30° nozzle at 125 lb pressure. Construction of the device is shown in Figure 1.

The burner has a combustion chamber or primary chamber represented by section "A" and a secondary chamber, section "B".

Primary air that supports combustion comes into the combustion chamber through 10-5/8 inch ports in the plate on the rear of the chamber. A second plate with matching holes fits just behind the base plate, and when this second plate is rotated, the ports can be closed or opened for the primary airflow adjustment.

Secondary air enters the burner through ports around the outside deflector at the rear of the burner. There are eight holes 1-1/2 inches in diameter for this secondary air. A band with eight matching holes has been placed around the burner at this location, and by rotating this band the ports can be closed or opened to adjust the secondary air.

Measurements of airflow through the burner have been made by inserting a tight-fitting tube three feet long over the 4-1/2 inch combustion chamber, then Pitot tube readings were taken on a sensitive differential pressure manometer across the diameter of this longer tube. This 4-1/2 inch tube was removed and a larger tube was placed over the 6 inch diameter secondary section and Pitot tube readings were again taken to get total airflow through the burner. The difference between the readings gives the secondary airflow to the burner. Calibrations were made so that airflow and primary-secondary airflow ratios are known for each position of the port adjusters.

With the burner installed in the wind tunnel, enough air can be blown through the primary burn chamber to literally blow the flame out; thus, combustion ceases when the primary ports are open wide when acetone is flowing at 2 gal per hour. When the primary ports are closed, combustion takes place in both the secondary portion and outside the burner, and a relatively hot flame is produced.

Maximum airflow to the burner at our installation with the present wind tunnel blower is about 0.5 lb of air per second through both primary and secondary chambers. Maximum airflow through the primary burn chamber at our installation is about 0.1 lb per second. The amount of air required for complete combustion of acetone flowing at 2 gal per hour is 0.041 lb per second. This gives a maximum stoichiometric ratio for air to the burn chamber of about 2.5, but as was mentioned earlier, the burner will not sustain a flame with this much air flowing through the primary section of the burner.

If the burner is ignited with the primary airflow shut off, the flame extends about three feet beyond the top of the burner and the flame temperature in the hottest part of the flame is about 1100C as measured by a chromel-alumel thermocouple. As the primary air ports are opened, the flame shortens and the flame temperature increases until it reaches about 1250C. At this point airflow measurements show airflow to be about 35 CFM through the primary section which gives a stoichiometric ratio very close to 1. As the airflow through the primary section is increased further, the flame temperature decreases and the flame shortens. The excess air serves to cool the flame and quench it quickly. The flame temperature drops eventually to about 500C before it is blown out.

RESULTS

Nucleation efficiency tests have been made on the burner effluent as the burner is operated with different amounts of primary air. More than 50 test runs have been made to determine the operating conditions that give maximum nuclei numbers at the warmest cloud temperatures. With high stoichiometric air ratio greater than 2, nuclei can be produced when a 5% AgI-NH_4I acetone solution is used that is active at between -2.5 and -3.0C with numbers in excess of 10^{11} nuclei per gram of AgI at -3C and 10^{14} at -17C. To obtain these results, primary airflow to the burner should be regulated to give a flame temperature of between 625 and 675C.

If airflow to the burner is such that the flame temperature is close to 1200C, the warmest cloud temperature at which ice crystals will form is around -6C. When the flame temperature is at 1200C the nuclei numbers active at cloud temperatures of -17 are in the same range (near 10^{14} per gm) as they are for the cool flame operation.

X-ray diffraction studies (Davis et al., 1973) of the generator effluents that are collected on fiberglass filter paper show that the crystallite size for the cool flame effluent and the hot flame effluent are not greatly different. For the hot flame effluent the mean crystallite size is close to 0.7 μm and the cool flame particles have a mean "crystallite"size of near .085 μm. From theory, this size difference would not be significant.

There is one other important feature that the x-ray diffraction studies have shown. When the generator is operated in the cool flame mode with an excess of air which gives active ice nuclei at -3 or warmer temperature, there is a trace of AgI-NH_4I complex present in the generator effluent. This AgI-NH_4I complex does not appear when the generator is operated in the hot flame mode by reducing the airflow to the combustion chamber.

Nucleation efficiency curves are given in Figures 2 and 3 showing the effects of flame temperature on nuclei numbers per gram of AgI. With this burner, the nucleation threshold for the AgI nuclei can be raised from -6C to -3C simply by adjusting the airflow to the primary burn chamber.

TABLE OF RESULTS

Burner Operating Conditions	Average nucleation efficiency in nuclei per gm of AgI				
	-3	-6	-10	-14	-17
Low Airflow giving hot flame	0	4.5×10^{11}	8×10^{12}	3.5×10^{13}	10^{14}
High airflow giving cool flame	3×10^{11}	9×10^{12}	5×10^{13}	8×10^{13}	10^{14}

CONCLUSION

Efficient operation of a silver iodide generator burning an acetone solution of AgI-NH_4I is dependent on the airflow to the combustion chamber, and if nuclei are to be produced that are active at the warmest possible cloud temperature, care must be taken to see that an excess of air is supplied to the burn chamber. With proper airflow to the burn chamber, it is possible to produce nuclei that are active at -2.5 to -3C. It is recommended that considerable attention should be given to proper burner operation for weather modification projects when acetone solutions of AgI-NH_4I are used.

ACKNOWLEDGEMENT

This research was supported by the following agencies: the U.S. Department of the Interior, Bureau of Reclamation, under Contract Number 14-06-D-6796 and the Naval Weapons Center, China Lake, California under Contract Number N00123-73-C-0775.

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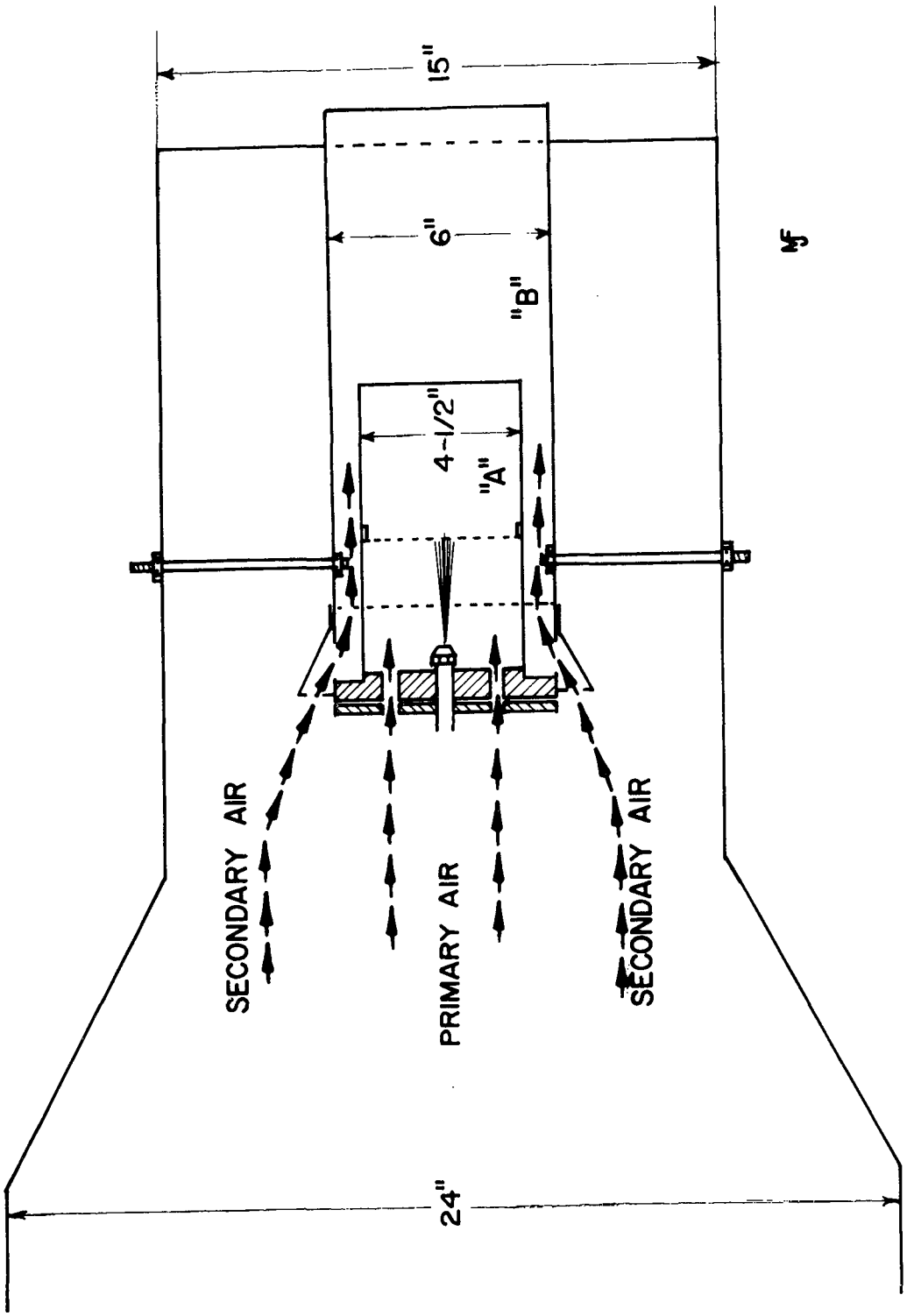


Fig. 1. The IAS experimental burner as modified from the NWC Airborne Jet Seeder.

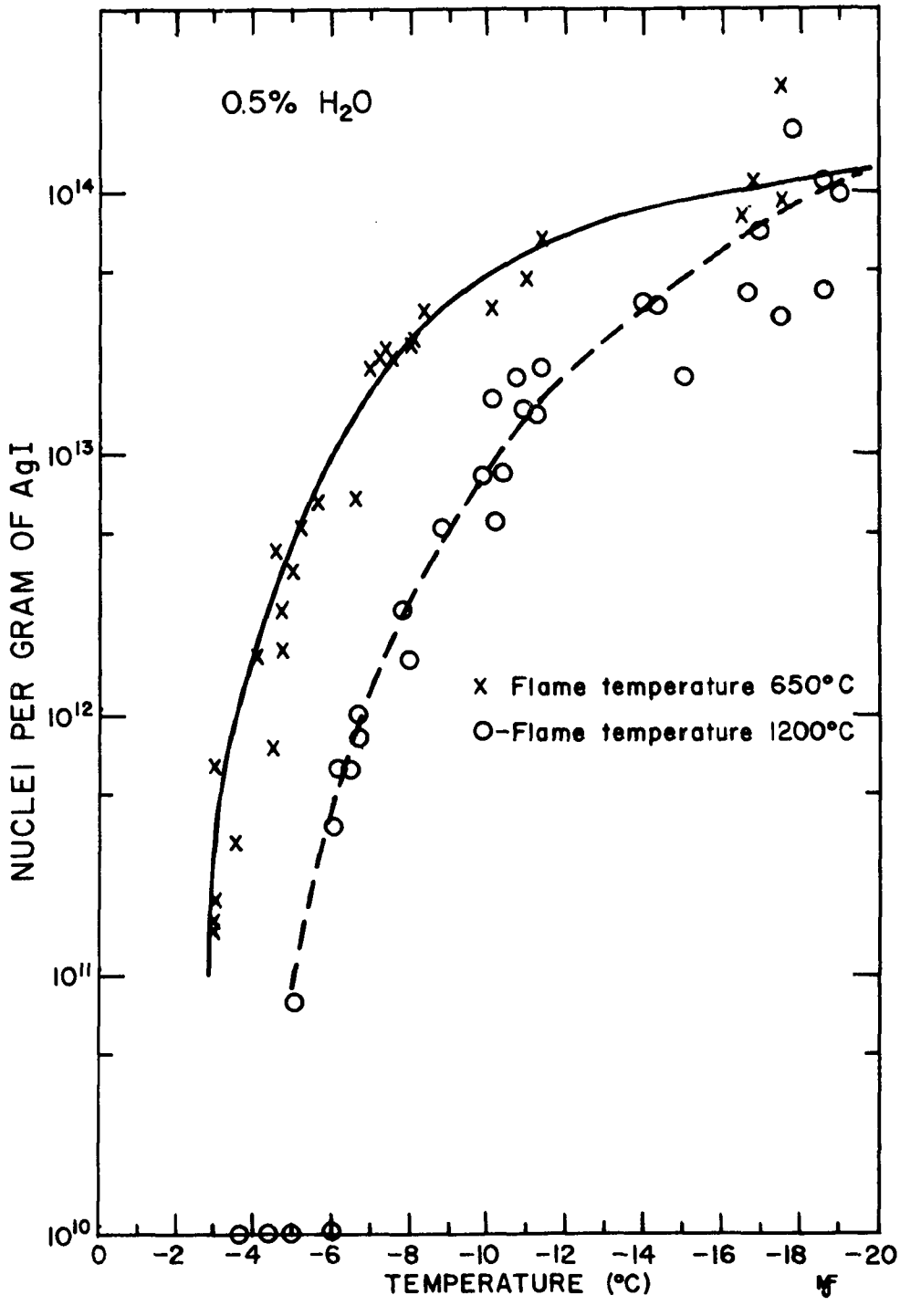


Fig. 2. Nucleation efficiency of 5% AgI-NH_4I acetone solution with 0.5% H_2O at flame temperatures of 650 and 1200C.

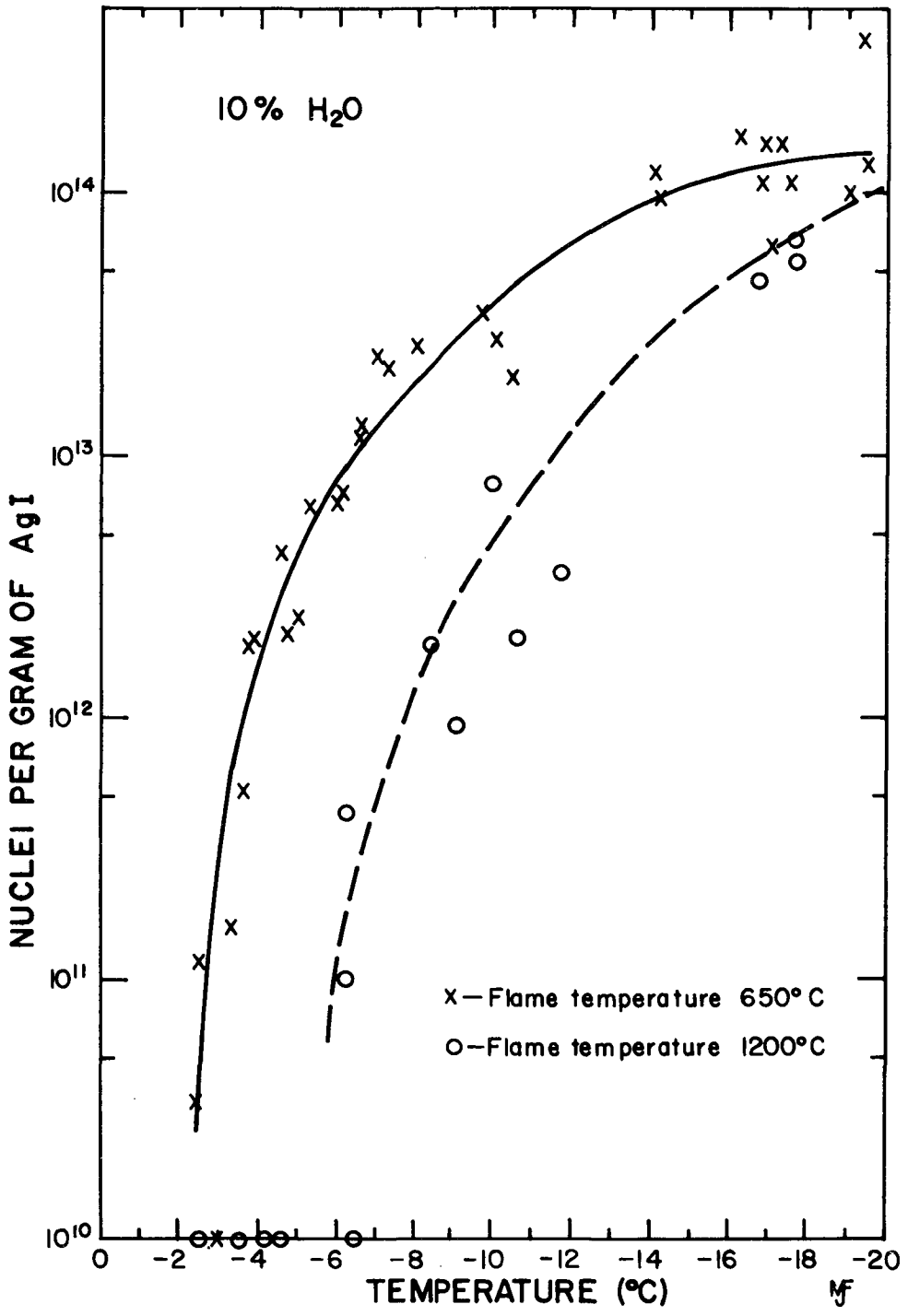


Fig. 3. Nucleation efficiency of 5% AgI-NH_4I acetone solution with 10% H_2O at flame temperatures of 650 and 1200C.

HAIL SUPPRESSION EFFECTS FROM SEEDING WITH SILVER IODIDE IN WESTERN NORTH DAKOTA

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INTRODUCTION

Recent reviews of hail suppression attempts using various cloud seeding techniques and agents have given evidence that hailfall on seeded days is different from hailfall on unseeded days (Schleusener et. al., 1972; Schleusener, 1968; Marwitz, 1973). The purpose of this paper is to present additional data from two project seasons of a cloud seeding project which sheds additional light on the question of seeding effects on hailfall.

Our organization has completed a four-year randomized cloud seeding experiment in western North Dakota. The project was sponsored jointly by the Division of Atmospheric Water Resources of the Bureau of Reclamation (USBR) and the Weather Modification Authorities of McKenzie, Mountrail, and Ward counties in North Dakota (Authorities). The objective of the USBR was to gain knowledge relating to enhancement of rainfall. The objective of the Authorities was to reduce hail damage and increase rainfall.

The project was conducted during the summers of 1969-1972 inclusive, and was randomized 75% seed and 25% no-seed. Each eight-day period throughout the project seasons were divided into 1 two-day no-seed period and 3 two-day seed periods. All cloud seeding operations were conducted under the direction of project meteorologists using ground based radar to assist in directing cloud seeding aircraft.

The project operated in McKenzie County only in 1969, 1970, and 1971. During 1969 and 1970, nine ground generators and two seeding aircraft were available for below cloud base seeding using a 3% silver iodide in sodium iodide acetone solution. In 1971 and 1972, the ground generator capability was deleted from the project. Nucleation efficiency studies carried out by the Institute's Cloud Physics Laboratory showed that silver iodide in an ammonium iodide acetone solution produced nuclei which were more effective at warmer temperatures than the sodium iodide solution (Blair et al., 1973). In 1971, two aircraft equipped with two each generators seeded using a 10% (by weight) AgI in NH_4I solution, dispersing about 400 gm/hr of AgI per generator. This solution proved troublesome in that it created corrosion problems in the generators (Davis and Schleusener, 1972). Therefore, in 1972 the concentration of silver iodide was reduced to 4% (by weight); a generator burn rate of about 190 gm/hr was used. All generator

parts were constructed of stainless steel. Additional changes during 1972 include the capability of seeding clouds with finely ground powdered salt, expansion of the project area to include Mountrail and Ward counties (Figure 1), and a total of five aircraft available for cloud seeding purposes. Three of these aircraft carried two each acetone generators and two aircraft each carried one generator plus up to 750 pounds of powdered salt.

All hail suppression cloud seeding was done below cloud base in the inflow areas of storms. Individual storm cells were seldom seeded at a rate greater than 400 grams of silver iodide per hour, since all available aircraft were usually needed to locate and seed the multiple updraft areas of storms posing a hail threat.

DATA COLLECTION AND ANALYSIS

A network of passive hail pads and rain gages was installed to provide data for evaluation. Local ranchers and farmers, acting as cooperative observers, recorded twice daily (1000 and 2200 CDT) rainfall observations on postcards and changed the aluminum hail pad indicators following hail events. The network (Figure 2) provided observational points of about 1 per 34 sq mi in McKenzie County and 1 per 99 sq mi in Mountrail and Ward counties. During 1971 and 1972, additional information was obtained from hail questionnaires filled out by the cooperative observers. Supplemental data were occasionally obtained by talks with residents of areas affected by hailfall.

Insured crop-hail loss data were obtained from the Crop-Hail Insurance Actuarial Association (CHIAA) for target areas. Insured crop liability amounted to about 10% of the total crip value in 1972, and it is believed this would also be fairly representative for prior years.

During 1971 and 1972, a quantitative radar system consisting of a 10-cm radar with a 10-foot antenna, a digital echo integrator, a seven-track digital tape recorder and a Nova minicomputer was made available to gather digitized radar echo data. This radar system, designated as the NCPR-1, was provided by the facilities laboratory of the National Center for Atmospheric Research. Radar data were obtained to a range of 120 km from Watford City, and times of gathering were usually limited to the times when echoes were present in McKenzie County. Thus, radar data were not logged for Ward County and northeastern Mountrail County and only occasionally for western and southern Mountrail County. The data were stored on magnetic tape, and processed on the National Center for Atmospheric Research CDC 7600/6600 computer system.

Additional data were obtained from 16-mm time-lapse photography of radar PPI scopes, radar echo overlays showing maximum reflectivity ractors and cloud tops, cloud seeding pilot reports, and project meteorologist logs of radar and other operational data.

Table 1 summarizes the parameters obtained from the data collected and used in this analysis. A more extensive analysis of all the data

collected, including the insured crop-hail loss data, will be presented in another paper.

Since the only radar data available to the project during 1969 and 1970 was of 3-cm wavelength, emphasis was turned to 1971 and 1972 10-cm radar data which alleviates any significant attenuation problems encountered when hail is present in the contributing region.

This paper presents an analysis of hail versus radar data selected from the data samples obtained in 1971 and 1972. The years 1971 and 1972 were selected for the current study because of the higher quality of radar data obtained during these years and because additional effort was also made during these years to obtain information to supplement the data from the basic hail pad network.

EFFECTS OF SEEDING ON RELATIONSHIPS BETWEEN HAIL AND STORM PARAMETERS MEASURED BY RADAR

Data Included in Analysis

Data used in this analysis were collected 15 June to 15 August 1971 and 1 June to 31 August 1972 -- the periods of randomized cloud seeding for hail suppression for the two years.

The majority of unseeded cases were obtained from no-seed days, but a few were obtained from storms which had been left unseeded on seed days due to limited resources and equipment malfunctions. When any doubt existed about whether or not a particular cell or cells had been seeded for hail suppression, its data were not used for this analysis.

Each set of observations used is for an accurately identified seeded or unseeded cell or group of cells, but observations making up a case were not always obtained at exactly the same time and place, e.g., HEMX and DMX may have been measured at different but adjacent hail pad locations, while ZMX and MEH may have been observed at slightly different times and places. It was not possible to collect adequate data to define all of the parameters in every case. Consequently, the same number of data points were not available for constructing each of the regression lines in Figures 3,4, and 5.

Comparison of MEH-HEMX Relationships (covariance analysis)

A covariance analysis was carried out to compare seeded and unseeded storms, using the maximum echo height (MEH) as the independent variable and the maximum reported hail energy (HEMX) as the dependent variable. It is based on 16 seeded and 16 unseeded cases. The data are plotted in Figure 3, and the results of the covariance analysis are given in Table 2.

Discussion of Results

The regression lines have low correlation coefficients, and null

hypotheses that the regression lines are the same cannot be rejected with a high degree of confidence (Table 2). However, a trend toward increasing HEMX with increasing MEH is apparent for unseeded storms but not for seeded storms (Figure 3). Inspection of Figure 3 leaves one with the impression that a large hail energy suppression effect may have been realized from seeding storms with tops above 40,000 feet MSL.

Comparison of ZMX-DMX Relationships (covariance analysis)

A covariance analysis was carried out to compare seeded and unseeded storms, using the maximum equivalent radar reflectivity factor (ZMX) as the independent variable and the maximum reported hail diameter (DMX) as the dependent variable. It is based on 20 seeded and 16 unseeded cases. The data are plotted in Figure 4, and the results of the covariance analysis are given in Table 3.

Discussion of Results

Although the correlation coefficient for unseeded cases is small, the tendency for unseeded cases to lie well above seeded cases (Figure 4) is supported by the covariance analysis (Table 3). The null hypotheses that (a) one line fits both samples and that (b) the adjusted means are the same are both rejected at the 99% confidence level.

Comparison of ZMX-HEMX Relationships (covariance analysis)

A covariance analysis was carried out to compare seeded and unseeded storms, using the maximum equivalent radar reflectivity factor (ZMX) as the independent variable and the maximum reported hail energy (HEMX) as the dependent variable. It is based on 22 seeded and 17 unseeded cases. The data are plotted in Figure 5, and the results of the covariance analysis are given in Table 4.

Discussion of Results

The null hypotheses that (a) one line fits both samples and that (b) both lines have the same slope are rejected at high confidence levels, but the null hypothesis that the adjusted means are the same cannot be rejected at a high confidence level (Table 4). Figure 5 shows a tendency for HEMX to increase much more rapidly with increasing ZMX in unseeded storms than in seeded storms. While the adjusted means are not statistically different, these data do suggest that seeded storms produced smaller HEMX than unseeded storms with equal ZMX and that the effect is greatest at high ZMX values.

Since a direct relationship exists between hail diameters and hail energies (Schleusener and Jennings, 1960), the suggestions that cloud seeding has produced a reduction in hailstone diameters (Figure 4) and in hail energies (Figure 5) are consistent. These are also consistent with the findings of previous theoretical studies that a reduction in maximum hailstone sizes at the ground should be realized from seeding in most cases (Dennis and Musil, 1973).

SUMMARY AND CONCLUSIONS

For the two summers (1971 and 1972) covered by this study, hail suppression cloud seeding was done by flying below cloud base and releasing silver iodide at rates of 190 to 400 grams per hour into each identifiable updraft area. The silver iodide was released by wing-tip generators burning a solution of silver iodide and ammonium iodide in acetone.

Comparison of radar parameters (maximum echo height and maximum reflectivity) versus hail parameters (maximum impact energy and maximum hailstone diameter) for seeded versus unseeded storms, using covariance analysis techniques, indicates a high probability that the seeding techniques used significantly reduced hail intensity.

ACKNOWLEDGMENTS

The North Dakota Pilot Project was sponsored by the Division of Atmospheric Water Resources Management, Bureau of Reclamation, U.S. Department of the Interior, under Contract Number 14-06-D-6660 and by the Weather Modification Authorities of McKenzie, Mountrail, and Ward counties, North Dakota.

Acknowledment is made to the National Center for Atmospheric Research, which is sponsored by the National Science Foundation, for providing the NCPR-1 radar system and standby power generating units and for use of its CDC 7600 computer for reducing NCPR-1 data.

Dr. Arnett S. Dennis provided innumerable ideas, guidance, and discussion throughout the analysis phase of the project and Mr. Douglas E. Cain did the covariance analysis.

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TABLE 1

Parameters Used in the Analysis

	Acronyms	Data Source	Units
1. Maximum Radar Echo Height	(MEH)	M-33, 3-cm radar and APS-42 3-cm radar	feet
2. Hail Energy Maximum	(HEMX)	Hail pad network	ft-lb/ft^2
3. Diameter of Maximum Hailstone	(DMX)	Hail questionnaire	inches
4. 10-cm Equivalent Radar Reflectivity Factor	(ZMX)	10-cm radar	dBz

TABLE 2

Comparison of HEMX versus MEH for
Seeded and Unseeded Storms

A. Results of Covariance Analysis

Null Hypothesis	f_1	f_2	F-test Results (probability level)
One line fits both samples	2	26	1.89 Pr(larger F)=.17
Two lines needed, both have same slope	1	26	1.71 Pr(larger F)=.20
Adjusted means are the same	1	27	2.01 Pr(larger F)=.17

f_1 = degrees of freedom for lesser mean square

f_2 = degrees of freedom for greater mean square

B. HEMX versus MEH Regression Lines

	Seeded	Unseeded
Correlation coefficient	-0.08	0.35
Intercept	4.96	-42.13
Slope	-0.04	1.47

TABLE 3

Comparison of DMX versus ZMX for
Seeded and Unseeded Storms

A. Results of Covariance Analysis

Null Hypothesis	f_1	f_2	F-test Results (probability level)
One line fits both samples	2	30	16.47 Pr(larger F)<.001
Two lines needed, both have same slope	1	30	0.12 Pr(larger F)=.88
Adjusted means are the same	1	31	33.77 Pr(larger F)<.001

f_1 = degrees of freedom for lesser mean square

f_2 = degrees of freedom for larger mean square

B. DMX versus ZMX Regression Lines

	Seeded	Unseeded
Correlation coefficient	.55	.18
Intercept	-0.91	-0.13
Slope	.017	.011

TABLE 4

Comparison of HEMX versus ZMX for
Seeded and Unseeded Storms

A. Results of Covariance Analysis

Null Hypothesis	f_1	f_2	F-test Results (probability level)
One line fits both samples	2	35	8.48 Pr(larger F)<.002
Two lines needed, both have same slope	1	35	5.37 Pr(larger F)<.03
Adjusted means are the same	1	36	1.87 Pr(larger F)≈.18

f_1 = degrees of freedom for lesser mean square

f_2 = degrees of freedom for greater mean square

B. HEMX versus ZMX Regression Lines

	Seeded	Unseeded
Correlation coefficient	.52	.60
Intercept	-25.14	-146.80
Slope	0.48	4.64

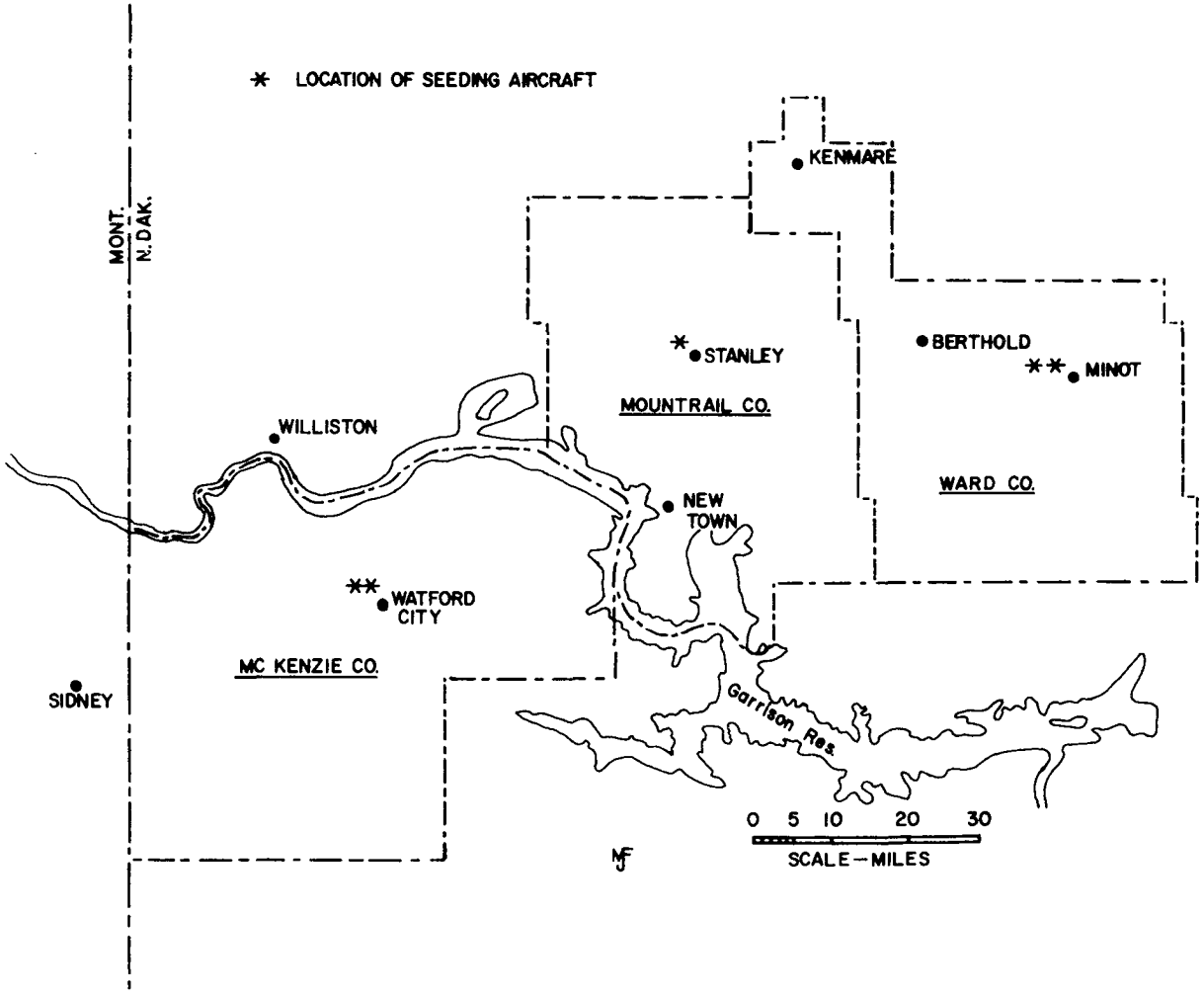


Fig. 1. Map showing the 1972 target area and aircraft locations. The 1969, 1970, and 1971 target area consisted of McKenzie County only. In 1972, project radar sites were located at Watford City and Berthold.

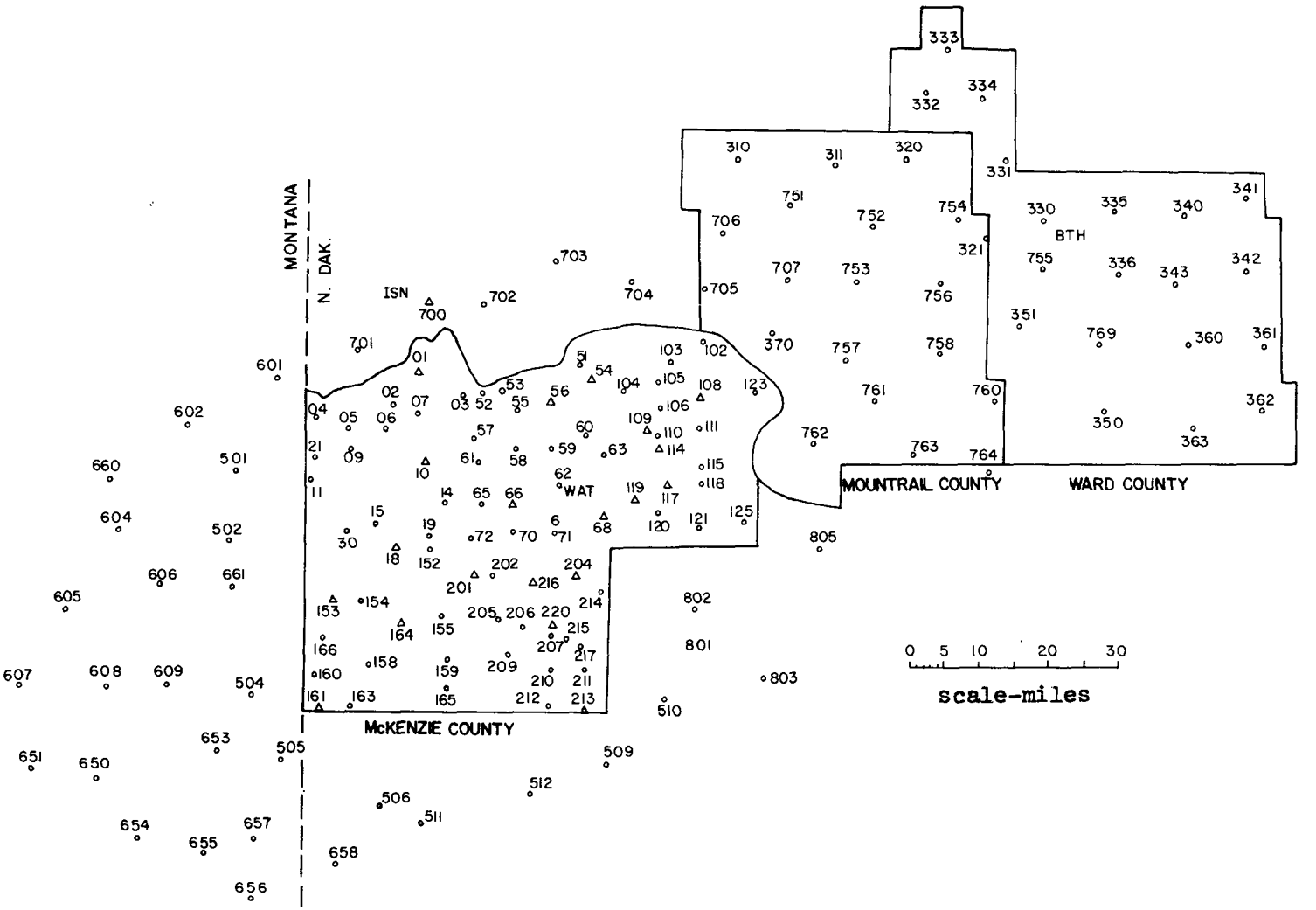


Fig. 2. Map showing the 1972 rain gage and hail pad network. Triangles indicate recording rain gages.

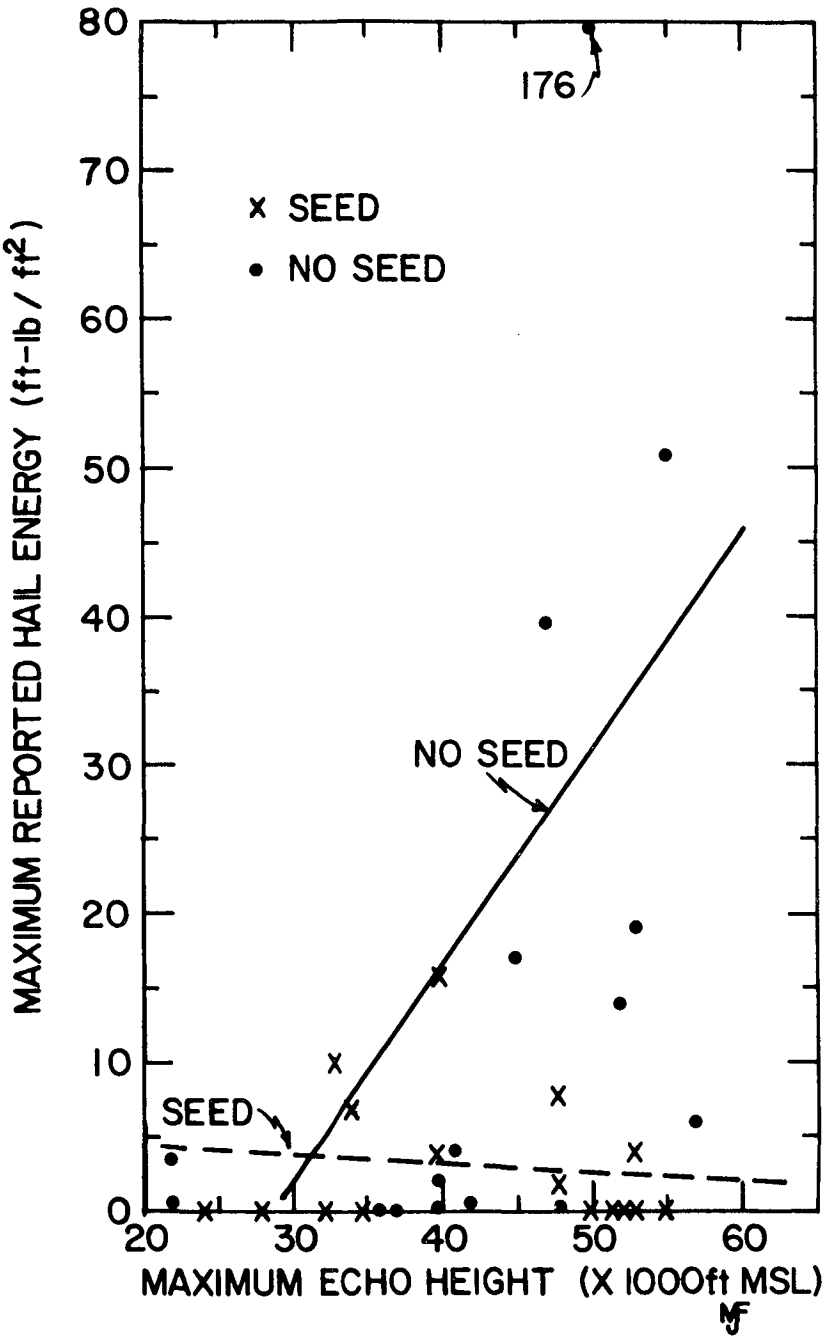


Fig. 3. Variation of maximum hail energy (ZMX) with maximum echo height (MEH) in seeded and unseeded storms.

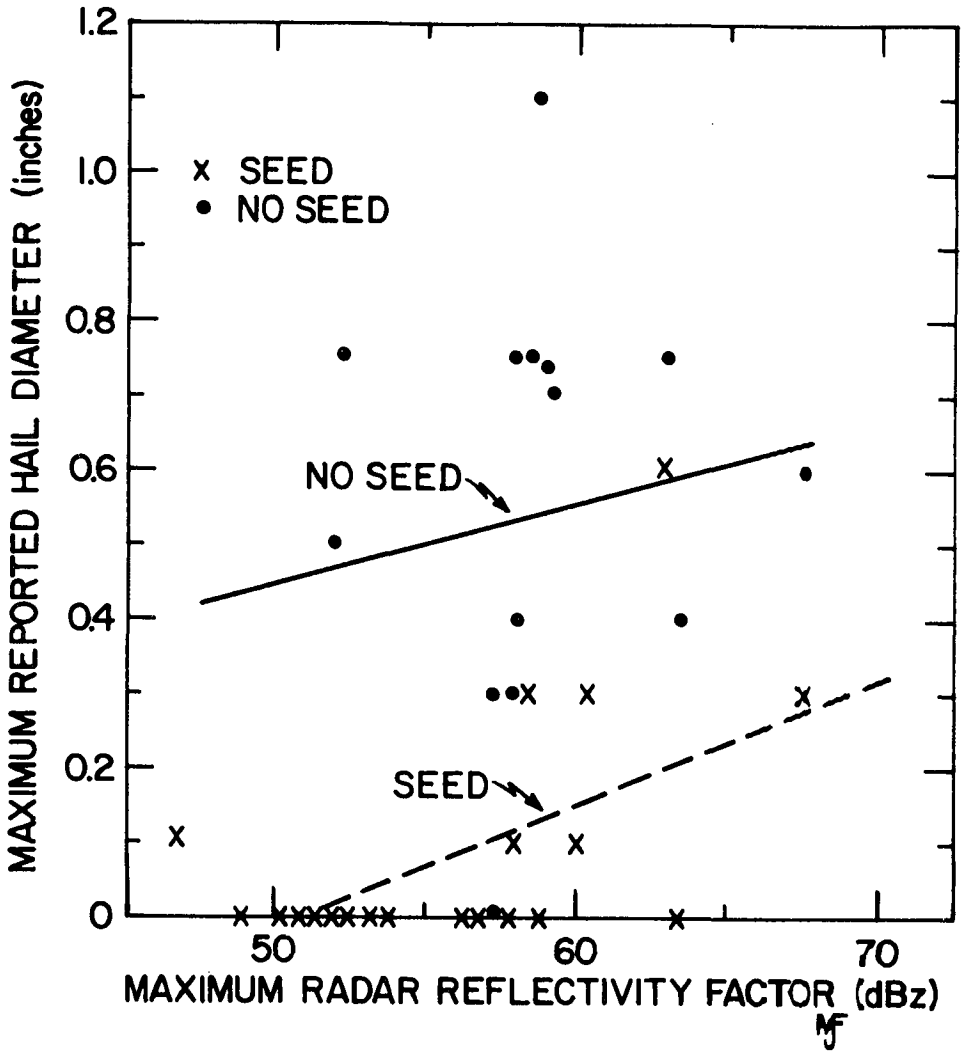


Fig. 4. Variation of maximum hail diameter (DMX) with maximum radar reflectivity factor (ZMX) in seeded and unseeded storms.

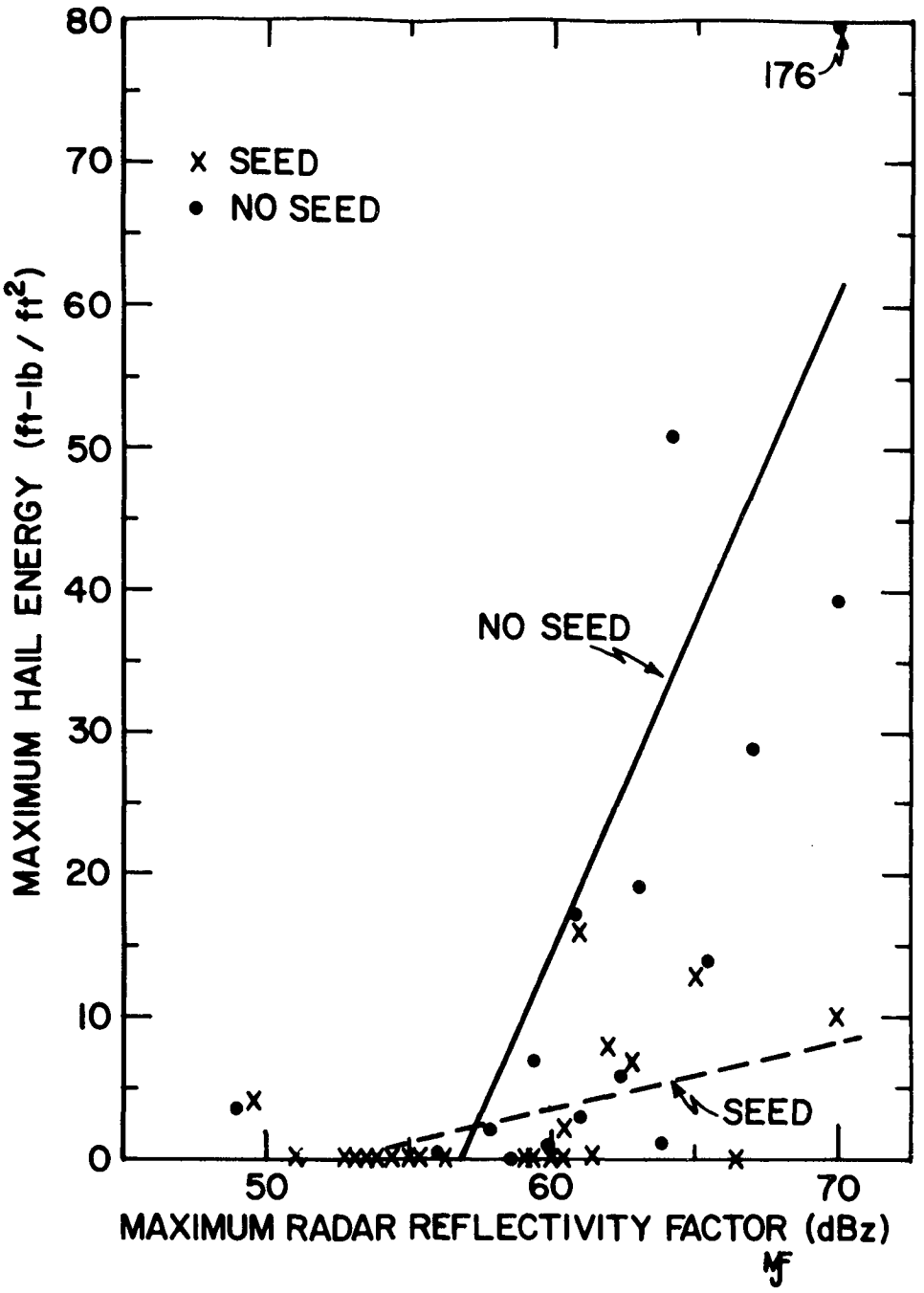


Fig. 5. Variation of maximum hail energy (HEMX) with maximum radar reflectivity factor (ZMX) in seeded and unseeded storms.

THE ANTI-HAIL CAMPAIGN IN ARGENTINA

Daniel Gómez

Argentina

The Anti-Hail Campaign in Argentina began in a more or less systematic way as far back as 1948, when engineer Julio Giorgi and his brother began experimenting with the use of solid propellant rockets similar to those used in Italy, but loaded with silver iodide instead of the explosives carried by Italian rockets.

Although these kinds of experiments did not give any definite results, several wine-producing firms decided to "sow" the storm-clouds by this method, purchasing rockets and beginning to use them ad hoc (this is the case of the Agrarian Syndicate and the Bodegas Arizu in the Provide of Mendoza, years 1955 to 1960). As these experiments were not being used in a planned or organized way they were, little by little, abandoned as the results showed neither any advantage nor financial benefits; the wine-producing firms covering their eventual losses through the "Agricultural Insurance" and occasionally by means of the use of anti-hail nets (which even today, are being used in certain districts, especially in Mendoza).

Simultaneously, in view of the serious losses caused annually, the National Weather Board began to intensify their studies, and started investigations towards obtaining the greatest possible amount of data as regards the phenomenon in this country and the eventual combatting of storms. With this object in view, and together with the Buenos Aires School of Exact and Natural Sciences, professors were sent to the most advanced countries at that time in this kind of study (Russia, France).

In the year 1958 an experimental hail-prevention campaign was planned and organized jointly with the National Weather Board, the Government of the Province of Mendoza (through the Institute of Agrarian Insurance), the School of Exact and Natural Sciences and the National Council of Scientific and Technical Research. This was carried out in an area of some 2,500 km^2, close to the city of Mendoza during the years 1959 to 1964. Some 100 burners using coal impregnated with silver iodide dissolved in acetone were used in the following way: When the Weather Forecasting Office foresaw the probability of rain and hail in a certain region, they advised the directors of the Company, who decided whether or not to carry out the work. From then on, instructions were given by radio to those in charge of the "sowing" in the zones indicated who then ignited the silver iodide generators, producing nuclei which rose toward the clouds.

The experiments were carried out with scientific rigor and seriousness (comparative systematic control, etc.) but the results were still not encouraging, owing partly to the use of burners, which could only, with difficulty, inject the iodide nucleant crystals on the spot and at the exact time required. In spite of the apparently disappointing failures,

the work was continued slowly, as the experience was useful as regards more knowledge being acquired of the meteorological mesometeorological, climatological processes and the physics and chemistry of the clouds of that zone.

In December 1971, the Council of Science and Technology (CONACYT) authorized the necessary funds to commence the development of a National Anti-Hail Campaign Plan, conducted by the National Commission of Space Research (CNIE) to be carried out also in the Province of Mendoza, using San Martin in the north of the Province as an experimental base. Shortly afterwards in 1972, the Government of said Province decided to support the campaign and voted funds for that purpose. The Universities of Mendoza, Cordoba, Buenos Aires, El Salvador, and later, the University of the South, joined the project, also with the special collaboration of the SMN (National Weather Board). In this way the ambitious plan of the artificial modification of the weather was put in hand.

Although there are other zones in the country where there are heavy hailstorms (alto Valle del Rio Negro in the Province of Neuquen, Province of Salta, in the Pampa Humeda, etc.) the spot was chosen due to the high frequency of days with hailstorms, plus the concentration and financial value of the crops, as well as the particular knowledge and relative information on hail gathered in that zone. For the development of the project three concentric zones were chosen, the center-base being the City of San Martin, some 80 km. to the south of the Province. The three zones are:

A. Defense zone (the inner one) with a radius of some 18 km. which was chosen owing to the existence of the method to be applied and the characteristics and distribution of the damage caused by hail (the average percentage of damage is 13.41%, the total average damage in vineyards in the whole province being 13.72%, years 1952/62).

B. Study zone, which surrounds the previous one, and which is representative for the climatic study by radar of the precipitating clouds (radius of the zone about 59 kms.).

C. One external control zone which surrounds the reference zone as far as the boundaries of the cultivated area.

The work will be carried out in the laboratory and on the ground in a theoretical-experimental manner and the method to be applied will be that of "sowing" the clouds with lead iodide by means of the use of solid propellent rockets recoverable by parachutes. The type of "sowing" will be means of tracks; i.e., the injection of the seeding agent will be carried out during the path of the rocket inside the clouds. At the same time, there will be studies and research into synoptic meteorology, aerology, radarmeteorology, cumulus dynamics, cloud physics and microphysics, hail climatology, atmospheric and cloud electricity and mesometeorology.

The evaluation of the effectiveness of the method will be made by technical physicists and statisticians. The physical control and evaluation

will be made at the actual time (during the test) with the data acquisition on the evolution of the parameters of the "cell" submitted to the "sowing" being accomplished by radar. Later the parameters obtained before and after the test will be analyzed using a computer B-3500 of the F.A.A. (Argentina Air Force).

The statistical evaluation will consist in comparing the representative variations of the damage caused by the hail in the defense and control zones before and after the experiments. The variables will be (1) area damaged, (2) percentage damaged, and (3) losses suffered in each zone.

The present work of preparation and organization is centralized in four different areas:

A. Radar Meteorology
B. Synoptic Meteorology
C. Cumulus Dynamics
D. Cloud Physics and Microphysics
E. Chemical agents with glaciogenic properties

The following equipment is available for developing the work in these areas:

A. Decca radar of 3 cm wave-length lent by SMN and already working in San Martin.
B. Radar FPS-18 of 10 cm wave-length, lent by the U.S. National Center for Atmospheric Research (NCAR) and now being adapted to requirements and the buildings for use of same.
C. 160 pluviohailmeters
D. 160 impact meters
E. 30 pluviographs
F. radio-drilling and communications equipment

At the same time prototypes of the recoverable rockets to be used (type 1 of 15 kg with 1 kg load, and maximum height obtainable at 85^{o} some 6 km. Type 2 of 32.5 kgs and maximum height obtainable at 85^{o} some 10 km.)

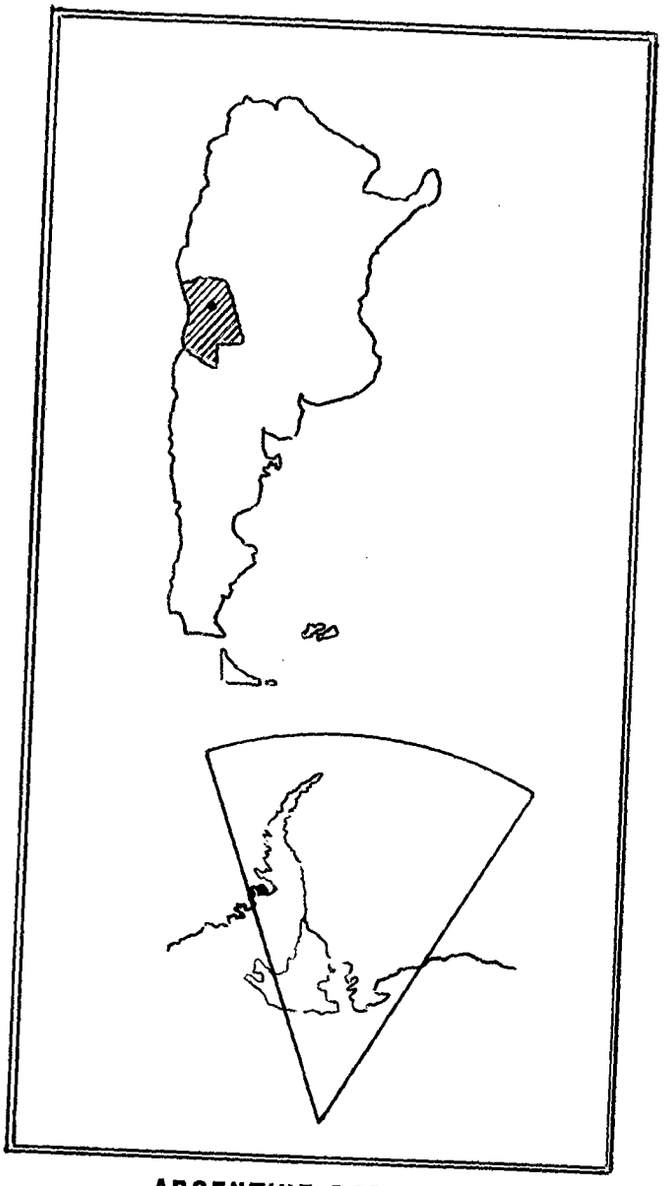
The chemical agent is placed in the ojive of the rockets and is lit at the required height by means of a timer which can be regulated from the ground. The propellant of the rocket type 1 is compound and the nozzle is annular to allow the container which holds the braking system and the timer to be placed behind the motor. In the rockets of type 2, the propellant is compound and has four nozzles bent ourwards, therefore the braking system is also placed at the back of the motor. Both models can be fired from the same type of transportable ramp with a capacity for four units. Dockets may be fired in sequence at intervals of 5 seconds, or one at a time as required. Between each one of the guides and the whole length of the "boom" there is a screen which prevents the gases of the fired rocket from affecting the other ones. The boom can move 360^{o} in azimuth and from 0 to 90^{o} in elevation.

Therefore, once the essential scientific and technical elements have

been assembled, the defense against hail can be carried out in a pilot zone during part of the 1974-75 season (from October to March, which is when there is a greater possibility of hail), with the object of facilitating the previous coordination of the participating teams and the training of the assistant staff of the project.

In view of the fact that the artificial modification of the weather requires an ample knowledge of the mechanisms which rule it, the evaluation of the results obtained with these tests will permit the perfecting and enlarging of the field of research, extending the objective work to other regions of the country thus contributing to its development, and increasing the technical-scientific knowledge as regards meteorological research.

FIGURE 1



ARGENTINE REPUBLIC
Dark Area correspond to the Province of Mendoza

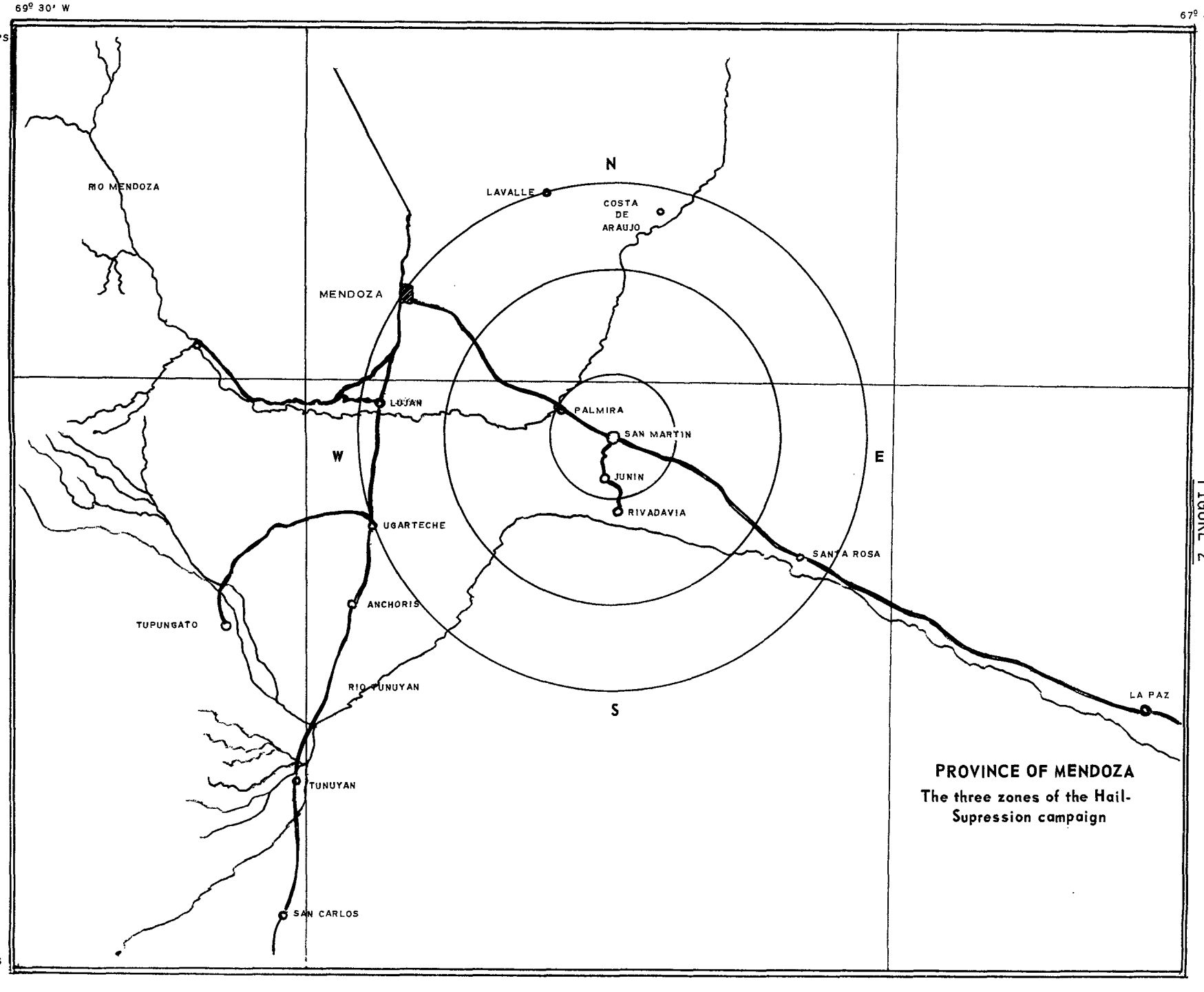

69º 30' W
67º 30' W
32º 30'S
33º50'S
RIO MENDOZA
LAVALLE
COSTA DE ARAUJO
N
MENDOZA
LUJAN
PALMIRA
SAN MARTIN
W
E
JUNIN
RIVADAVIA
UGARTECHE
SANTA ROSA
ANCHORIS
TUPUNGATO
RIO TUNUYAN
LA PAZ
S
TUNUYAN
SAN CARLOS
PROVINCE OF MENDOZA
The three zones of the Hail-Supression campaign

FIGURE 2

A RANDOMIZED CLOUD SEEDING EXPERIMENT IN THE DECCAN PLATEAU, INDIA - PRELIMINARY RESULTS

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ABSTRACT

A randomized experiment, using warm seeding technique, has been undertaken in the low rainfall region east of Poona in the Deccan Plateau. The experiment, for the first year, was conducted on 13 pairs of seedable days during the southwest Monsoon period, June to September, which is the period considered for seeding. The results showed positive trend on 7 pairs, negative trend on 4 pairs and inconclusive trend on 2 pairs, and are not statistically significant. The design of the experiment and the results are presented and discussed.

1. INTRODUCTION

Warm cloud seeding experiments on randomized basis, using ground-based generators and aircraft, have been in progress in India since 1957. Such experiments have recently been gaining ground elsewhere too (Schock, 1968; White, et al., 1970; Hall, et al., 1971; Biswas and Dennis, 1971; Koscielski, et al., 1971; Cunningham and Glass, 1972; and Serpoly and Andro, 1972).

Experiments using ground based generators were conducted at Jaipur (26°35'N, 75°50'E; 436 meters above MSL), Delhi (28°35'N, 77°12'E; 218 meters above MSL) and Agra (27°10'N, 78°10'E; 108 meters above MSL) in north India and at Munnar (10°05'N, 77°05E; 1457 meters above MSL) over the hill regions in south India (Roy, et al., 1961; Biswas, et al., 1967; Ramana Murty and Biswas, 1968; Chatterjee, et al., 1969). A series of experiments using aircraft was conducted at Delhi in 1962 (Roy, et al., 1964). The results of the 18 experiment-seasons of seeding in north India using ground-based generators suggested an increase of about 21% in the season's total rainfall (Biswas, et al., 1967). The experiment using aircraft, which was conducted on 18 occasions, indicated positive results on 7 occasions, negative results on 2 occasions, and inconclusive results on the remaining 9 occasions (Roy, et al., 1964).

The Deccan Plateau in India, which is classified as a dry farming zone, is often affected by drought. Until recently no cloud seeding experiment was undertaken in this region. The available results of the long

series of experiments referred to above in northern India cannot be considered as applicable to this region, for the meteorological conditions of the two regions, as described later, are not the same. A cloud seeding experiment has therefore been undertaken in the Deccan Plateau. The results for the first year are now available, and these are presented below along with the design of the experiment. Also, visual observations were made of the developments following seeding when individual clouds had been repeatedly seeded. A summary of these observations is also presented. A number of physical measurements were made inside clouds during the seeding experiment and these will be presented separately.

2. EXPERIMENTAL AREA

The experimental area is situated on the lee side of the Western Ghats and is about 40 km east of Poona (18°32'N, 73°51'E and 559 meters above MSL) and 150 km from the west coast. Figure 1 shows a view of a 3-dimensional chartograph of the Western Ghats and the experimental area. The experimental area is divided into three sectors, each 40 km X 40 km. The central one is the buffer sector, and the adjoining northern and southern ones are the experimental sectors. The average raingauge density in the experimental sectors is about one per 80 sq. km. Efforts are being made to increase this density. The area selected is situated in the low-rainfall region of the Deccan Plateau. Figure 2 shows the experimental area with the existing raingauge locations.

(a) Orography

The west to east orographic profile, from the coast of Bombay to the plateau of Poona, is shown in Figure 3. The surface rises from the west to east, on the average, to 0.8 km in a distance of 65 km and then ends in a plateau of average height of 0.6 km. The Western Ghats extend from north to south along the west coast. The rainfall during the period of southwest monsoon, June to September, on the windward side of the Western Ghats, is strongly orographic. The precipitation increases with altitude from the coast on the windward side and falls off sharply on the lee side. For example, normal rainfall during the monsoon season is 1966 mm at Bombay (coast), 4114 mm at Lonavla (crest), and 523 mm at Poona (plateau). It is only 327 mm at Bhond (buffer sector). The rainfall distribution along the orography was studied by Sarker (1966).

(b) Meteorological Conditions

The experimental area lies directly in the path of the monsoon westerlies. Prominent weather developments take place in the area when there is a trough of low pressure off the west coast. The area also experiences heavy rainfall either when a depression from the east coast takes a more southerly course or when the axis of the monsoon through in the mid-troposphere (2.5 to 3.5 km) is situated along a more southerly latitude (19-20°N).

The meteorological conditions referred to above of the experimental area are not the same as those of the areas previously experimented in north India. The latter are mentioned below for reference. The Delhi and Agra areas are located close to the axis of the sea level summer monsoon trough, the trough being generally observed as a pressure minimum at the surface and also as a shear zone between the low level westerlies and the overlying easterlies. The Jaipur area is located near the summer-time surface heat low, and lies to the southwest of seasonal position of the axis of monsoon trough.

(c) Winds

The predominant wind direction in the area, from surface to 3 km and above, during the season is westerly. The wind is therefore nearly normal to the direction in which the two experimental sectors and the buffer sector are oriented suggesting minimal contamination to either of the experimental sectors (control), when the other sector (target) is seeded.

(d) Rainfall correlation

Rainfall data are available for 3 raingauge stations each, in the north and the south sectors for many years prior to the year of commencement of the experiment. The monthly data, corresponding to 24 monsoon seasons (1946 to 1962 and 1964 to 1970) and the daily data corresponding to one good monsoon season (1964) and one bad monsoon season (1966), were analysed. The monthly data showed a correlation of 0.67, significant at 0.1 per cent level. The daily data showed a correlation of 0.23, significant at 2.5 per cent level during the bad monsoon, and 0.56, significant at 0.5 per cent level during the good monsoon.

3. SEEDABLE DAYS

The classification made of seedable days has been based on the following criteria: (i) forecast amount of low cloud, (ii) forecast wind, (iii) conditions for weather development in the Poona region as inferred from study of daily synoptic charts, (iv) meteorological debriefing reports available from other flights in the region, and (v) current weather conditions in the experimental sectors reported by special weather telegrams. A day has been considered as seedable when the forecast is 3 okta or more of low cloud in the case of (i), westerly wind with speed not exceeding 20 knots up to 3 km above MSL, in the case of (ii), and when conditions are favorable in one or more of the cases at (iii), (iv) and (v).

4. EXPERIMENT

A randomized cross-over design having two experimental sectors with a buffer in between has been adopted. All successive seedable days classified according to 3 above have been grouped in pairs. The sector

to be seeded on the first day of each pair of seedable days has been decided by random numbers. This procedure automatically decides the sector to be seeded on the second day of each pair.

5. AIRCRAFT AND SEED DISPENSING-GADGET

The aircraft used is a DC-3 which was chartered from M/S Air Works, India, Bombay, and specially instrumented for the purpose. The seed-dispensing gadget consists of a funnel (Figure 4) which is fitted inside the aircraft. The funnel is coupled, through a venturi, to a dispensing duet assembly which is fitted under the fuselage (Figure 5). The funnel ends in an adjustable slit which can be operated by a mechanical lever from inside the aircraft. The gadget operates on the pressure developed inside the venturi while in flight. Also, an agitator (Figure 6) which operates at 300 r.p.m. was fitted above the slit to help free flow of the seeding material.

The rate of discharge of the material from the gadget can be controlled by operating the mechanical lever referred to above. It is adjustable in the range 0 to 30 kg per minute or per 3 km flight path. The funnel can safely accommodate, at a time, 150 kg of the seeding material. The cruising speed of the aircraft is about 180 kmph.

6. FLIGHT PROCEDURE AND SEEDING OPERATION

The flight procedure followed on any seedable day depended upon the type of seeding adopted, namely area cloud seeding or individual cloud seeding, which in turn was primarily decided by the prevailing cloud conditions in the seeding sector.

If the area was densely covered with cumulus clouds, area cloud seeding was done. For this purpose the flight path followed was in the form of an extended loop commencing from a little distance upwind of the western border of the sector and terminating at the same distance before the eastern border of the sector as shown in Figure 7. The sector was seeded in this manner covering the whole area once. The upwind distance considered from the western border varied with the prevailing wind speed and corresponded to the estimated distance covered by the wind in 15 minutes time period. This procedure has been adopted, keeping in view that after seeding it would take about 10 minutes for release of precipitation from cloud (Sutherland and Booker, 1973) and about 5 minutes for the precipitation to reach the ground.

If the area is sparsely covered with cumulus clouds, individual cloud seeding was done. The isolated clouds present in the sector were repeatedly seeded. The flight path followed for this purpose was repeated traverses in those clouds. The maximum number of traverses made for seeding in a single cloud was eight.

In both the cases of seeding referred to above, the operation was carried out at a level of a few tens to a few hundreds of meters inside the cloud from the base. The seeding material was dispersed in the first case at the rate of 10 kg per 3 km flight path. The rate was increased by 2 to 3 fold in the second case. The seeding material used, as in the earlier experiments (Roy et al., 1964), is a pulverised mixture of common salt and soapstone, taken in the ratio 10:1, with particle mode diameter of about 10 microns. Figure 8 shows the track of the seeding plume as seen from ground when the material was being dispersed at a height of 1 km at the rate of 30 kg per 3 km flight path. The period chosen for seeding was the southwest monsoon season, which is from June to September.

8. RESULTS

The preparations for the experiment were completed by 1973. The experiment for the first year commenced from 14 June 1973 and ended by September 1973. Seeding was done during this period on 26 days (13 pairs) which were classified as seedable according to the criteria adopted.

The details of seeding operation, namely seeded sector, duration of seeding, level of seeding, and quantity of material seeded on each seedable day, are given in Table 1. The duration of seeding on a seedable day veried from 35 to 205 minutes. The amount of material seeded varied from 625 to 1500 kg.

The results are presented under two groups: (i) Visual observations on developments following repeated seedings of isolated clouds (individual cloud seeding), and (ii) analysis of rainfall data relating to all the 26 days of seeding (area seeding and individual cloud seeding combined).

(i) Visual observations

As already mentioned, repeated seedings were carried out on days when the cloud density in the area was sparse. The clouds present on such occasions were generally isolated. On some of those occasions, there were clouds of large vertical thickness (> 2 km) too. The developments noted of the seeded clouds ranged from dissipation to incidence of heavy rain depending upon their vertical thickness at the time of commencement of seeding. When rain was detected following seeding, an attempt was invariably made to check whether that rain was reaching ground by coming out from inside the cloud and then flying well below the cloud base. The incidence of rain could be detected both by the hitting sound of the rain drops and by their splashing on the wind shield of the aircraft.

A summary of the visual observations, based on a minimum of six cases of seeded clouds each, under the different categories of cloud thickness considered, is given in Table 2.

Dissipation was observed in shallow clouds of less than 300 meters vertical thickness. The feature became noticeable after the completion of

seeding in the second traverse. Rain was observed in thick clouds of more than 1 km vertical thickness. Such features became noticeable after the completion of seeding in the second or the third traverse. The above features were more markedly noticed when higher rates of seeding approaching 30 kg per 3 km flight path were used.

The vertical thickness of cloud referred to in Table 2 was estimated by flying, invariably, at the base and top of the cloud in question. When this was not found possible, a visual estimate of the cloud thickness was made in consultation with the pilots.

(ii) Analysis of rainfall data

Each seedable day is considered either as a north-seeded day or a south-seeded day depending upon whether the north or the south sector was seeded on that day. Each pair of days consists of one north-seeded day and one south-seeded day. Each sector thus becomes once a seeded sector (target), and once a not-seeded sector (control) after completion of seeding on a pari of days. Each pair of days, therefore, embodies two seeded sectors and two not-seeded sectors. The values of mean rainfall T, T' recorded per raingauge station in the seeded sectors, and the values of mean rainfall C, C' recorded in the not-seeded sectors, on the north-seeded and south-seeded days, are given for each pair of days in Table 3.

The square root value of the ratio product $\frac{T}{C} \times \frac{T'}{C'}$, which represents the result of seeding, is shown in column 8 of Table 3. If the value is greater than 1, the result is positive. If the value is less than 1, the result is negative; and if the value is 1 or indeterminate, the result is inconclusive. Of the experiments conducted on 13 pairs of days, positive results were indicated on 7 pairs, negative results on 4 pairs, and inconclusive results on 2 pairs. The positive results ranged upward of 16 per cent, and the negative results ranged up to 100 per cent. Application of the Mann-Whitney test, which is non-parametric, on the series TT' and CC' showed that the results are not significant.

9. CONCLUSIONS

Cumulus clouds in the Deccan Plateau responded to warm seeding by common salt. Depending upon their thickness, the seeded clouds either dissipated or rained.

The marked positive response to seeding, exhibited by individual clouds of vertical thickness 1 km and more (clouds of such thickness were present on the seeded days), is not seen adequately reflected in the analysis of rainfall data, for, negative results were suggested on as many as 4 pairs of days as against positive results on 7 pairs. The use of 24 hours' rainfall data in the analysis, when the duration of the seeding was only 35 to 205 minutes, is one possible contributory cause for the discrepancy noted. The lack of close correlation between the daily rainfall values of the two sectors may be another such cause.

The following improvements have to be considered for incorporation in the experiments for the coming years. (i) The selection of seedable days should also be based on criterion of a minimum thickness of the prevailing cloud. (ii) The duration of seeding is to be increased so that repeated seedings become possible on occasions of area seeding also. (iii) Reports of rainfall are to be obtained at least twice in 24 hours, in case self-recording raingauges cannot replace the present ordinary raingauges.

10. ACKNOWLEDGEMENTS

The offices of the Director General of Observatories, at Delhi, Poona, and Bombay, extended their full co-operation for the experiment. The Indian Air Force provided necessary facilities for undertaking the experiment from the airport at Poona. M/S. Air Works India provided an enthusiastic air crew for the operation.

The authors express their deep sense of gratitude to the above organizations. The Instruments and Observational Techniques Division of the Institute took active part in the program of physical measurements. The authors express their sincere gratitude to the Division.

FIGURE LEGEND*

Figure 1: A 3-dimensional chartographic view of the Western Ghats and the experimental area. 'A' is north sector; 'B' is south sector; and 'C' is buffer sector.

Figure 2: Experimental area.

Figure 3: Orographic profile from the coast (Bombay) to plateau (experimental area).

Figure 4: Funnel of the seeding gadget fitted inside the aircraft.

Figure 5: Seed dispensing duct fitted to the fuselage of the aircraft.

Figure 6: Agitator fitted inside the seeding gadget.

Figure 7: Flight path followed for area seeding.

Figure 8: Track of the seeding plume as seen from the ground.

*Authors did not submit the actual figures.

TABLE 1

Date	Sector seeded	Duration of seeding (minutes)	Level of seeding above MSL (km)	Quantity of material seeded (kg)
1973				
June 14	North	160	2.3	1350
16	South	125	1.5	1500
27	South	165	2.3	1075
28	North	40	2.0	625
29	North	40	2.3	700
30	South	90	2.0	1500
July 1	South	55	1.9	775
2	North	90	1.7	1500
10	North	75	1.7	1250
12	South	45	2.1	1100
14	North	35	1.4	950
16	South	70	1.8	1450
17	North	90	2.0	1150
19	South	85	1.5	750
21	North	65	2.0	1500
22	South	205	1.7	1300
24	North	100	2.0	1500
August 3	South	80	2.1	1500
4	North	65	2.1	1500
5	South	60	2.1	1300
6	South	40	1.8	1500
8	North	100	2.4	1500
11	South	90	2.0	1500
12	North	60	1.8	1500
13	North	60	2.1	1500
16	South	50	2.3	950

TABLE 2

Summary of the visual observations made on isolated seeded clouds of different vertical thickness.

Vertical thickness	Observation
less than 300 meters	dissipation
300 - 500 meters	tendency for dissipation
500 - 1000 meters	tendency for rain
1 - 2 km	rain
greater than 2 km	heavy rain

TABLE 3

Pair	Date	North-seeded days mean rainfall in mm per station		Date	South-seeded days mean rainfall in mm per station			Result
		Target (T)	Control (C)		Target (T')	Control (C')	$(\frac{T}{C} \times \frac{T'}{C'})^{\frac{1}{2}}$	
	1973			1973				
1.	June 14	0.00	0.00	June 16	0.00	0.00	Indeterminate	Inconclusive
2.	June 28	9.10	3.83	June 27	15.33	27.07	1.16	Positive
3.	June 29	15.86	0.85	June 30	18.15	21.94	3.93	Positive
4.	July 2	5.93	1.21	July 1	16.35	40.13	1.41	Positive
5.	July 10	1.05	0.00	July 12	0.00	0.66	Indeterminate	Inconclusive
6.	July 14	6.08	12.51	July 16	0.45	1.27	0.42	Negative
7.	July 17	0.31	0.13	July 19	2.63	0.25	5.01	Positive
8.	July 21	0.00	0.25	July 22	0.03	0.19	0.00	Negative
9.	July 24	0.16	0.00	Aug. 3	9.23	11.90	Infinity	Positive
10.	Aug. 4	6.88	20.30	Aug. 5	9.50	12.17	0.51	Negative
11.	Aug. 8	7.67	4.95	Aug. 6	0.48	5.76	0.36	Negative
12.	Aug. 12	1.17	0.22	Aug. 11	1.00	0.18	5.44	Positive
13.	Aug. 13	0.68	0.22	Aug. 16	0.44	0.36	1.94	Positive

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THE EFFECT OF OZONE ON LEAD AND SILVER IODIDE

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During the summer of 1966, while studying the quality of the air in northern Arizona, I discovered and later described (1) a simple but highly effective method for measuring the number of submicroscopic lead particles in the atmosphere, presumably coming from automobile exhaust.

Since that time I have made such measurements in many parts of the world. The most recent intensive series was obtained on shipboard during a cruise to witness the total eclipse of the sun. We sailed from New York City to Tenerife in the Canary Islands, then to Dakar in Senegal, West Africa and thence back to New York City. In that series of observations a cold chamber lined with black velvet, and which had an average temperature of -20C was used. The period of observations extended from June 22 to July 8, 1973.

The procedure for making the observations was similar to many others which I have made for measuring ice nuclei during the past 27 years. A sample of air is obtained using a plastic bag or other container having a volume of about 50 liters. The air sample is then transferred to the cold chamber in such a manner as to displace the air within the cold chamber. A parallel beam of light is used to illuminate the interior.

For determining the concentration of submicroscopic lead particles, a bottle containing iodine crystals at a temperature of 20C or warmer is then placed at the bottom of the chamber for 10 seconds. This permeates the sample air in the cold chamber with iodine vapor. A distinct iodine smell is noted. A cloud is then formed by introducing water vapor into the chamber. A cloth wet with water having a temperature of 20C is an easy way to produce a supercooled cloud. If any ice nuclei are present, they form ice crystals within 30 seconds and glint in the light beam.

If the sample air contains either submicroscopic particles of lead or silver, they react with the iodine vapor to form a metallic iodide which then serves as a very effective nucleus for ice crystal formation. (2)

THE CONCENTRATION OF NUCLEI DURING THE ECLIPSE '73 CRUISE

During the Eclipse Cruise the first measurements were made when the ship was about 1000 miles east southeast of New York City. Only a very few ice crystals were observed despite the high concentration of iodine vapor. During most of the observations in the very clean oceanic air, the concentration ice nuclei was less than 1 per liter at -25C, with the concentration 65 per cc of cloud condensation nuclei (CCN) and 210 per cc of Aitken nuclei (CN). This concentration was observed until we reached the vicinity of the Canary Islands. As we approached the island, the concentration of ice

nuclei increased dramatically. At dockside a concentration of 50,000 per liter was measured, with the CCN 2900 and CN 42,000 per cc. The concentration remained at about this level until we left the area and were again in clean oceanic air. With the decrease in fine particles, the concentration of particles which reacted with the iodine vapor dropped in the same manner. With the concentration of CCN 130 and CN 580 per cc, the level of ice nuclei was less than 1 per liter.

A similar series of observations was obtained at Dakar. At that location we had to anchor in the harbor several miles from the land. The concentration of ice nuclei observed on the ship at that location was 20,000/liter. This increased concentration was accompanied by a concentration of CCN of 900 and CN of 12,000 per cc.

The next morning we were again at sea heading for New York with the value of CCN of 130 and CN of 540 per cc, and the ice nuclei concentration was back to a few per liter. This low concentration of both ice nuclei, cloud condensation and Aitken nuclei remained at this level until we were within a few hundred miles of New York. Since we were obliged to pack all of our gear for disembarkation, it was not possible to obtain measurements of ice nuclei or lead particles in the New York Bight area or close to Manhattan.

A DISCREPANCY IN LEAD IODIDE CONCENTRATIONS IN AMBIENT AIR

In the 1973 Journal of Weather Modification, Grant and Corrin (3) reported fine particle lead measurements in urban as well as country air that are very much lower than I have found in my measurements. In fact, the values they have reported for raw automobile exhaust are three to four orders of magnitude lower than those which I have regularly measured in ambient air at least a mile from a heavily traveled highway. A comparison of their findings with mine as a function of temperature and concentration is shown in Figure 1. The Grant/Corrin "B" curve is plotted from data published in the J.W.M. article referenced. The "A" curve represents a typical curve obtained at my home laboratory two miles northwest of Schenectady, New York in a suburban area about a mile from the New York State Thruway.

In their paper Corrin and Grant calculated the mean diameter of the "numbers of particles activated and the amount of lead present (approx. 0.12 μgm/liter). Calculations show that the mean diameter of the particles would be around or less than 100 Å." They conclude "that particles of this size could not be expected to serve as ice nuclei in the manner observed."

As a matter of record, (4) Cheng, of my staff, made electron micrographs of replicas which I supplied him, of ice crystals grown in air containing automobile exhaust exposed to iodine vapor, and found small clusters of 90 Å diameter particles in the center of each replica.

Thus I find it difficult to explain the four orders of magnitude difference between the measurements of Corrin and Grant and mine. It is

particularly puzzling since their data is obtained from measurements made with raw gasoline while mine represents measurements of ambient air which is at least a mile distant from heavily traveled highways. When I use auto exhaust, I find concentrations at least two orders of magnitude higher than my ambient air values, which thus gives concentrations a million times greater than the values reported by Corrin and Grant.

In attempting to explain the large difference between my findings and those of Corrin and Grant, I have wondered if the presence of ozone in their sample air could be the cause of their much lower values.

THE DEACTIVATION OF SILVER AND LEAD IODIDE BY OZONE

Some years ago I discovered that a small amount of ozone would completely deactivate silver iodide. I observed that if a concentration of 1,000,000 particles per liter of silver iodide smoke was put into a cold chamber operating at -20C, and then a small amount of ozone was added to the air of the chamber, all trace of the presence of the silver iodide smoke in its ice nucleation role would vanish. In about five minutes the ozone deactivation effect would disappear and the chamber would again show the high concentration of silver iodide ice nuclei which characterizes the presence of this aerosol.

The same effect occurs with lead iodide. In my home laboratory I have a cold chamber that normally operates at a temperature of -20C which is utilized for the continual observation of the concentration of small particles of lead in the ambient air. Concentrations very depending on wind direction and day of the week. From Monday to Friday, when the major vehicular highway upwind of my laboratory carries heavy auto traffic, the lead values are two to five times higher than on Saturday and Sunday.

When this chamber containing saturated iodine vapor is warmed to -16C, the ambient outside air shows a concentration of 100,000 ice crystals per liter of ice nuclei most of the time.

With these conditions, it is possible to reduce this concentration of crystals to the order of 1 per liter by introducing 50 parts per billion of ozone into the chamber air. After about five minutes, as with my earlier silver iodide observations, the effect of the ozone disappears and the concentration of ice crystals returns to previous levels.

When ozone deactivates lead or silver iodide, the supercooled cloud which replaces most of the ice crystals can be seeded with dry ice (5) or any other method for producing active ice embryos.

Figure 2 shows the type of crystals which grow on the submicroscopic lead particles which react with iodine vapor. Figure 3 shows crystals that grow in the supercooled cloud which forms after most of the lead iodide nuclei are deactivated by ozone. The supercooled cloud was seeded with rapidly expanded air. (6) Apparently a few lead iodide particles remained active. The featureless plates which dominate are characteristic of those

produced by homogeneous nucleation at -16C.

THE POSSIBLE EFFECT OF OZONE IN CLOUD SEEDING ACTIVITIES

This effect of ozone on silver and lead iodide raises an interesting fundamental question about the stability of silver and lead iodide used in weather modification activities.

In the early days of cloud seeding activities, considerable uncertainty developed with respect to the stability of silver iodide nuclei.

Vonnegut and I, in a cooperative experiment with Reynolds and Hume, found (7) that silver iodide smoke in a large dark container lost activity for ice nucleability by an order of magnitude in 24 hours. When exposed to brilliant New Mexico sunlight, a similar smoke had its effective nuclei reduced at the rate of two orders of magnitude per hour. In a later experiment at Schenectady, New York, a similar loss in ice nucleating activity was found when the smoke was exposed to the light of an ultraviolet lamp. A reinterpretation of these findings suggests that the cause of the deactivation we observed was probably due to the ozone produced by the ultraviolet light.

To my knowledge, ozone has not been considered to be related to the deactivation of silver iodide nuclei from cloud seeding generators, despite the fact that it is the chemical reaction between ozone and potassium iodide producing free iodine which is used in an instrument for measuring ozone concentrations.

Since there is increasing evidence that the major source of ozone is the stratosphere rather than urban areas, its presence and concentration should be considered as a factor in the successful conduct of cloud seeding operations.

It may also be of considerable importance to realize that the oxidation of heavy metals by this reaction with ozone may be one of the important "sinks" for stratospheric ozone. This evidence that ozone reacts with lead and other heavy metals also raises a number of serious questions about the reality of high ozone concentrations in cities. The lead compounds emitted by automobiles should serve as effective "getters" for ozone in urban areas. It has been my observation, based on many field studies, that the cyclic olefin-ozone reaction (8) produces considerably lower concentrations of condensation nuclei in the center of Los Angeles and the adjacent smoggy areas such as Pasadena, Riverside and Hollywood than are found in the peripheral regions of Long Beach, Pacific Palisades, the Santa Monica Mountains and the Mount Baldy area east of Claremont. Such findings imply that there are still many areas of research peripheral to classical cloud physics and weather modification that need attention.

This is but one more indication of the truly remarkable balancing factors which are an inherent feature of the global atmosphere and its reactions. It is only when man is ignormant of these checks and balances, and

operates in such a way as to violently disrupt these natural forces and reactions that developments occur that may become irreversible.

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TITLES OF FIGURES

Figure 1. Ice crystal concentration related to temperature of a cold chamber. Chamber containing automobile exhaust is saturated with iodine vapor and then filled with a supercooled cloud. A curve represents Schaefer data. B curve represents Grant-Corrin data.

Figure 2. Ice crystals grown on ice nuclei which formed in a supercooled cloud following the reaction between auto exhaust and iodine vapor.

Figure 3. Ice crystals grown on embryos generated by homogeneous nucleation in a supercooled cloud which was formed after the deactivation with ozone of the nuclei produced by the reaction of auto exhaust and iodine vapor.

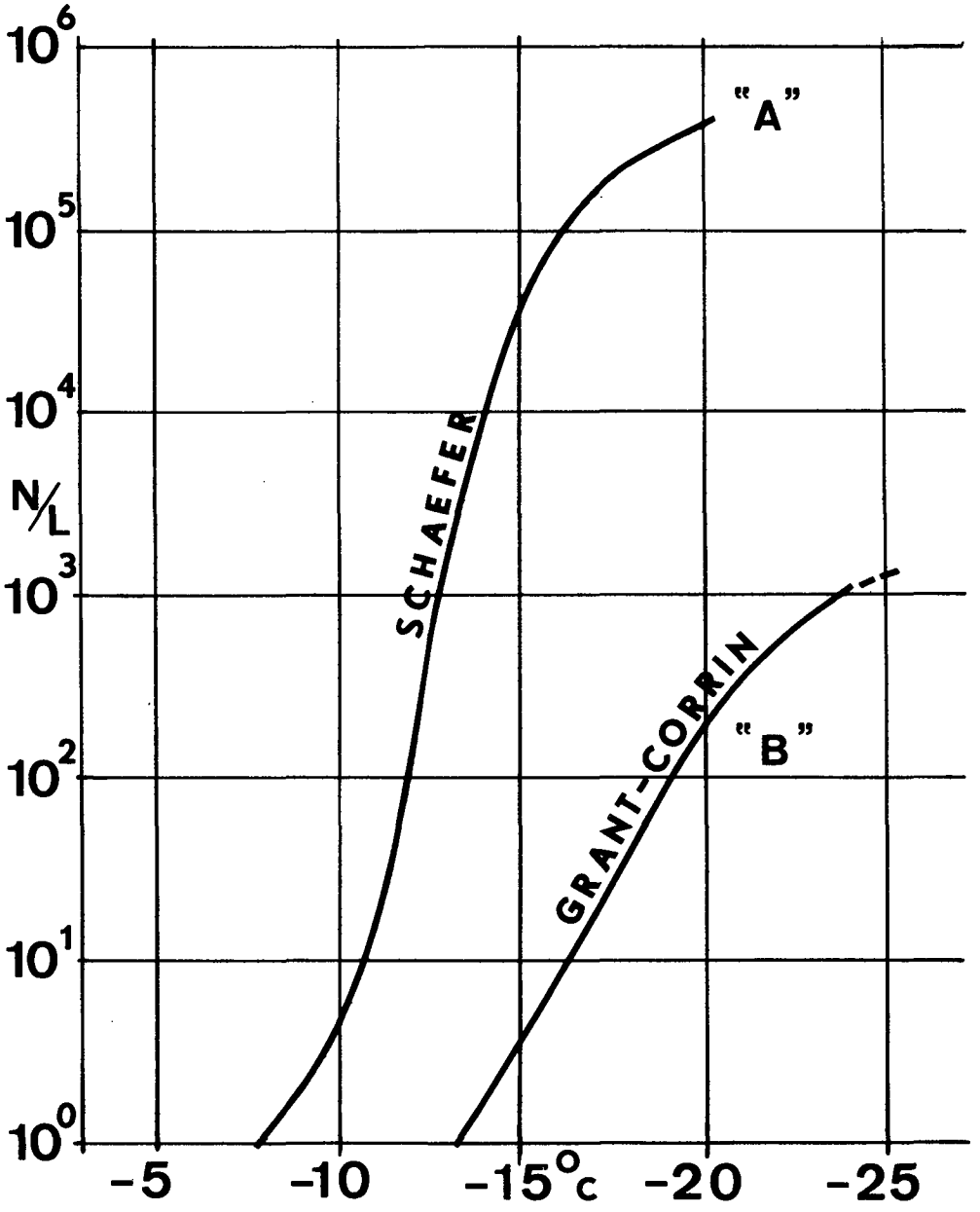

10^6
10^5
10^4
N/L
10^3
10^2
10^1
10^0
"A"
SCHAEFER
"B"
GRANT-CORRIN
-5
-10
-15°c
-20
-25

FIG 1

FIGURE 2

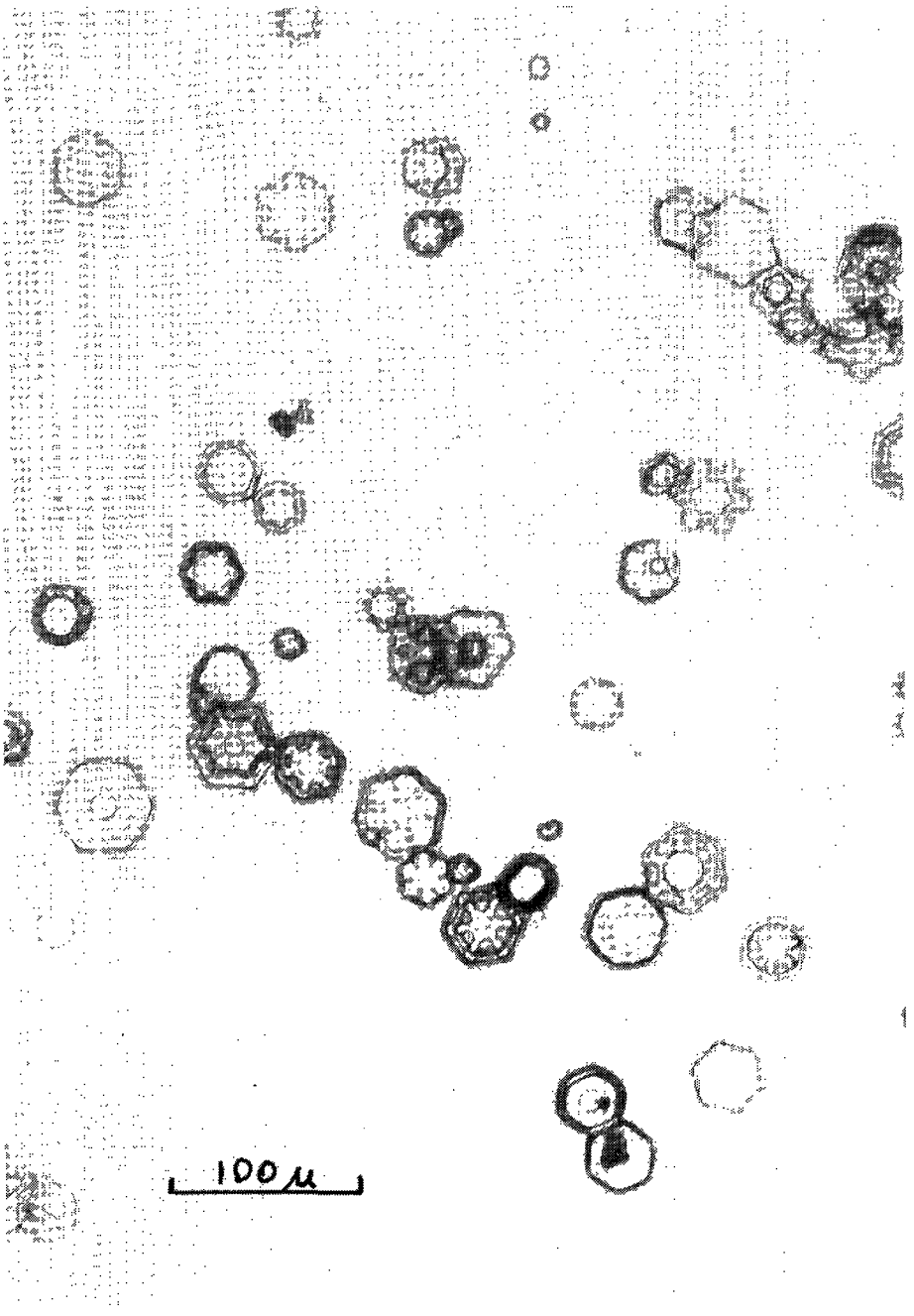


FIGURE 3



FIELD MIXING PROCEDURES FOR AgI-NH_4-ACETONE SOLUTIONS

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ABSTRACT

This note describes a procedure for mixing large amounts of silver iodide-ammonium iodide-acetone solutions in a short time, while in the field. One person can mix 60 gallons of this solution in 45 minutes with this method.

INTRODUCTION

Field personnel of the South Dakota Weather Modification Program have been confronted with the problem of preparing large quantities of silver iodide-ammonium iodide-acetone solutions during the operational season of the program. Recommended preparation procedures by other groups[1] were time consuming and, therefore, tedious. A mixing procedure was developed and used in the field during the 1973 season.

MIXING CHEMISTRY

Consideration of the solubility characteristics of the solution ingredients and the principle of chemistry known as the common ion effect led to the development of the procedure described herein. A mole ratio of $2AgI:1NH_4I$ is used.

Because ammonium iodide is soluble in water, the two are first mixed together. Water quantities used in this preparation technique are sufficient to easily dissolve the ammonium iodide into an H_2O - NH_4I solution.

The H_2O - NH_4I solution is then mixed into a portion of the required quantity of acetone so that the I^- concentration is very high. This enables rapid absorption of the AgI powder as it is added during the mixing procedure.

PROCEDURE

The procedure for mixing a silver iodide in acetone solution in the field is described below. All components were kept on location in the field. The ammonium iodide and silver iodide were purchased from the

[1]Obtained through discussions with individuals of these organizations.

supplier in sealed packages containing the amounts specified in Table 1.

FIRST: Make certain the NH_4I crystals are broken up fairly well. (Not larger than pea size.)

SECOND: Place the granulated NH_4I in the bottom of a large mixing container. (A 7-gallon polyethylene pail was used.)

THIRD: Pour the distilled water onto the NH_4I in the container. Swirl this mixture for 1.0 minutes or until the NH_4I crystals are fully dissolved. The resulting mixture will have a pale yellow color.

FOURTH: Add approximately[1] 1.0 gallon of acetone to this (H_2O and NH_4I) solution. There is no need to mix as the pouring will have mixed it sufficiently. This solution will also have a pale yellow color and will appear clear.

FIFTH: Sprinkle the ENTIRE amount of AgI into the container of solution. This helps in the solution of the AgI.

SIXTH: Immediately, swirl the solution and AgI vigorously until all the AgI dissolves.[2] This usually requires about 2 minutes of swirling action. This solution should be clear and have a yellow appearance.

SEVENTH: Pour the remaining acetone into the container to yield 5.0 gallons of solution. Pour this solution into a storage container.

DISCUSSION

This mixing procedure almost eliminates the need for storing AgI solutions, because of the rapid rate in which the solution can be mixed. This method proved valuable by saving field personnel considerable time in preparing the solutions.

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[1]This is approximate because slight variations are not critical. However other solution strengths will require other optimum amounts.

[2]Sometimes a few little balls of AgI form from the rotary motion of the swirling. These can be crushed easily and a few seconds more of swirling will allow them to be dissolved.

TABLE 1

The Chemical Ratios for 5 Gallon Mixes of 2% AgI Solution

Chemical Component		Grams / 5 Gallons	Weight (%)
Acetone	(C_3H_6O)	14,982	96.81
Silver Iodide	(AgI)	308	1.99
Ammonium Iodide	(NH_4I)	95	.61
Distilled Water	(H_2O)	90	.58

MONITORING OF CLOUD CONDENSATION NUCLEI AT THE ARCATA-EUREKA AIRPORT, CALIFORNIA

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INTRODUCTION

This paper outlines the results of observations of cloud condensation nuclei and of the chemical composition of aerosols found in the vicinity of the Arcata-Eureka airport in northern California in September, 1973. The work was carried out in connection with a program of warm fog clearing experiments conducted by the Naval Weapons Center to evaluate the possible effects of nuclei concentration on the formation and stability of fog and to see what effect this might have on the success or failure of attempts to clear the fog. Nuclei in the Arcata area arise from the sea, from forest fires, from a number of industrial operations such as sawdust burning and lumbering, and from wind blown dust and similar sources.

The Cloud Condensation Nuclei (CCN) were counted at a supersaturation with respect to liquid water of 0.23%, using a Mee Industries CCN counter, Model No. 130. This value was chosen on the basis of work by Mason (1971), that indicates a close correlation between concentrations of cloud droplets and of CCN that can be activated at supersaturations of a few tenths of one percent. The instrument was operated continuously from 11 September to 19 September. During this period, the fog and stratus regime transitioned into that of winter storms, permitting observations during relatively stable air and during periods of instability.

A four stage, rotating drum, cascade impactor, capable of segregating particles by size, a Lundgren Impactor, Model 4220, was used to capture samples of the atmospheric aerosol. The impactor was operated from 0645 on 15 September to 0245 on 16 September, 1973. Both instruments were operated at a remote location, away from the airport.

MEASUREMENTS OF CCN BY THE MEE COUNTER

In Fig. 1 through 6, CCN are plotted versus time. Wind direction and velocity are shown at hourly intervals. Changes in wind direction greater than 90^{0} are indicated by the symbol ¢ .

The CCN counter was put in continuous operation at 2000 PDT on September 11th using a supersaturation of 0.23, Fig. 1. At 2030 PDT a check was made of nuclei counts at lower and higher supersaturations. About 160, 400 and 1800 nuclei/cc were observed at supersaturations of 0.1, 0.23 and 3.1 percent, respectively. The counts at the lower supersaturation are approximately half way between those for maritime and continental air as found by Twomey (1959) and the counts at the high supersaturation

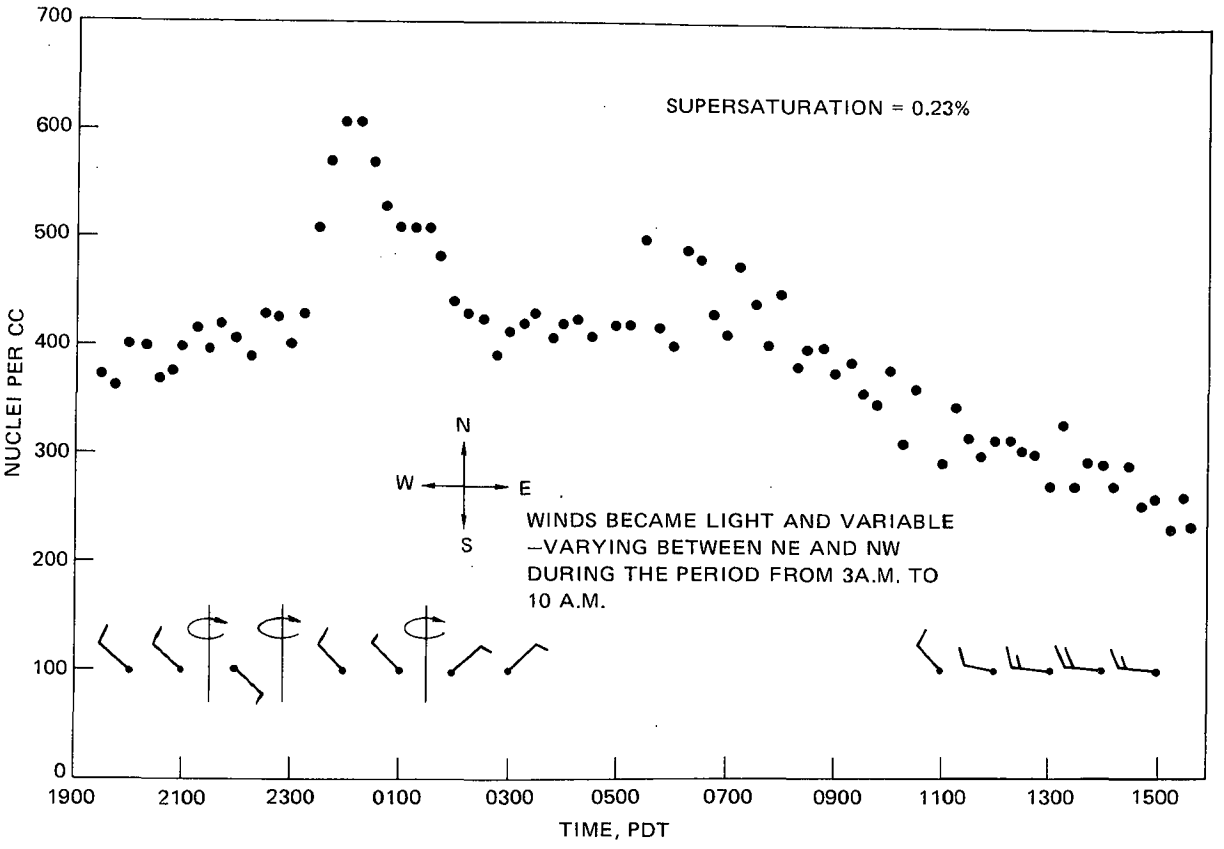


Fig. 1. The number of CCN per cc plotted against time, PDT, for September 11th to 12th, 1973. Wind direction and velocity are shown at hourly intervals in the lower part of the figure.

are about the same as those found by Twomey for continental air. One would think with the wind from the north-west (off the ocean) that counts would be more in line with those found by Twomey for maritime air. Apparently, smoke from forest fires to the south had circulated around to the north over the sea and had mixed with the marine air over the ocean.

At about 2130 PDT, the northwest wind shifted to a light southeasterly flow until almost 2300 PDT whereupon it switched back to the northwest at 5 to 10 knots. Near midnight, the CCN count abruptly increased from about 400 to 600 per cc. Apparently, smoke from the Arcata area had circulated out to sea and came into our site with the northwest wind. The CCN count dropped rapidly as the northwesterly flow set in, and leveled off to around 400 per cc at about 0300 PDT on September 12th.

Winds became light and variable, mostly varying between northeast and northwest, during the period from 0300 to 1000 PDT. Stratus, with bases at 600 ft and tops at 1800 ft, were treated from above with electrically charged water droplets between 0600 and 0700 PDT with no apparent success. During this period of treatment, CCN counts varied from about

400 to 500 nuclei per cc at ground level. As the day progressed, the counts slowly decreased, and the wind from the west increased after 1100 PDT. At about 1450 PDT, another fog dissipation test with electrically charged water droplets was conducted and the sun broke through the stratus momentarily after treatment. The CCN count during this treatment was only 250 nuclei per cc at ground level. Problems with the recorder occurred at about 1600 PDT and readings after that time were lost; however, counts were decreasing to 200 nuclei per cc. The stratus remained throughout that afternoon and evening.

No CCN were recorded continuously until after 1800 PDT on Sept. 13, (see Fig. 2). Previously, the sky had cleared of stratus at about 1230 PDT, and between 1315 and 1330 PDT, manually recorded readings of CCN averaged about 200 per cc. CCN counts, Fig. 2, were about 300 per cc at 1800 PDT which slowly decreased, on the average, to below 200 per cc until almost 2400 PDT, whereupon they suddenly increased to about 650 nuclei per cc at

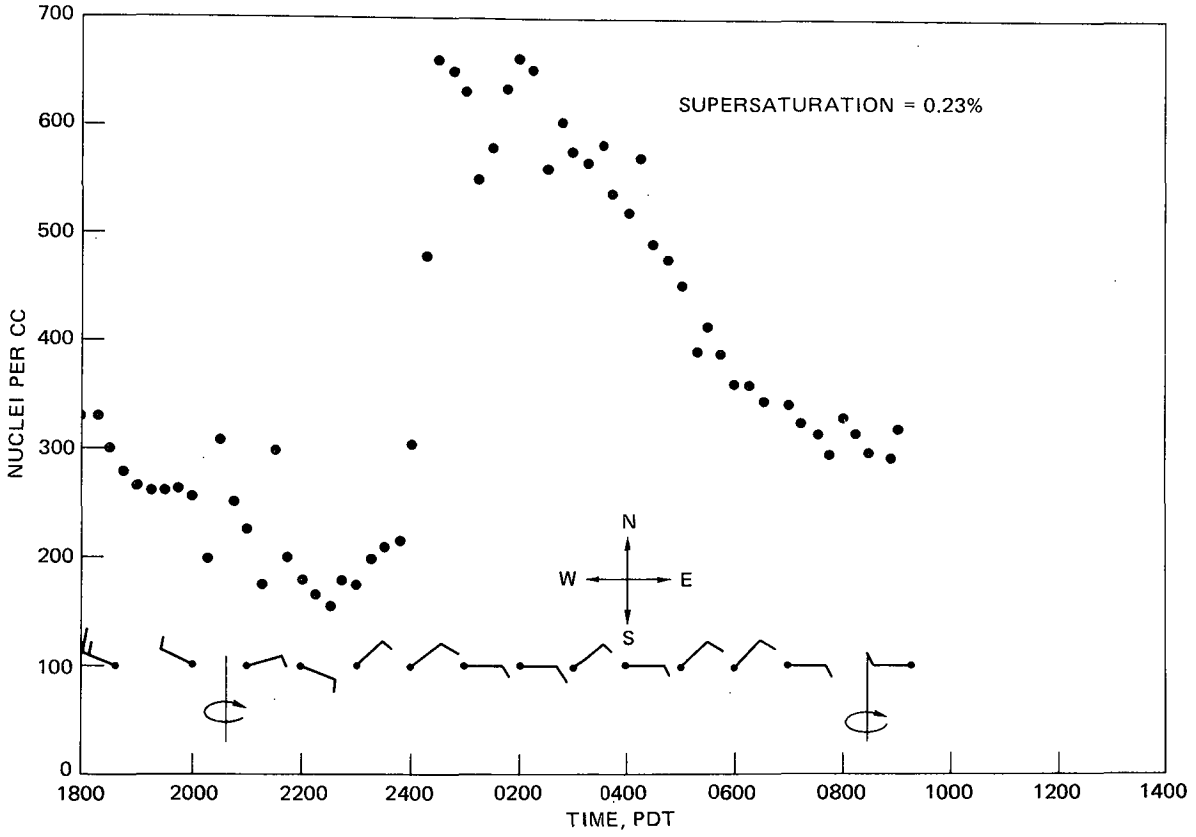


Fig. 2. The number of CCN per cc plotted against time, PDT, for September 13th to 14th, 1973. Wind direction and velocity are shown at hourly intervals in the lower part of the figure.

0030 PDT. This increase was probably due to the change in air flow from westerly to easterly at about 2040 PDT. This CCN count was the highest observed during the entire period of monitoring. Possibly it was due to smoke from Arcata, held under an inversion layer. A strong inversion existed at the time; the temperature at 20 ft was 5°F colder than the temperature at 50 ft for the period 2045 to 0815 PDT. The air aloft was dry; at the 50 ft level the difference between the temperature and the dew point ranged from 3 to 5°F while at the 20 ft level the difference ranged from 2 to 4°. No fog formed. The CCN count fell steadily after 0200 PDT to about 300 per cc at 0900 PDT, at which time recorder failure precluded further monitoring.

Continuous monitoring of CCN began again on September 15 at 0600 PDT, when the CCN count was 400 per cc (see Fig. 3). A seeding test was conducted during the period 0625 to 0650 PDT during which the CCN count decreased from 390 to 310 per cc. As recorded by the visibility measuring

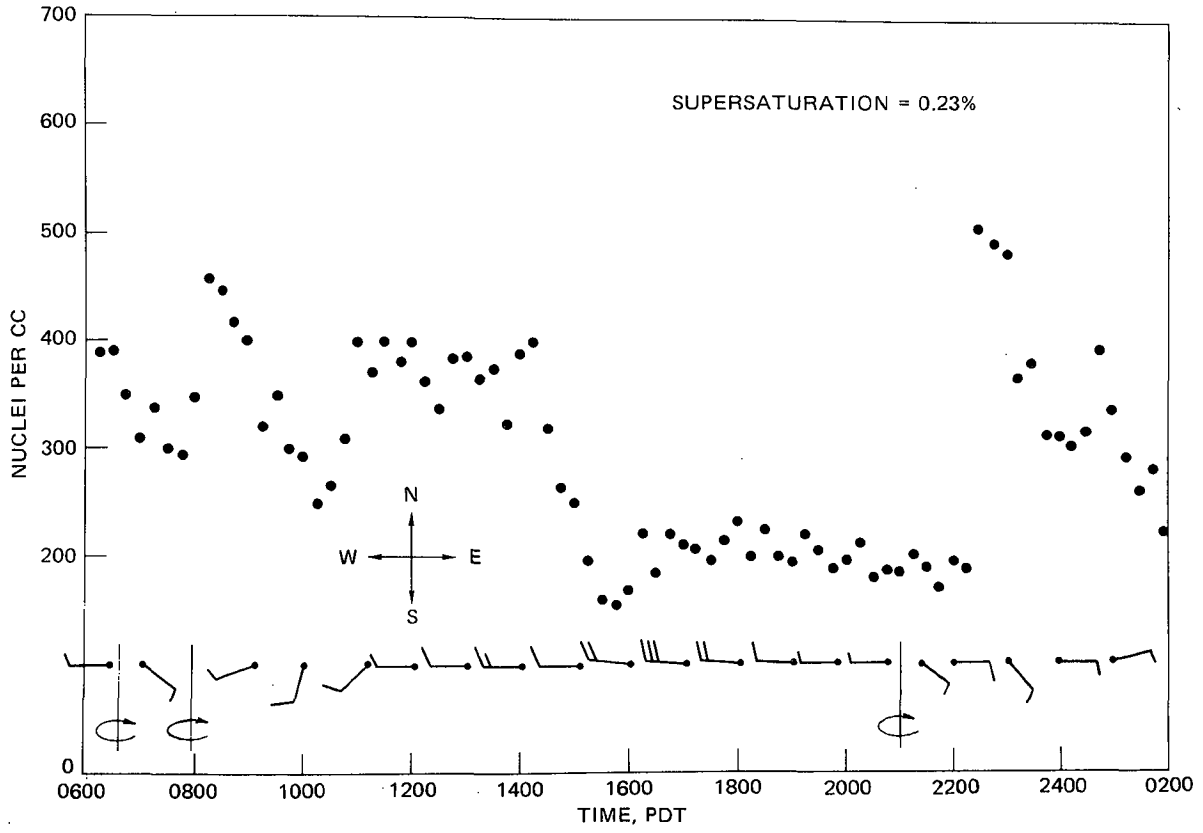


Fig. 3. The number of CCN per cc plotted against time, PDT, for September 15th, 1973. Wind direction and velocity are shown at hourly intervals in the lower part of the figure.

device (Videograph, Model B), a sharp increase from 0.25 to 1.6 miles in visibility occurred at 0647 to 0707 PDT. A maximum visibility of 3.25 miles occurred at 0728 PDT at which time the CCN count reached a minimum of about 300 per cc. At 0720 PDT, another seeding test was initiated which lasted until 0805 PDT. However, visibility decreased from 2 to 0.35 miles during the period 0745 to 0810 PDT. During the same time period, the CCN increased from 295 to 460 per cc. The wind had shifted from light westerly to light southeasterly at 0640 PDT and then shifted back to a WSW direction at about 0755 PDT. Apparently, a parcel of CCN-contaminated air had come into the test area with the southeasterly wind and this possibly contributed to the failure of the second test.

The CCN count dropped from 460 to 250 per cc during the period 0815 to 1015 PDT with an onshore wind from the WSW, and at 1000 PDT, the wind shifted to the SW direction, whereupon the CCN increased from 250 to 400 per cc. Up to 1230 PDT, fog conditions remained with a 300 ft ceiling and one-mile visibility, or less. The CCN remained fairly constant at about 360 to 400 per cc until 1400 PDT when the stratus broke up and the sun came out. The wind had increased up to 15 knots from the west at 1400 PDT. After 1400, the CCN count dropped to a low of 155 per cc at 1545 PDT. The CCN averaged about 200 per cc from 1600 to 2215 PDT. However, the wind shifted from westerly to southeasterly at 2100 PDT, and later, the CCN increased sharply to 500 per cc at 2230 PDT.

Fog with a ceiling of 300 ft, and one mile or less visibility had formed at 2115 PDT and persisted until 0430 PDT on September 16. The CCN counts fell from a high of 500 per cc at 2230 PDT to a low of 220 per cc at 0200 PDT (see Fig. 4) on September 16. A small increase to 340 nuclei per cc occurred shortly after 0300 PDT and then increased to 410 nuclei per cc shortly before 0600 PDT. The wind had continued light from a generally easterly direction between 2100 and 1100 PDT.

During the period 0600 to 1045 PDT on September 16, CCN gradually decreased to 130 per cc. After 0900 PDT, the stratus dissipated and the weather became clear and sunny. A gradual wind shift to a southwesterly direction began prior to 1100 PDT. The CCN count increased after 1100 PDT to a maximum of 360 per cc at 1315 PDT. This peak in CCN count corresponded to an abrupt decrease in visibility, as shown by the Videograph, of from 10 to 0.5 miles. After 1315 PDT, the CCN decreased to about 160 per cc at 1700 PDT and varied from 150 to 200 per cc until 0500 PDT on September 17 (see Fig. 5). Winds during this period were light and variable, mostly easterly to northeasterly.

On the morning of September 17, a strong inversion existed from 0300 to 0800 PDT (i.e., the 20 ft level was from 2 to 6^{o}F colder than the 50 ft level.) The CCN count had decreased to about 120 per cc at 0800 PDT. When the inversion broke at 0800 PDT, the wind switched from a light northeasterly flow to a southerly direction, and the CCN count abruptly increased to 375 per cc. Much smoke or haze had been noted previously to the southeast of the test area. At 0810 PDT, with a clear sky at the observing site, fog tended to come up to the other side of the air strip from the ocean and dissipate. The wind switched to the west at 0925 PDT.

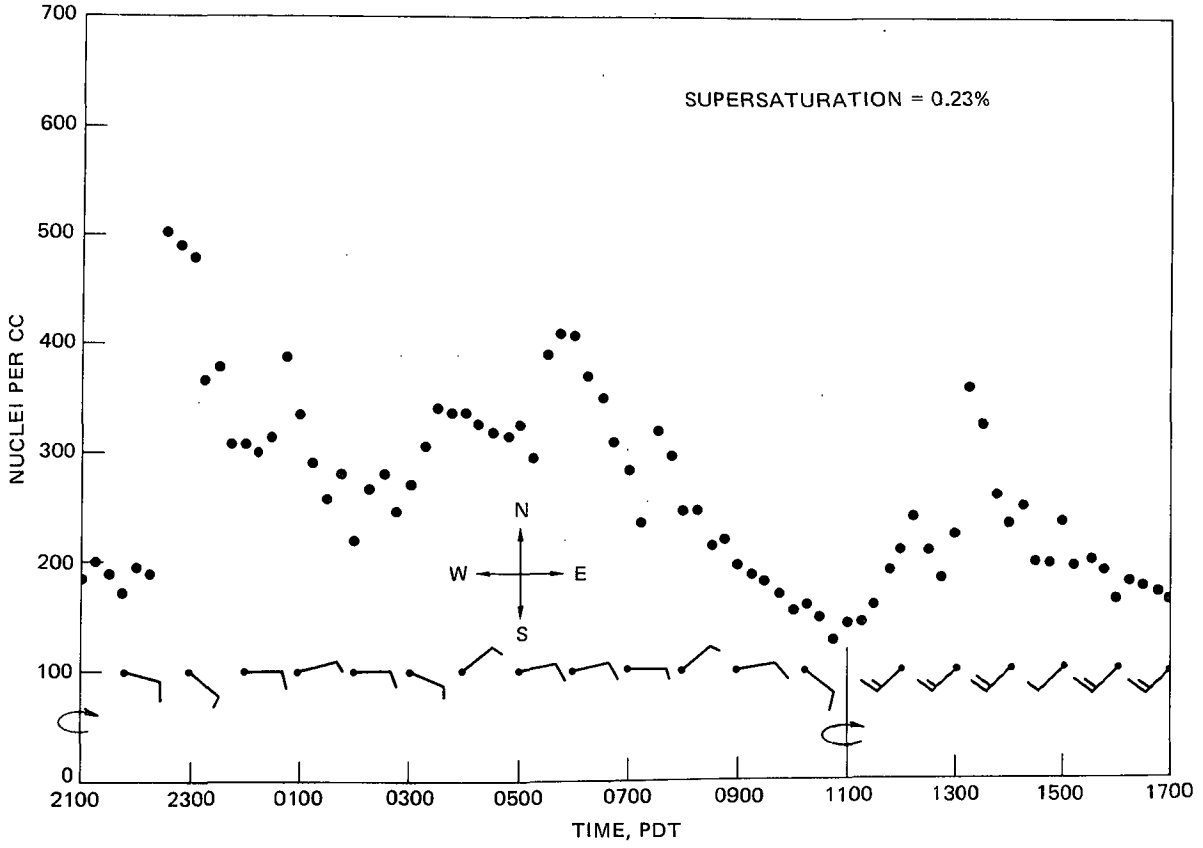


Fig. 4. The number of CCN per cc plotted against time, PDT, for September 16th, 1973. Wind direction and velocity are shown at hourly intervals in the lower part of the figure.

It may be asked, whether the fog was unstable due to the low number of CCN which had drifted to sea during the night and morning hours, or whether it dissipated due to other meteorological conditions.

After 0900 PDT, the CCN decreased, with some variations at 1300 PDT which may have been due to aircraft traffic, to below 100 per cc after 1730 PDT (see Fig. 6). Frontal fog came in from the west at 1445 PDT and lasted until 1505 PDT, after which increasing cloudiness occurred. Rain fell for less than an hour after 1856 PDT. Unfortunately, no wind records exist after 1300 PDT because of malfunction of the recording equipment. The CCN count generally varied from 50 to 80 per cc throughout the evening and morning hours until 0600 PDT on September 18th. Precipitation started at 0530 PDT with drizzle, and developed into rain by 0700 PDT which stopped at about 0730 PDT. CCN counts after 0700 PDT decreased to between 0 and 30 per cc. The relative humidity became so high that the dry and wet bulb

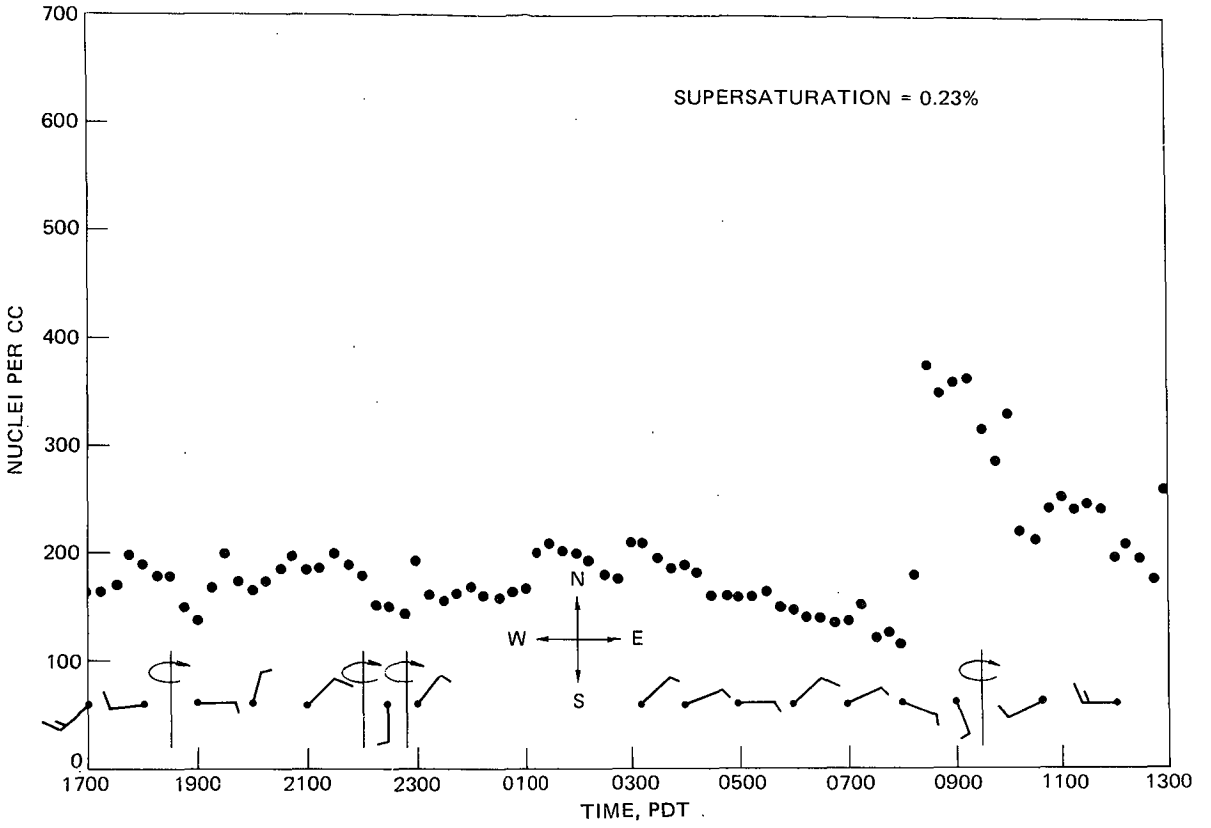


Fig. 5. The number of CCN per cc plotted against time, PDT, for September 16th to 17th, 1973. Wind direction and velocity are shown at hourly intervals in the lower part of the figure.

temperatures of an electronic psychrometer (Mee Industries, Inc., Model No. 501) were the same, during this period of precipitation, without the formation of ground-fog. It is possible that supersaturated conditions may have existed for a time. The lack of CCN may well have prevented formation of fog.

The low CCN counts (0-30 nuclei per cc) existed during rain, throughout September 18 and 19. In fact, at a supersaturation of 3%, only 25 to 60 CCN per cc were found during these last two days. Apparently, the precipitation had scavenged a majority of the CCN out of the atmosphere.

MEASUREMENT OF TRACE ELEMENTS

The Lundgren impactor was set at an airflow rate (4 cfm) such that aerosol particles as small as 0.15 μm radius were captured. The various size ranges of particles, captured on paraffin coated Mylar film on the revolving drums, are shown in Table 1. The films are sent to the University of California at Davis, where trace elements were determined by cyclotron activation analysis. A summary of the analysis of various

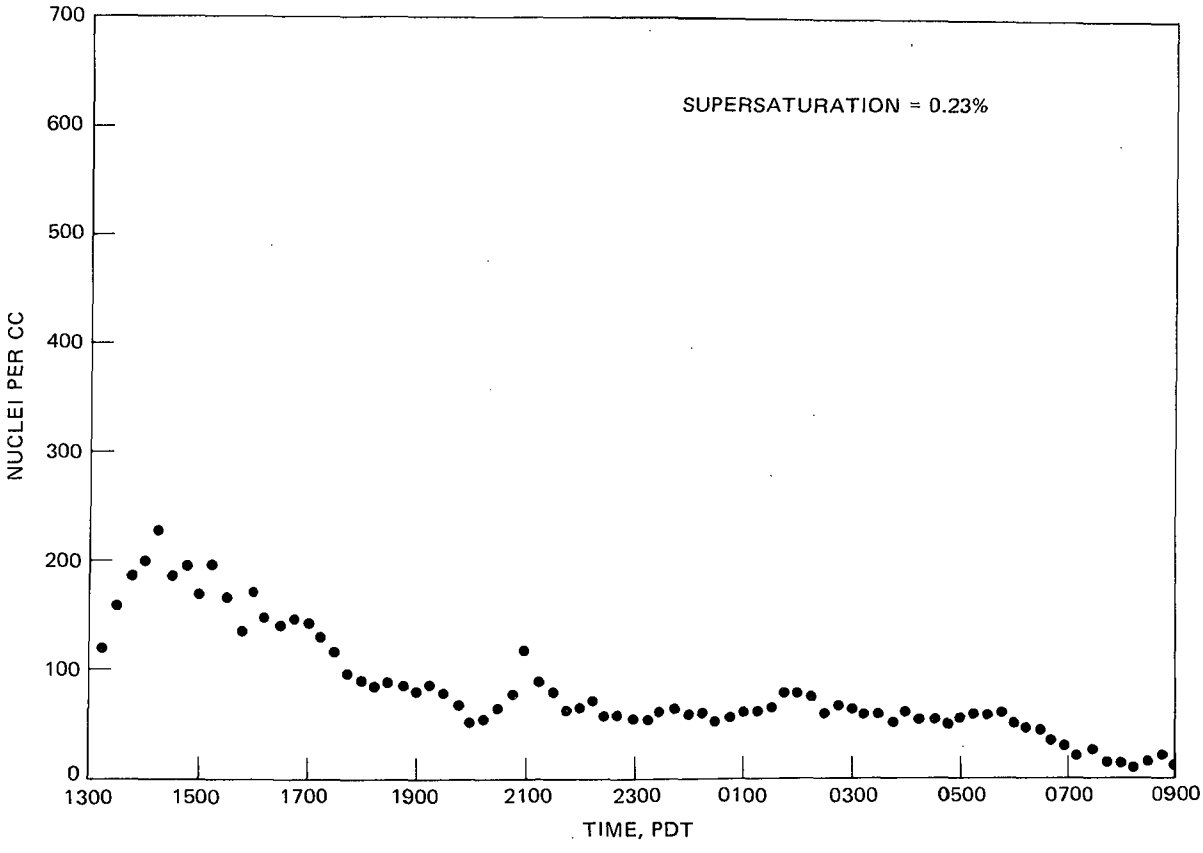


Fig. 6. The number of CCN per cc plotted against time, PDT, for September 17th to 18th, 1973. No wind recordings existed for this period.

elements is shown in Table 1 for five consecutive time periods, expressed as nanograms of the element per m^3 of air.

In Table 2, the mole ratios, Na/K, Na/Si, Cl/Na and S/Cl, are shown for the various time intervals. All the captured particles above 0.15 μm are included in these ratios. For comparison, the mole ratios for the Eastern Pacific and Scotts Bluff, Arizona as found near sea level by Delany et al. (1973) are shown in Table 2.

Junge (1956), found that the S/Cl ratio is higher for the air of coastal areas than for sea water. This fact is true for the air at Arcata (see Table 2). If this ratio exceeds a value of about 0.5, man-made aerosols are usually thought to be present. From Table 1, it also may be seen that the S/Cl mole ratio at Arcata decreased with increasing particle size, an observation also made by Junge.

The Na/K ratio is a very good indicator of the origin of the aerosol. Delany et al. (1973), found that, over a continental site, this ratio was

TABLE 1. Trace element analysis of aerosol collected by the Lundgren impactor on September 15th to 16th. Amounts of the elements are shown in units of nanograms per cubic meter of air.

Time, PDT	Particle Radius			
	>5μm	1.5 to 5^{+}μm	0.5 to 1.5^{+}μm	0.15 to 0.5^{+}μm
Sodium				
0645-1045	171	245	273	77
1045-1445	229	436	552	232
1445-1845	91	570	548	159
1845-2245	330	665	323	120
2245-0245	51	86	*	90
Magnesium				
0645-1045	134	35	95	96
1045-1445	92	125	150	28
1445-1845	68	133	118	44
1845-2245	62	88	77	58
2245-0245	19	*	120	*
Chlorine				
0645-1045	869	602	437	165
1045-1445	741	1113	*	*
1445-1845	452	1821	767	*
1845-2245	1236	1848	554	*
2245-0245	*	*	*	*
Potassium				
0645-1045	43	59	31	59
1045-1445	40	93	96	106
1445-1845	10	60	56	*
1845-2245	43	67	*	24
2245-0245	24	13	*	52

TABLE 1 (continued).

Time, PDT	Particle Radius			
	>5μm	1.5 to 5^{+}μm	0.5 to 1.5^{+}μm	0.15 to 0.5^{+}μm
Calcium				
1645-1045	63	44	40	*
1045-1445	141	207	147	36
1445-1845	36	93	66	*
1845-2245	83	91	27	15
2245-0245	*	*	39	17
Iron				
0645-1045	60	63	28	40
1045-1445	57	107	61	14
1445-1845	17	73	29	20
1845-2245	62	78	37	21
2245-0245	69	51	33	18
Sulfur				
0645-1045	*	*	185	286
1045-1445	68	221	975	1788
1445-1845	*	110	183	785
1845-2245	97	119	93	655
2245-0245	34	24	111	685
Silicon				
0645-1045	96	67	41	46
1045-1445	106	159	124	*
1445-1845	63	82	85	35
1845-2245	106	149	45	42
2245-0245	136	112	111	52

Only a trace of maganese and bromine (i.e., 12 and 24 nanograms per cubic meter of air, respectively) were found at 2245 to 0245 PDT with radii of 1.5 to 5^{+}μm and 0.15 to 0.5^{+}μm, respectively .

*Not detectable

TABLE 2.

Mole ratios of important elements for particle radii larger than 0.15 μm.

Location, Material, or Time, PDT	Na/K	Na/Si	Cl/Na	S/Cl
0645-1045	6.8	3.7	1.8	0.2
1045-1445	7.4	4.5	0.8	1.9
1445-1845	18.6	6.3	1.4	0.4
1845-2245	18.3	5.1	1.6	0.3
2245-0245	4.5	0.7	0	---
Eastern Pacific*	23.8	0.7	1.0	---
Scotts Bluff*	0.7	0.04	0.6	---
Seawater†	47.4	---	1.2	0.055
Continental Soil†	0.85	0.02	0.013	---
Sedimentary Rock(clays and shales)†	0.5	0.04	0.013	---

*Mole ratios found by Delany et al. (1973) near sea level.

†Mole ratios as shown by Delany et al. (1973) and Junge (1963).

nearly the same as in the continental soil, and in sedimentary rock, while a high Na/K ratio which approached that of seawater was found in the marine air over the ocean (see Table 2). As indicated by Delany et al., the Na/Si ratio shows many of the features of the Na/K ratio, but it does not identify the marine air as well as the Na/K ratio. Our data for the Na/Si ratio show less silicon than do those of Delany et al.

The Cl/Na ratio as discussed by Delany et al. can vary below and above the same ratio for seawater, In fact, Miyake (1948), who analyzed fog precipitation in Japan, found that Cl/Na ratios show chlorine depletion in sea fogs and chlorine enrichment in high-altitude mountain fogs. The ratios were 1.18 and 3.25, respectively. Also, the Cl/Na ratios given by Delany et al. at altitudes above 5 km over continental areas show an excess of chlorine when compared to the same ratio for sea water.

Table 3 shows chlorine- and sulfur-containing particle concentrations. These concentrations were calculated assuming the smallest particle in each size range and assuming the dry forms of sodium chloride and ammonium sulfate. In reality, sodium chloride and ammonium sulfate may exist as

TABLE 3

Particle concentrations (based on the smallest particle radius in each range) of chlorine and sulfur assumed as dry sodium chloride and ammonium sulfate. Values given are number of particles per cubic centimeter.

Time, PDT	Particle Radius				
	5μm	1.5 μm	0.5 μm	0.15 μm	>0.15 μm
			Sodium Chloride		
0645-1045	0.0013	0.034	0.67	9.3	10.2
1045-1445	0.0011	0.063	*	*	0.06
1445-1845	0.0007	0.103	1.18	*	1.28
1845-2245	0.0019	0.104	0.85	*	0.96
2245-0245	*	*	*	*	*
			Ammonium Sulfate		
0645-1045	*	*	0.86	49.3	50
1045-1445	0.0003	0.038	4.5	308	313
1445-1845	*	0.019	0.85	135	136
1845-2245	0.0005	0.020	0.43	113	113
2245-0245	0.0002	0.004	0.52	118	119

*Not detectable

solution droplets at sufficient humidities. For example, a solution droplet of sodium chloride at 95 percent relative humidity is about 2 times larger in radius than when it is at low relative humidities. Therefore, the particle concentrations in Table 3 may be low, since the relative humidity was over 75 percent on the average during the period for which the data were taken. The number of solution droplets per cc were probably 20 to 200 percent larger than the number of dry particles. The assumption that most of the chlorine is in the form of sodium chloride is fairly realistic. As can be seen in Table 1, the amount of sodium is usually smaller than the amount of chlorine needed for stoichoimetric balance for the case of sodium chloride; thus the chlorine may be associated with some magnesium potassium and calcium whose equivalent weight relationship to chlorine is similar to that of sodium to chlorine. The assumption that the sulfur is in the form of ammonium sulfate is somewhat artificial because sulfur exists in several chemical forms. In reality, the sulfur-containing particle concentration could be lower than those shown in Table 3. For example in the most extreme case, the concentration could be a factor of four

smaller than the concentrations in Table 3 if all the sulfur existed in the elemental form.

For the period 0645 to 1045 PDT on September 15, the Na/K ratio of Table 2 indicates a mixture of continental and marine air on the basis of values given by Delany et al. (1973). However, the observed Na/Si ratio is much higher than the value for marine air found by Delany et al., although they indicate that this ratio is not as good as the Na/K ratio for identifying the marine layer. Based on the above mentioned observations of the Cl/Na ratio, by Miyake (1948) and Delany et al., some of the air during the period 0645 to 1045 PDT may have originated from higher continental elevations. The S/Cl ratio was small, indicating that man-made nuclei were not present in any significant number. From Table 3, the total number of NH_4SO_4 and NaCl particles was near 60 per cc (or more depending on the relative humidity as discussed above). This concentration is far from the CCN average of 325 per cc found with the Mee counter. Apparently, this difference is due to particles having radii between 0.10 and 0.15 μm, which were not captured by the last stage of the impactor, and to particles containing elements that were not detected such as nitrogen in the form of nitrates. The particle concentration of 10 per cc (possibly up to about 20 per cc depending on the relative humidity) for sodium chloride was the largest found for any of the time periods. It has been found by this author (see Table 3) and others (Junge - 1963) that the total number of sea-salt particles is too small to be of any major importance for the formation of cloud or fog droplets since the concentration of all chloride particles larger than 0.1μm is of the order of 1 to 10 per cc.

During the period of 1045 to 1445 PDT, the CCN count as read from the Mee counter seemed to hold steady at near 400 per cc after increasing from a low of 250 per cc as discussed in the previous section. The increase followed a wind shift, to the SW (see Fig. 3), at about 1000 PDT, although by about 1200 PDT, the wind had shifted to the west. As noted from the S/Cl ratio of Table 2, the airflow from the SW apparently brought a parcel of air containing sulfur-rich CCN into the area. The source could have been the pulp mills located near Eureka. The fog conditions remained at a 300 ft ceiling with one-mile or less visibility until 1230 PDT. Also, as shown in Table 3, the total sulfur (assumed as NH_4SO_4) particle concentration was 313 per cc (and possibly larger as discussed above) for those particles over 0.15μm. The number of chloride particles was found to be negligible during this period. Also, the Cl/Na ratio showed the air to be richer in sodium than is normal; possibly in the form of sodium sulfate or sodium sulfite. The Na/K and Na/Si ratios, as in the previous time period, were indicative of mixed continental and marine aerosols.

During the two periods 1445 to 1845 PDT and 1845 to 2245 PDT, the wind was from the west and the ratios of Table 2 indicate more of a marine influence. The S/Cl ratio substantially lowered indicating a lessening of the influence of man-made aerosols. In Table 3, the sodium chloride particle concentration was of order 1 per cc, but the sulfur, assumed as ammonium sulfate, particle concentration was about 100 per cc, and possibly

larger, depending on the relative humidity, for the two periods, over which the Mee counter showed 200 CCN per cc. A fog formed at 2115 PDT, during the low CCN count of 200 per cc, but an hour later the count shot up to 500 per cc. This high CCN count occurred over such a small time interval compared to the four-hour period that it is hard to determine how much effect it had on the S/Cl ratio.

In the last time period, i.e., 2245 to 0245 PDT, there appeared to be no unnaturally high sulfur content in the air higher than the previous two periods (see Table 1 and 3). The CCN count decreased steadily from 500 to about 250 per cc during this period. The wind was from the east during much of the period although initially it had switched rapidly around to the SE from the west. The air during this period must have had more of a continental influence than the air of any of the previous time periods as indicated by the ratios of Table 2.

SUMMARY

Although monitoring with the Mee counter was conducted over a short period, the CCN counts varied widely, depending on meteorological conditions, especially wind direction. It was noted that CCN, during normal diurnal flow in a fog-producing regime, increased sharply sometime between 2200 and 2400 PDT in the cases cited in Figure 1, 2, 3, and 4. Some increases were noted, also, between 0500 and 0800 PDT as shown in Figures 1, 3, 4, and 5. Based on only two days (Figures 1 and 3), there are indications that existing fog suppression methods are quite effective when CCN are below 300 per cc as measured at a supersaturation of 0.23% while for counts over 400 per cc they are ineffective.

Based on the data taken with the Lundgren impactor, the chemical character of the atmospheric aerosol can vary greatly at Arcata. Three types of aerosol regimes were found. One type occurred with an easterly flow in the early morning hours. The air was found to contain a mixture of continental and marine aerosols with a low amount of sulfur-rich particulate matter. Another regime was encountered with a southwesterly wind that occurred, in this case, during the forenoon hours. The air contained a mixture of continental and marine aerosols, but with a high sulfur content which was indicative of man-made sources. The third type of regime is that primarily composed of marine aerosol of low sulfur content. This regime occurred in the afternoon when the wind was blowing relatively strongly from the west.

Sulfur in the assumed form of ammonium sulfate existed in relatively large numbers of particles between 0.15 to 0.5 μm. The number of sodium chloride-containing particles was negligibly small in the 0.15 μm and larger size ranges. This observation was noted for all samples taken and agrees with others (Junge-1963) that the number of sodium chloride particles is too small to be of any significant importance in the formation of fog.

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FIGURE CAPTIONS

Figure 1. The number of CCN per cc plotted against time, PDT, for September 11 - 12, 1973. Wind direction and velocity are shown at hourly intervals in the lower part of the figure.

Figure 2. The number of CCN per cc plotted against time, PDT, for September 13 - 14, 1973. Wind direction and velocity are shown at hourly intervals in the lower part of the figure.

Figure 3. The number of CCN per cc plotted against time, PDT, for September 15, 1973. Wind direction and velocity are shown at hourly intervals in the lower part of the figure.

Figure 4. The number of CCN per cc plotted against time, PDT, for September 16, 1973. Wind direction and velocity are shown at hourly intervals in the lower part of the figure.

Figure 5. The number of CCN per cc plotted against time, PDT, for September 16 - 17, 1973. Wind direction and velocity are shown at hourly intervals in the lower part of the figure.

Figure 6. The number of CCN per cc plotted against time, PDT, for September 17 - 18, 1973. No wind recordings existed for this period.

A REVIEW OF SURFACE HAIL SENSORS

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ABSTRACT

A review of commonly used surface hail sensors is presented. They have been classified into two major categories: passive sensors and recording sensors. The passive sensors are relatively inexpensive and do provide certain useful hail data. The recording sensors are much more expensive but provide more useful data including time of hail. Included in the review of each sensor are principles of operation, types of data obtained, operation advantages and disadvantages, and approximate cost.

INTRODUCTION

Major hailstorm research for aircraft, hail insurance, and hail suppression interests began after World War II and has continued to the present time. The broad area of hail research encompassed by these interests included many studies about surface hail.

The methods of obtaining surface hail information varied according to the objectives of the particular research. For example, commercial hail insurance companies have kept detailed daily hail loss records (Changnon, 1972), and these data are a tremendous source of information for evaluating economic loss due to hail. Other studies required the collection of hailstones, and they were collected in cold storage boxes or wire baskets tended by farmers (List, 1961; Carte, 1963; Douglas and Hitchfield, 1958). Another method of collecting desired data has involved use of mobile units (Summers, 1968; Renick, 1969; Renick, 1970). Airborne radiometric studies (Roads, 1973) have been used to determine the areal extent of hailstreaks. Thus, the methods of obtaining information about the occurrences of point hailfalls have varied from simply having residents observe hail to the development of sophisticated remotely operating hail sensors.

Initial data on surface hail came largely from observers, but as radar-hail research grew (Changnon, 1972a) many measurements were needed where observers could not be secured. The development of inexpensive, passive hail sensors (Decker and Calvin, 1961; Schleusener and Jennings, 1960; Wilk, 1961) came about because of these needs. These sensors were capable of providing some basic information about the occurrence of surface hail.

The subsequent needs for information about time of hail led to the discovery of how the standard recording raingage could be modified to get

hail time (Changnon, 1966). The need for more exacting information resulted in the design and development of recording hailgage instrumentation (Mueller and Changnon, 1968; Fermstad, 1968).

The purpose of this paper is to describe and compare these and other sensors, Included will be the advantages and disadvantages of their operation, and type of data obtained. To facilitate the description of the sensors, they have been divided into two categories: passive sensors and recording sensors. Various calibration techniques have been developed for each sensor, but space does not permit detailed descriptions of these.

PASSIVE SENSORS

There are several types of passive hail sensors. The most widely used is the hailpad. There are several types of hailpads, but basically the devices consist of a semi-resilient material (such as styrofoam) wrapped with aluminum foil or similar covering. The aluminum foil wrapped hailpads are mounted on various supporting stands and placed in the field. Figure 1a shows the type of hailpad commonly used by the Illinois State Water Survey in its Illinois networks. It is 12 inches by 12 inches and is wrapped with household aluminum foil. Several research projects use similar aluminum foil wrapping. When hail occurs, the stones make dents in the aluminum foil.

There are obviously distinct advantages and disadvantages to the use of hailpads. The advantages of the hailpads are that they are inexpensive ($\sim$ \$3.00 each), are easy to service and work with, and do provide the following type of useful information:

1) Yes-No about hail occurrence.

2) The number of hailstones per unit area by simply counting, and an estimate ($\pm$ 20% errors) of stone size by measuring the dent size.

3) An estimate of the energy and momentum imparted by hailstones (based on dent size).

4) An estimate of the mass of hail.

5) If the pads are field-installed in large numbers and with sufficient densities in a network, they can provide adequate information on the areal extent of hail, usually on a hail-day basis. If data are collected over a period of years, the above types of informationon can provide valuable climatological information about hail occurrences which are important in helping to evaluate hail suppression projects.

The disadvantages of the hailpads include the following aspects:

1) They can usefully record only one hailfall between servicing events. Should two or more hailfalls occur, one cannot separate the hail dents from the multiple storms.

2) If stones cause overlapping dents, a measurement error occurs, and this becomes a major problem when very large numbers of stones occur.

3) The calculations of energy, momentum, and mass are only semi-quantitative.

4) No information is obtained about windblown stones.

5) There is no time of hail information, a distinct problem in the study of individual storms. However, this problem has been partially overcome in the Illinois hail studies by installing hailpads near weighing bucket recording raingages that have been altered (evaporation funnel removed) so that hailstones hit into the bucket, deflect the pen arm, and this leaves a spike on the rainfall trace (Fig. 1b). This spike can give reasonable accurate time of hail and its duration (Changnon, 1966).

There are other types of passive sensors that can measure windblown hailstones. One developed in Illinois was called a hailstool (Fig. 1a). It is easily attached to a pole or post, and has an overhanging, circular sensing area plus a circular vertical sensing area, and both are aluminum foil-wrapped styrofoam. The top circular sensing area gives the same information as the hailpad.

The large circular top and the smaller but longer circular sensing area below the top platform together allow measurement of the vertical and azimuth angles of the windblown hailstones. If stones fall within 13 degrees of the vertical, none hit the lower cylinder due to the overhang of the top sensing area. If the hailstones fall at an angle greater than 14^{o} from the vertical, they impinge upon the foil wrapped around the lower cylinder and a limiting vertical angle can be assigned. The azimuth angles of the stones are determined by their dent locations around the vertical cylinder (Changnon, 1973). This device costs about $12.

Figure 2 shows a view of a 5-sided hail sensor developed in Illinois called a hailcube. Vertical and azimuthal angles of hailfalls are obtained by calculating a relationship between the number of stones that occur on the vertical and horizontal sensing surfaces. In addition, the horizontal components of hailstone velocity, momentum and energy can be calculated. The cost of this instrument is $12 to $13.

Figure 3 is a view of an instrument developed by the National Weather Service in cooperation with the Texas Agricultural Extension Station at Lubbock, Texas. The hail-wind detector stands approximately 6 feet above ground, and the instrument acts like a wind vane in that it rotates so as to face the wind. The aluminum sheets are gridded in angles of degrees from the vertical which allows one to determine vertical angle of incidence. The hailstones are measured and counted in each 15^{o} gridded section. This information is then used to enter a trigonometrically derived graph that allows calculation of the number of stones per unit area. The most obvious disadvantage occurs when hail falls vertically (little or no wind) because this

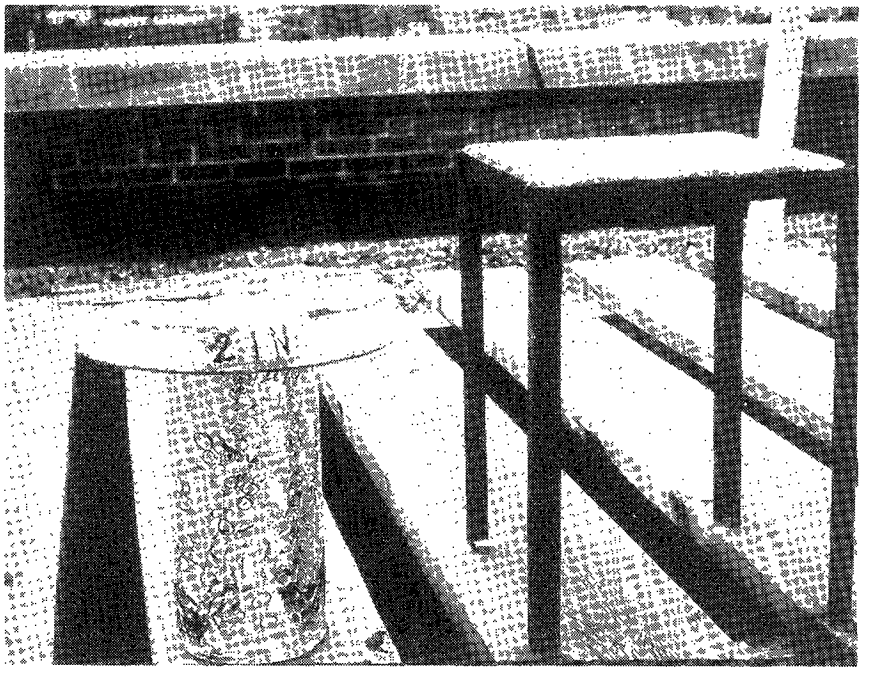


Figure 1a. Illinois aluminum covered hailpad (right) and hailstool (left)

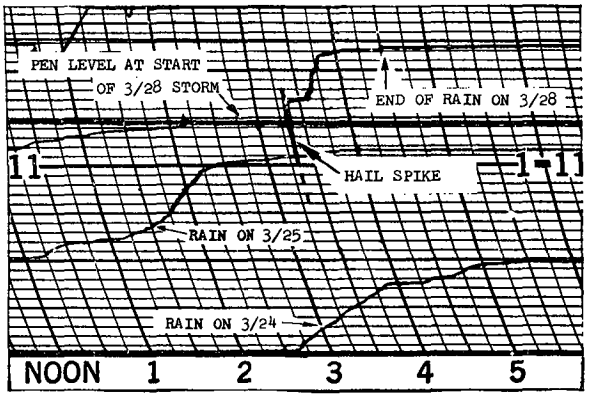


Figure 1b. Hail spike on a recording raingage chart

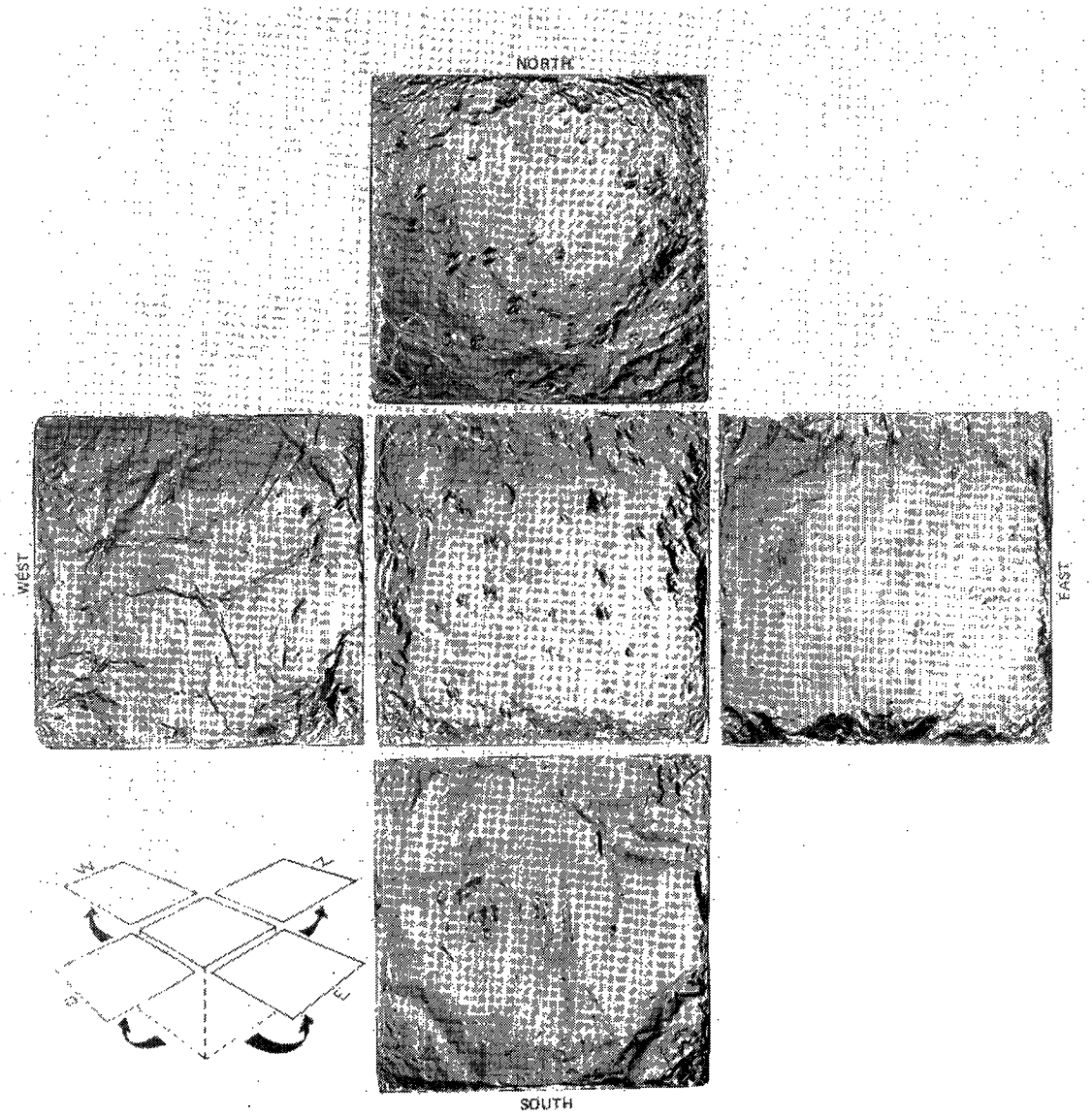


Figure 2. An Illinois hailcube showing dents on the top and two vertical pads made by a hailfall

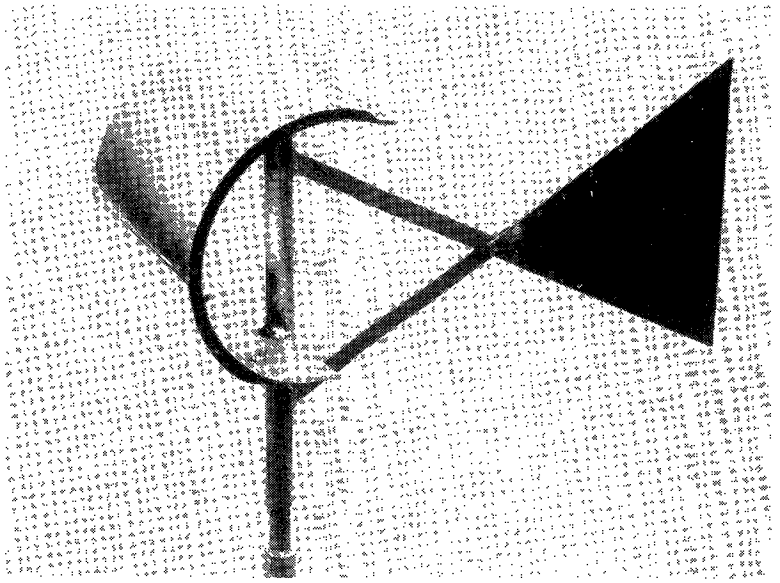


Figure 3. Hail-wind detector designed by the National Weather Service Office in cooperation with the Texas Agricultural Extension Office at Lubbock, Texas

instrument is based on the assumption that there will be sufficient wind with the hailfall so that the instrument's sensing surface will be turned into the direction from thich the hail is falling. The cost of the instrument is about $30.

RECORDING HAIL SENSORS

The need for instruments to give more sophisticated surface hail data, such as hail occurrence duration, time, number and size of stones, momentum, energy, crop damage, stone type, and frequency, has led to the development of several recording hailgages.

The South Dakota School of Mines and Technology developed a geophone hailgage (Fermstad, 1968). It consists of a 6-inch sensing plate which transfers the hailstone impact and momentum to a large mass. A geophone is attached to the mass and acts as a velocity transducer. Electronic circuits derive from the geophone an electrical pulse whose amplitude is a function of the hailstone momentum.

The geophone hailgage 1) gives information on size, number, and time of occurrence of hailstones, 2) covers the reasonable range of momenta, 3) gives a unique and reproduceable output of momentum values, 4) operates off batteries, and 4) records the data on a tape recorder. Essentially, the

geophone gage is designed to furnish a measurement that has practical application and is related to crop damage. The time distribution of stones and their sizes provide useful information in assessing hail suppression efforts and hailstorm characteristics.

The primary disadvantage to this hailgage is the small sensing area. This may yield a somewhat unrepresentative stone size distribution (Changnon and Staggs, 1969; Changnon and Towery, 1972). Another disadvantage to the geophone gage is that the cost of the gage is approximately $300.

The Illinois hailgage (Mueller and Changnon, 1968) is a mechanical gage based on the ballistic pendulum theory (Fig. 4a and 4b). The basic concept is to mechanically link and record the vertical displacement of a 14-inch diameter sensing platform as an amplitude deflection on a motor-driven recording chart. This recording system incorporates a constant speed drum drive to provide an accurate time scale for the hailfall record. After the drum has moved for 10 minutes, it activates a clock which runs until the gage is serviced, thus allowing exact determination of time of hail. After one 10-minute recording cycle, the gage is again in a position awaiting the next hail occurrence which starts the process again (and another clock). The gage is designed to record three separate 10-minute (or shorter) hail occurrences between servicing. The gages are often placed alongside a recording raingage and a hailpad to obtain as much comparative information as possible. The advantages of the gage are that it:

1) gives information on the size (if $\geq$ 3/8-inch diameter), number, and precise time of occurrence of each hailstone;

2) operates from batteries and thus can be installed in remote areas;

3) can record three long hail occurrences between servicing;

4) has a reasonably adequate sensing area size.

The disadvantages of the Illinois hailgage are:

1) the gage is sensitive to initiation by strong gusts, and wind can deflect the platform so that it produces occasional traces similar to those done by hail;

2) the gages require considerable maintenance for proper performance;

3) they do not sense adequately hailstones with diameters of 1/4-inch or less;

4) they are somewhat expensive, approximately $250.00 each.

NOAA (personal communication with Byron Phillips) has developed a mechanical hail momentum sensor (Fig. 5a and 5b). The 14-inch diameter sensing area is made of pressed formed aluminum. This provided adequate strength at lightweight and helped reduce wind effects. The central system is mounted on springs which provides the non-linear response needed for the two-order of magnitude difference in hailstone momentum.

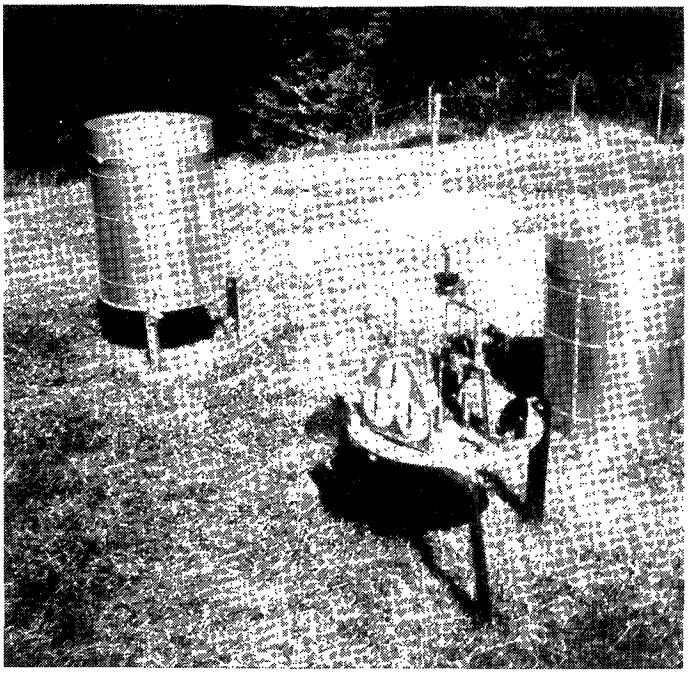


Figure 4a. Illinois recording hailgage

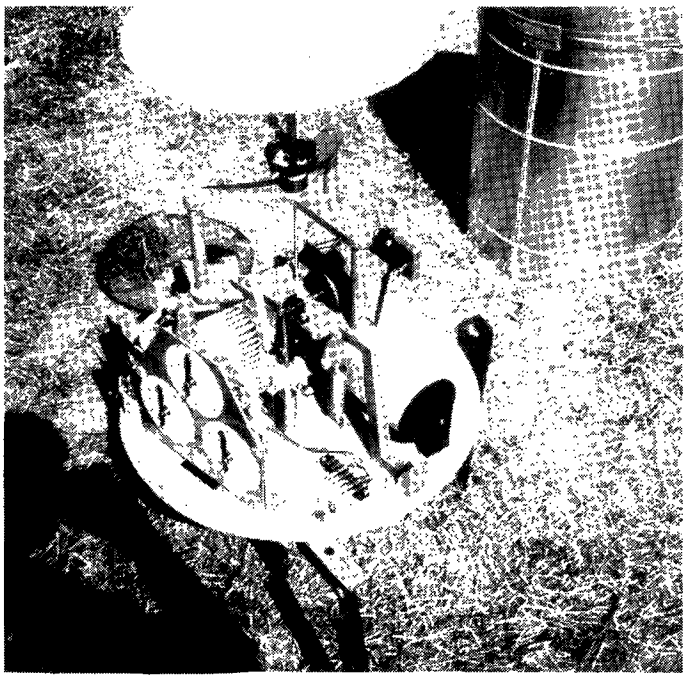


Figure 4b. Close-up of Illinois recording hailgage

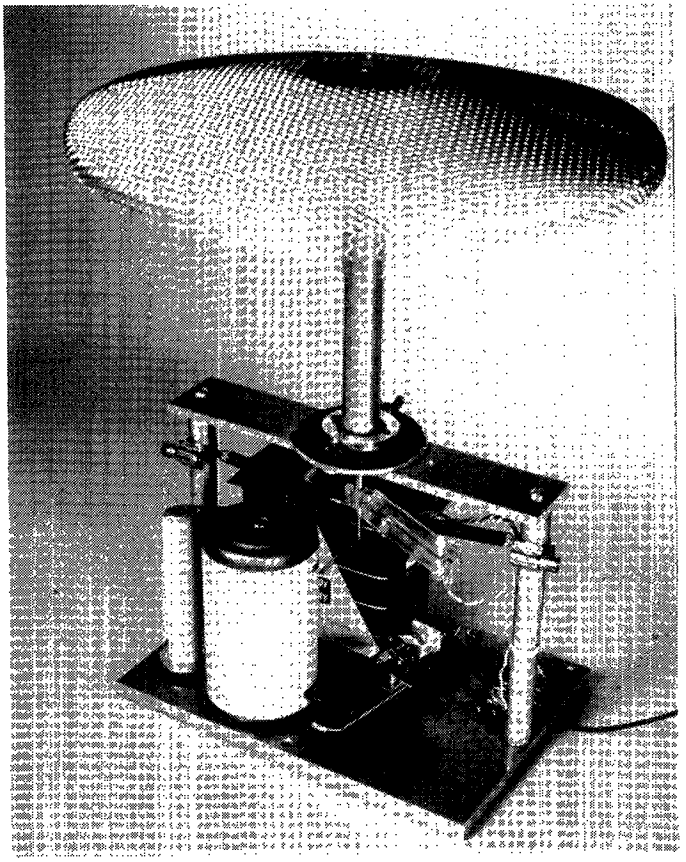


Figure 5a. NOAA developed recording hailgage

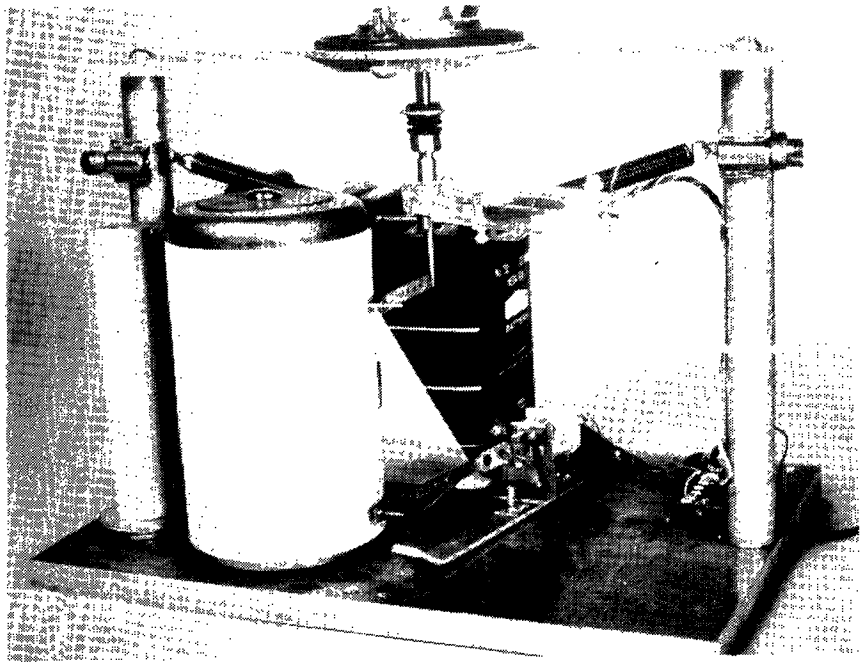


Figure 5b. Close-up of NOAA developed recording hailgage

A relative movement of 1/2 mm of a magnet in an inertia-designed switch activates the gage. The recorder drum is driven by a DC motor which feeds the paper at approximately 1 mm per second. The top pen arm writes on waxed recorder paper, and the displacement length is related to hail momentum. The lower pen arm indicated beginning and ending times of hailfall. A similar pen and relay are mounted to write on the 24-hour clock chart of a weighing bucket raingage which is located adjacent to the recording hailgage. The second pen gives ± 2 minute accuracy for beginning and end times of the hailgage operation. Once the hailgage is running, it continues to operate as long as hail impacts occur greater than once per 1.5 minutes. Thus, the drum rotation continues until 1.5 minutes after the final hailstone impact.

The advantages and disadvantages of the hail momentum gage are similar to the Illinois hailgage. One big advantage of the NOAA gage is that it is relatively inexpensive, approximately $50, compared to the other recording hailgages. The large differential in price is related to several things. Primarily this is due to the absence of clocks in the gage, but it thus requires the presence of a $300 recording raingage, which the South Dakota and Illinois gages do not require.

The primary disadvantage to the NOAA gage is that it too is sensitive to wind. Another disadvantage is its dependence upon an adjacent recording raingage for the beginning time of the hailfall.

The National Hail Research Experiment is using, in addition to hailpads and the NOAA hailgage, a rain-hail separator (personal communication with Randy Nicholas). Two types have been designed - a recording and a non-recording type. Both versions have a 14-inch square opening that receives any rain and/or hail. The rain passes through a screen into a container and the hailstones roll or slide down the screen into a second container. The non-recording version of the hail separators can be automatically closed at a specified time by a clock and spring-loaded lid. The separators are serviced daily at which time the precipitation from both the rain and hail containers are measured. The recording hail separator operates identically in the receipt of the precipitation. However, the hailstones fall into a water filled container, and the amount of water displaced is equal to the mass of hail.

The displaced water flows into a calibrated automatic siphon device. The amount of water displaced in each 5-minute period is recorded by a digital recorder on 35 mm film, allowing some estimate of the hail rate and duration on a 5-minute basis.

COMPARISON OF SENSORS

Table 1 is a comparison of the sensors, revealing the information they provide and their approximate cost. All of the sensors provide similar information. The differences in information provided is primarily about windblown hail and time. All sensors give information about whether hail occurred or not and mass of hail. The mass of hail is more accurately

measured by the recording sensors. Three sensors (hailstool, hailcube, hail-wind detector) provide information about the windblown hail such as the azimuth-vertical angle of arrival of the hail and horizontal and total energy. The four recording gages give almost all parameters except in those cases related to windblown hail. However, the NHRE recording rain-hail separator does not give information about the number and size of stones.

The initial cost of the passive and recording sensors differs greatly. The passive sensors are least expensive, costing as little as $3.00 and the recording ones costing up to $400.00. The cost of servicing a network of each type sensor is probably more expensive for the passive sensors because they can usefully record only one hailfall. The analysis cost is somewhat variable. The cost for passive sensors is somewhat expensive for the initial counting and measuring because of the hand analysis.

SUMMARY

There are basically two types of hail sensors: passive which is very inexpensive and yields useful data; and the recording which is 10 to 100 times more expensive. For this additional cost, one obtains detailed time information which is not available from a passive sensor. Choice of sensor will depend on available funds, required number of sensors, and hail information requirements. Most of the recording sensors have serious limitations relating to their inability to sense small (1/4 inch) and wind-blown hailstones.

ACKNOWLEDGEMENTS

We wish to thank the other agencies who developed sensors for their cooperation in providing information to us. Support for the research reported on herein came from National Science Foundation grant GI-37859 and UCAR Sub-contract 25-73. The advice of Griffith M. Morgan, Jr., is appreciated.

Table 1. Comparison of Hail Sensors Showing the Type Instrument, Information Provided, and Instrument Initial Costs.

Type of Information	Hailpad	Hailstool	Hail cube	Hail-Wind Detector	Illinois Recording Hailgage	NOAA Momentum Sensor	NHRE Non-Recording Hail-Rain Separator	Recording Hail-Rain Separator	South Dakota Geophone Gage
Number of Stones	X	X	X	X	X	X			X
Stone Size	X	X	X	X	X	X			X
Hail Mass	X	X	X	X	X	X	X	X	X
Kinetic Energy:									
Horizontal			X	X					
Vertical	X	X	X	X	X	X			X
Total			X	X					
Momentum	X	X	X	X	X	X			X
Azimuth-Vertical Angle of Fall		X	X	X					
Time of Hail					X	X		X(2)	X
Duration of Hail					X	X		X(2)	X
Hail Rate					X	X			X
Dollar Cost	3	15	15	30	250	50(1)	50	400	300

(1) This does not include the cost of a recording raingage required to be adjacent to the hailgage to time of occurrence.

(2) These values are limited to 5-minute accuracy.

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WEATHER MODIFICATION ACTIVITY REPORTS
November 1, 1972 to December 31, 1973

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Environmental Modification Office
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ABSTRACT

All nonfederally sponsored weather modification activities in the United States and its territories must, by law, be reported to the Secretary of Commerce. Recent agreements with applicable Federal agencies also provide for reports of their weather modification activities. The same law also requires that summaries of the reported activities be published periodically. This summary, therefore, is an analysis of 67 activity reports submitted to the National Oceanic and Atmospheric Administration, which administers the weather modification reporting program on behalf of the Secretary. Reports received from November 1, 1972, to December 31, 1973, have been reviewed and grouped into categories covering project purpose, location, sponsors, operators, modification equipment, techniques, seeding agents and related factors.

INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) has administered, on behalf of the Secretary of Commerce, a weather modification reporting program authorized by Public Law 92-205. This law, a copy of which is given in appendix A, requires the reporting of all nonfederally sponsored weather modification activities in the United States and its territories. Rules for carrying out this legislation were published by NOAA in the Federal Register, with an effective date of November 1, 1972. A copy of the rules is provided in appendix B.

Amendments to these reporting rules were published in the Federal Register and were scheduled to go into effect on February 15, 1974. These amendments, shown in appendix C, include questions on operational safeguards and environmental impact as well as a statement covering interference with Federal weather modification research projects.

Federal agencies with weather modification projects also began to report their experimental activities to NOAA on November 1, 1973. This was the result of an agreement obtained by the Secretary of Commerce from appropriate agencies at the request of the Interdepartmental Committee for Atmospheric Sciences and the Office of Management and Budget. With the reporting of both Federally and nonfederally sponsored activites, a central source of information currently exists on all weather modification projects being conducted in the United States. The reporting procedures for

Federal agencies are presented in appendix D.

In accordance with Public Law 92-205, summaries of records on reported weather modification activites that take place in the United States shall be published from time to time. The first summary of activity reports, covering the reporting period from November 1, 1972, to March 22, 1973, was published in March 1973 (Charak and DiGiulian 1973). The present publication is a summary of 67 reports received from November 1 1972, through December 31, 1973. It includes analyses of data on project purpose, sponsors, operators, phenomena to be modified, target locations, target areas, and modification techniques, apparatus, agents and dispersing rates. Additional information is provided on modification days, missions, duration of seeding activites, and amounts of seeding agents.

BACKGROUND

In 1966, the National Science Foundation (NSF) began collecting reports on weather modification activites under Public Law 85-510. Two years later, Congress enacted Public Law 90-407, part of which repealed the powers of the Foundation to require persons to report. During those two years, NSF published summaries of the reported activities covering fiscal years 1967 and 1968. These summaries were included in the NSF annual reports on weather modification that were submitted to the President and the Congress (National Science Foundation 1968, 1969).

From 1968 until passage of Public Law 92-205 in 1971, no Federal department or agency was authorized to collect activity reports. However, pertinent activities of this period are described in the NOAA summary of weather modification research and operational activities during FY 1969-71 (National Oceanic and Atmospheric Administration 1973a). A similar report covering FY 1972 has also been published (National Oceanic and Atmospheric Administration 1973b). These NOAA summary reports continue the type of annual report formerly prepared by the NSF for fiscal years 1959-68. However, more timely information on the weather modification reporting program is summarized in this series of reports, initiated by Charak and DiGiulian (1973).

REPORTING FORMS

The current formats for the reports required by the reporting regulations are shown in appendices E and F. An initial report (appendix E) is to be submitted in advance of a planned activity. The information requested includes project operational or experimental dates, purpose, target and control areas, as well as details on weather modification equipment, agents, and techniques. Also included are questions on project safeguards and environmental effects.

The combined interim and final report form is shown in appendix F. Any person engaged in a weather modification project or activity on October 1 of any year must submit an interim report containing information

for prior months on such items as number of days that actual modification activities took place, number of modification days per atmospheric phenomenon, number of modification missions, hours of operation for apparatus, and type and amount of agent used. For the final report at the end of a project, the totals of these categories are to be reported.

A daily log (appendix G) for each item of weather modification apparatus is not submitted to NOAA, but is maintained by the operator and made available for inspection by NOAA upon request. Information to be recorded consists of the date apparatus is used; its position or location; time when modification activity began and ended; type, rate, and amount of agent used; and type of phenomena modified. The reporting rules also require that certain other records be maintained by the operators.

SUMMARY OF DATA

A listing of the 68 initial reports of weather modification activities, submitted to NOAA between November 1, 1972, and December 31, 1973, can be obtained from NOAA. According to newspaper articles, the activity proposed in file number 73-030 was cancelled prior to any operations. Thus, only 67 reports will be summarized herein. The data from these reports as well as from the available interim and final reports have been reviewed and grouped into various categories of interest. These categories are discussed in the following sections.

Number of Activities:

Of the 67 reports received during the specified period, 65 described nonfederally sponsored weather modification activities, and 2 others covered Federally sponsored projects. The low number of Federally sponsored activities reflects the fact that Federal reporting began on November 1, 1973, a year after initiation of the reporting program for nonfederally sponsored activities. Available are the proposed and actual dates for the operational or experimental periods. It should be noted that 37 of the activities have been completed, that 29 are still listed as active, and that 1 project has not sent information on dates of operations. Seven of these active projects are new starts at previously reported locations. Since operators have up to 90 days to report that a project has been terminated, some of the 29 active projects may have ended before December 31, 1973.

Operators:

Table 1 shows the number of activities sponsored by various types of operators. One commercial weather modification concern carried out 16 of the 67 modification projects. Another firm undertook six projects, and a third company was responsible for five projects during the reporting period.

TABLE 1

WEATHER MODIFICATION ACTIVITY OPERATORS

Type	Operators	Activities
Commercial weather modifiers	20	55
Municipal districts	4	6
Individuals	2	2
Universities	1	2
Power companies	1	1
Community associations	1	1
Total	29	67

Sponsors:

Table 2 is a listing of reported activities by sponsor. Often, a project or activities has several sponsors, particularly where the airlines and the airport authorities were concerned with fog dispersal. Also, some activities and their sponsors were seasonal repeaters. Of the 60 different sponsors identified from the initial reports for these projects, the largest segment consists of 14 community groups, each sponsoring a project. In the private sector are one paper company, a rancher, three resort owners, and a laboratory. The sponsors of the two Federal projects are the Bureau of Reclamation (Department of the Interior) and the Bonneville Power Administration.

TABLE 2

WEATHER MODIFICATION ACTIVITY SPONSORS

Type	Sponsors	Activities
Community associations	14	14
Airlines	8	11
Municipal districts	8	10
Counties	10	6
Private sector	6	6
Airport authorities	3	5
Power companies	5	5
States	1	5
Cities	2	2
Federal	2	2
Universities	1	1
Total	60	67

Purpose and Phenomena:

A review of the reported data shows that there were five purposes for the activities: precipitation increase (rainfall and snowfall), fog dispersal, hail decrease, weather modification research, and "radiation" removal. Table 3 shows the number of activities devoted to these purposes. The total number is greater than the 67 reported projects because some projects have two purposes.

Also shown on table 3 are the types of phenomena on which modification attempts were to be made. Of the 83 activities specified, 63 were devoted to modification of clouds. Warm fog conditions account for 5 activities and cold fog for 14.

TABLE 3

WEATHER MODIFICATION PURPOSE AND PHENOMENA TO BE MODIFIED

Activities	Reported Purpose	Phenomena
24	Precipitation	Clouds
19	(Rainfall)	Clouds
6	(Snowfall)	Clouds
19	Fog dispersal	Warm or cold fog
13	Hail decrease	Clouds
1	"Radiation" removal	Atmospheric
1	Research	Clouds
83		

Location by State:

For the reporting period, 19 States are represented in the 67 weather modification activities. The geographical distribution of these projects is shown in figure 1 at their approximate target area locations. Table 4 shows the number of activities for the various States. Oklahoma has the greatest concentration with 12 projects; California follows with 11. It should be emphasized that all these activities do not occur at the same time. For example, many projects are seasonal.

Total Areas:

Also presented in table 4 are the target areas summarized for each State. The total target area for the reported activities is about 134,000 square miles for the 19 States; this total is less than 4 percent of the area of the United States. In those cases where an activity has been repeated in the following year at the same location, the target area has not been included for the second time. South Dakota and Utah have the largest target areas; several States have small target areas where fog modification is planned at airport locations.

Techniques and Apparatus:

Examination of the information in appendix H shows that ground-based or airborne dispensers of various types are used for introducing seeding materials into the clouds or fogs. Two of the activities use a ground-based technique that proposes to manipulate "orgone" energy or "radiation" in order to modify weather conditions (Eden 1972). Thirty-seven methods are ground-based; 32 operations involve aircraft as the carrier for the seeding agent. Two projects use aircraft and ground-based generators.

The commonest type of equipment for the weather modification activities is the ground-based, arc-type AgI burner. Nine other types of weather modification apparatus are used: propane burners or generators; pyrotechnic flares; a ground-based mobile spray system; dispensers for ejecting dry ice from aircraft that include electric hoppers, spreaders, metered hoppers and blowers, suction tubes, and funnels; and "cloud busters" consisting of pipes grounded into a water supply.

TABLE 4

TARGET AREAS AND ACTIVITIES FOR EACH STATE

State	Activities	Target area (mi^2)
Arkansas	1	900
California	11	5,678
Colorado	1	1,300
Idaho	5	3,874
Illinois	1	2
Iowa	2	4
Michigan	3	1,951
Montana	2	1,656
Nebraska	1	2
Nevada	1	5
New York	1	-
North Dakota	6	16,172
Oklahoma	12	12,840
Oregon	2	2
South Dakota	6	44,516
Texas	3	4,900
Utah	3	40,010
Washington	4	8
Wyoming	2	180
Total	67	134,000

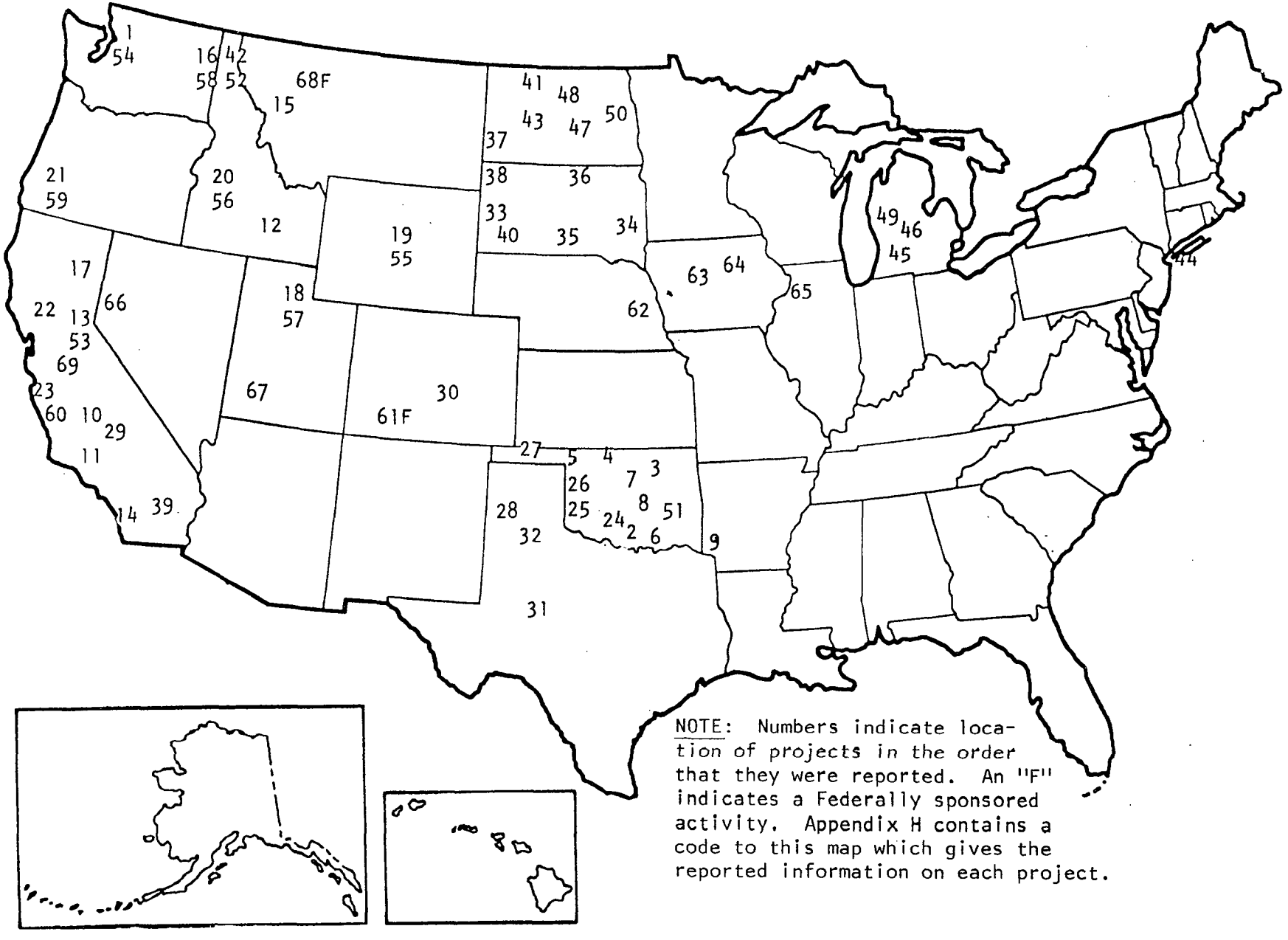


Figure 1. -- Reported Federally and nonfederally sponsored weather modification activities - November 1, 1972, to December 31, 1973.

Agents:

Inspection of the data in appendix H shows that the nucleating agents used for the reported activities are pure silver iodide, crushed carbon dioxide (dry ice), water droplets, polyelectrolytes, propane, and combinations of silver iodide with other ingredients in solids or solutions. A polyelectrolyte can be defined as a polymeric material having an electrical charge.

Silver iodide, by itself or in combined form, is the agent in 50 projects. Dry ice is used in 14 activities, and polyelectrolytes are specified in 5 projects. More than one agent is used in some activities.

Dispensing Rates:

The data indicate that the aircraft dispensing rates for a unit of modification apparatus are appreciably higher than the rates for ground-based burners or generators (although the length of dispensing time in aircraft operations is usually shorter). Silver iodide dispensing rates range from 0.5 grams per hour (burner) to 320 grams per hour (pyrotechnic); an individual flare (pyrotechnic) burns for less than a minute. The approximate dispensing rates for dry ice and polyelectrolytes range from 11 to 1,300 kilograms per hour.

Information from Interim and Final Reports:

Twenty-four operators filed the required interim reports for projects considered active on October 1, 1973. The data from 14 of these interim reports and from the 37 final reports submitted by December 31, 1973, have been examined and summarized. Interim reports were used if a final report had not been submitted. One interim report and three final reports were incomplete; replies to requests for the missing data had not yet been received from the operators.

Because some data are lacking, any summary of the available interim and final reports would be less than complete at this time. However, the data were reviewed, and the results are shown in table 5. The entries cover the initial 11 months of the reporting program and provide a good estimate of nonfederally sponsored weather modification activity for the period.

The modification days noted in Table 5, item (a) are days on which actual weather modification activities took place. Items (b) through (e) show the number of days on which modification activities were conducted, segregated by each of the predominant types of weather phenomena involved in the operations. Normally, the total of entries in (a) would equal the total of (b) through (e). The discrepancy can be explained by the lack of reported data and the likelihood that more than one cloud system was involved in a day's operations.

Estimates of the amounts of seeding agent used in the initial 11 months can be taken a step further. The amount of silver iodide dispensed

in airborne operations was 552 kilograms. The remainder of the silver iodide (509 kilograms) was used in ground-based seeding activities. Dry ice and polyelectrolytes were used in other airborne activities to disperse fog.

TABLE 5

SUMMARY OF INTERIM AND FINAL REPORT DATA

(Nov. 1, 1972 - Sept. 30, 1973)

(a)	Modification days (cumulative)	1,989
(b)	Modification days (stratiform clouds)	474
(c)	Modification days (isolated clouds)	933
(d)	Modification days (organized clouds)	522
(e)	Modification days (fog)	67
(f)	Modification missions	2,732
(g)	Airborne apparatus operation, hours	1,780
(h)	Ground-based apparatus operation, hours	38,912
(i)	Dry ice used, kilograms	9,298
(j)	Polyelectrolyte used, kilograms	544
(k)	Silver iodide used, kilograms	1,061

CONCLUDING REMARKS

The initial, interim, and final reports of weather modification activities in the United States for the period November 1, 1972 to December 31, 1973 have been summarized in this publication. In four cases where the reports were incomplete, the operator was requested to provide the missing information. Analysis of the reports for 65 non-federally sponsored projects and for the 2 federally sponsored projects revealed several types of information. The 67 projects reported to NOAA show that about one-fourth were carried out by one commercial operator; nearly half the activities were to increase precipitation; about one-sixth of the activities to decrease hail; and about one-fourth to disperse fog. Nineteen States had some activity; Oklahoma and California led in total numbers of activities. The total target area for all the reported activities was about 134,000 square miles; South Dakota and Utah had the largest target areas. Further examination of the reports indicated that most of the activities were ground-based; that the arc-type silver iodide burner was the commonest type of ground-based equipment; and that silver iodide was the most popular seeding agent inasmuch as it was used in 50 projects.

For the first 11 months of the reporting program, the total number of modification days (cumulative) was estimated at nearly 2,000 during the reporting period of 370 days. Ground-based weather modification apparatus operated for about 39,000 hours; airborne apparatus, for about

1,800 hours. The amount of silver iodide consumed was about 1,100 kilograms; the amount of dry ice dispensed to modify fog was about 9,300 kilograms.

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Public Law 92-205
92nd Congress, H. R. 6893
December 18, 1971

An Act

To provide for the reporting of weather modification activities to the Federal Government.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That, as used in this Act— Weather modification reporting.

(1) The term "Secretary" means the Secretary of Commerce.

(2) The term "person" means any individual, corporation, company, association, firm, partnership, society, joint stock company, any State or local government or any agency thereof, or any other organization, whether commercial or nonprofit, who is performing weather modification activities, except where acting solely as an employee, agent, or independent contractor of the Federal Government.

(3) The term "weather modification" means any activity performed with the intention of producing artificial changes in the composition, behavior, or dynamics of the atmosphere. 85 STAT. 735

(4) The term "United States" includes the several States, the District of Columbia, the Commonwealth of Puerto Rico, and any territory or insular possession of the United States. 85 STAT. 736

SEC. 2. No person may engage, or attempt to engage, in any weather modification activity in the United States unless he submits to the Secretary such reports with respect thereto, in such form and containing such information, as the Secretary may by rule prescribe. The Secretary may require that such reports be submitted to him before, during, and after any such activity or attempt. Report requirement.

SEC. 3. (a) The Secretary shall maintain a record of weather modification activities, including attempts, which take place in the United States and shall publish summaries thereof from time to time as he determines. Records, publication.

(b) All reports, documents, and other information received by the Secretary under the provisions of this Act shall be made available to the public to the fullest practicable extent.

(c) In carrying out the provisions of this section, the Secretary shall not disclose any information referred to in section 1905 of title 18, United States Code, and is otherwise unavailable to the public, except that such information shall be disclosed— Confidential information. 62 Stat. 791.

(1) to other Federal Government departments, agencies, and officials for official use upon request;

(2) in any judicial proceeding under a court order formulated to preserve the confidentiality of such information without impairing the proceeding; and

(3) to the public if necessary to protect their health and safety.

SEC. 4. (a) The Secretary may obtain from any person whose activities relate to weather modification by rule, subpena, or otherwise such information in the form of testimony, books, records, or other writings, may require the keeping and furnishing of such reports and records, and may make such inspection of the books, records, and other writings and premises and property of any person as may be deemed necessary or appropriate by him to carry out the provisions of this Act, but this authority shall not be exercised to obtain any information with respect to which adequate and authoritative data are available from any Federal agency. Authority of Secretary.

Noncompliance.

(b) In case of contumacy by, or refusal to obey a subpena served upon any person pursuant to this section, the district court of the United States for any district in which such person is found or resides or transacts business, upon application by the Attorney General, shall have jurisdiction to issue an order requiring such person to appear and give testimony or to appear and produce documents, or both; and any failure to obey such order of the court may be punished by such court as a contempt thereof.

Penalty.

SEC. 5. Any person who knowingly and willfully violates section 2 of this Act, or any rule issued thereunder, shall upon conviction thereof be fined not more than $10,000.

Appropriations.

SEC. 6. There are authorized to be appropriated $150,000 for the fiscal year ending June 30, 1972, and $200,000 each for the fiscal years ending June 30, 1973, and June 30, 1974, to carry out the provisions of this Act.

Approved December 18, 1971.

LEGISLATIVE HISTORY:

HOUSE REPORT No. 92-458 (Comm. on Interstate and Foreign Commerce).
SENATE REPORT No. 92-537 (Comm. on Commerce).
CONGRESSIONAL RECORD, Vol. 117 (1971):
Sept. 28, considered and passed House.
Dec. 6, considered and passed Senate, amended.
Dec. 9, House concurred in Senate amendments.

GPO 69-139

Title 15—COMMERCE AND FOREIGN TRADE

Chapter IX—National Oceanic and Atmospheric Administration, Department of Commerce

SUBCHAPTER A—GENERAL REGULATIONS

PART 908—MAINTAINING RECORDS AND SUBMITTING REPORTS ON WEATHER MODIFICATION ACTIVITIES

On June 10, 1972, a notice of proposed rule making on maintaining and submitting records regarding weather modification activities was published in the FEDERAL REGISTER (37 F.R. 11679). Interested persons were given until September 11, 1972, to submit written views, objections, recommendations, or suggestions in connection with the proposed rules. The comments received in response to the notice have been considered and revisions have been made in the rules for clarity, simplicity, and utility.

The purpose of these rules is to provide for the reporting to the Secretary of Commerce of weather modification activities taking place within the United States. The Secretary is charged under law to assemble and retain records of such weather modification activities, to make these records publicly available to the fullest extent practicable, and to publish summaries thereof from time to time. By so doing, among other things, expertise in the field of weather modification will be increased, and scientists and other concerned persons will have access to information about past and ongoing efforts at weather modification, can determine whether their activities will be necessary or duplicative, can check both desirable and undesirable atmospheric changes against records of weather modification, and can be alert to possible territorial overlappings of weather modification operations.

Therefore, pursuant to the authority contained in Public Law 92-205, 85 Stat. 735, December 18, 1971, the National Oceanic and Atmospheric Administration (NOAA) amends Title 15, Code of Federal Regulations, by the addition of Part 908, adopting the rules set forth below. These rules will be administered by the Administrator, National Oceanic and Atmospheric Administration, on behalf of the Secretary of Commerce, pursuant to the Secretary's delegation of authority in section 3, subparagraph .01t of the Department of Commerce Organization Order 25-5A.

HOWARD W. POLLOCK,
Acting Administrator.

OCTOBER 18, 1972.

The rules are as follows:

Sec.

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AUTHORITY: The provisions of this Part 908 issued pursuant to the authority contained in Public Law 92-205, 85 Stat. 735, December 18, 1971.

§ 908.1 Definitions.

As used in this part, terms shall have the meaning ascribed in this section.

(a) *Administrator.* The Administrator of the National Oceanic and Atmospheric Administration.

(b) *Person.* Any individual, corporation, company, association, firm, partnership, society, joint stock company, any State or local government or any agency thereof, or any other organization, whether commercial or nonprofit, except where acting solely as an employee, agent, or independent contractor of the Federal Government.

(c) *Weather modification activity.* Any activity performed with the intention of producing artificial changes in the composition, behavior, or dynamics of the atmosphere.

(d) *United States.* The several States, the District of Columbia, the Commonwealth of Puerto Rico, and any territory or insular possession of the United States.

(e) *Persons whose activities relate to weather modification.* Persons engaged in weather modification activities or engaged in the distribution or sale of weather modification apparatus or materials known by them to be destined for use in weather modification activities.

(f) *Project.* A related series of weather modification activities having a common objective.

(g) *Modification mission.* One or more airborne weather modification activities intended to affect the same target area, or one or more weather modification activities carried out by items of ground-based weather modification apparatus intended to affect the same target area. For purposes of these rules, activities that extend beyond 1 calendar day shall constitute a separate mission for each day that they continue.

(h) *Target area.* The ground area within which the effects of the weather modification activity are expected to be found.

(i) *Control area.* A preselected, untreated ground area used for comparison with a target area.

(j) *Weather modification apparatus.* Any apparatus used with the intention of producing artificial changes in the composition, behavior, or dynamics of the atmosphere. For example: Seeding generators, propane devices, flares, rockets, artillery projectiles, jet engines, etc.

§ 908.2 Persons subject to reporting.

Any person engaged or intending to engage in any weather modification activity in the United States shall be subject to the reporting provisions of this part.

§ 908.3 Activities subject to reporting.

(a) The following, when conducted as weather modification activities, shall be subject to reporting:

(1) Seeding or dispersing of any substance into clouds or fog, to alter drop size distribution, produce ice crystals or coagulation of droplets, alter the development of hail or lightning, or influence in any way the natural development cycle of clouds or their environment;

(2) Using fires or heat sources to influence convective circulation or to evaporate fog;

(3) Modifying the solar radiation exchange of the earth or clouds, through the release of gases, dusts, liquids, or aerosols into the atmosphere;

(4) Modifying the characteristics of land or water surfaces by dusting or treating with powders, liquid sprays, dyes, or other materials;

(5) Releasing electrically charged or radioactive particles, or ions, into the atmosphere;

(6) Applying shock waves, sonic energy sources, or other explosive or acoustic sources to the atmosphere;

(7) Using aircraft propeller downwash, jet wash, or other sources of artificial wind generation; or

(8) Using lasers or other sources of electromagnetic radiation.

(b) In addition to the activities listed above, other similar activities falling within the definition of weather modification as set forth in § 908.1 are also subject to reporting.

(c) The requirement for reporting shall not apply to activities of a purely local nature that can reasonably be expected not to modify the weather outside of the area of operation. This exception is presently restricted to the use of lightning deflection or static discharge devices in aircraft, boats, or buildings, and to the use of small heat sources, fans, fogging devices, aircraft downwash, or sprays to prevent the occurrence of frost in tracts or fields planted with crops susceptible to frost or freeze damage. Other exceptions may be made in the future by rule of the Administrator.

§ 908.4 Initial report.

(a) Any person intending to engage in any weather modification project or activity in the United States shall provide a report of his intention, to be received by the Administrator at least 10 days before the commencement of such project or activity. This report shall contain at least the following:

(1) The designation, if any, used by the operator for the project or activity;

(2) The following dates for weather modification activities:

(i) The date the first actual weather modification activity is to be undertaken;

(ii) The date on which the final modification activity is expected to occur;

(3) The name and address of the person for whom the project or activity is to be performed;

(4) The purpose of the project or activity;

(5) A map showing the approximate size and location of the target and control areas, and the location of each item of ground-based weather modification apparatus, precipitation measuring device, and, for airborne operations, the airport;

(6) A description of the weather modification apparatus, modification agents, and the techniques to be employed;

(7) The name and address of the responsible individual from whom log books or other records of the project or activity may be obtained; and

(8) Optional remarks, to include any additional items which the person deems significant or of interest and such other information as the Administrator may request the person to submit.

(b) If circumstances prevent the signing of a contract or agreement to perform, or receipt of an authorization to proceed with, a weather modification activity at a date early enough to comply with paragraph (a) of this section, the initial report shall be provided so as to be received by the Administrator within 10 days of the date of signing of the contract or agreement, or receipt of authorization to proceed. In such cases, the report shall be accompanied by an explanation as to why it was not submitted at least 10 days prior to the commencement of the activity.

(c) In the event that circumstances beyond the control of the person liable to report under these regulations prevent the submission of the initial report in a timely manner as described above, the report shall be forwarded as early as possible, accompanied by an explanation as to why a timely report has not been provided. If such explanation is deemed adequate, the Administrator will consider the notice as timely filed.

§ 908.5 Interim reports.

(a) Any person engaged in a weather modification project or activity in the United States on October 1 in any year shall submit to the Administrator, not later than 90 days thereafter, an interim report setting forth as of such date the information required below with respect to any such continuing project or activity not previously furnished to the Administrator in a prior interim report; provided that the October 1 date shall not apply if other arrangements have previously been made with the written approval of the Administrator.

(b) The interim report shall include the file number assigned by the Administrator and shall provide a summary of the project or activity containing at least the following information for each month:

(1) Number of days on which actual modification activities took place;

(2) Number of days on which weather modification activities were conducted, segregated by each of the predominant types of weather phenomena;

(3) Number of modification missions that were carried out;

(4) Total number of hours of operation of each type of weather modification apparatus (i.e., net hours of agent release);

(5) Total amount of agent used. If more than one agent was used, each should be totaled separately (e.g., carbon dioxide, sodium chloride, urea, silver iodide).

(c) The totals for the items in paragraph (b) of this section shall be provided for the period covered by the interim report.

§ 908.6 Final report.

Upon completion of a weather modification project or activity the person who performed the same shall submit a report to the Administrator not later than 90 days after completion of the project or activity. The report shall include the file number assigned by the Administrator and the following items:

(a) Information required for the interim reports (to the extent not previously reported).

(b) The total number of days on which actual modification activities took place during the project or activity.

(c) The total number of days during the project or activity on which weather modification activities were conducted, segregated by each of the predominant types of weather phenomena.

(d) The total number of modification missions that were carried out under the project or activity.

(e) The total number of hours of operation of each type of weather modification apparatus during the project or activity (i.e., net hours of agent release).

(f) The total amount of modification agent(s) dispensed during the project or activity. If more than one agent was used, each should be totaled separately (e.g., carbon dioxide, sodium chloride, urea, silver iodide).

(g) The date on which the final weather modification activity occurred.

§ 908.7 Supplemental reports.

Notwithstanding other regulations, a supplemental report in letter form referring to the appropriate NOAA file number, if assigned, must be made to the Administrator immediately if any report of weather modification activities submitted under § 908.4, § 908.5, or § 908.6 is found to contain any material inaccuracies, misstatements, and omissions. A supplemental report must also be made if there are changes in plans for the project or activity.

§ 908.8 Maintenance of records.

(a) Any person engaging in a weather modification activity in the United States shall maintain a record of such activity. This record shall contain at least the following, when applicable:

(1) A chronological record of activities carried on, preferably in the form of a daily log, which shall include the NOAA file number assigned to the project, the designation of each unit of weather modification apparatus, and at least the following information for each unit:

(i) Date of the weather modification activity.

(ii) Position of each aircraft or location of each item of weather modification apparatus during each modification mission. Maps may be used.

(iii) Time when weather modification activity began and ended.

(iv) Total duration of operation of each unit of weather modification apparatus (i.e., net hours of agent release).

(v) Type of each modification agent used.

(vi) Rate of dispersal of each agent during the period of actual operation of weather modification apparatus.

(vii) Total amount of agent used. If more than one agent was used, report total for each type separately.

(viii) Number of days on which weather modification activities were conducted, segregated by the predominant types of weather phenomena.

(2) The monthly totals of hours of modification activity, the amount of modification agent used, and the number of days on which weather modification activities were conducted, segregated by each of the predominant types of weather phenomena, shall be shown on the daily log sheet for the last day of each month.[1]

(b) When the activity involves ground-based weather modification apparatus, records of the following shall also be maintained, when applicable, but need not be made part of the daily log:

(1) The location of each item of weather modification apparatus in use and its identification such as type and manufacturer's model number. If the apparatus is not commercially available, a brief description of the apparatus and the method of operation should be recorded.

(2) The name and address of the person responsible for operating each weather modification apparatus;

(3) The altitude and type of weather phenomenon subjected to weather modification activity during each operational period (e.g., cumulus clouds between 10,000 and 30,000 feet m.s.l.; ground fog).

(c) When the activity involves airborne weather modification apparatus, records of the following shall also be maintained, when applicable, but need not be made a part of the daily log:

For each airborne weather modification apparatus run: altitude, air speed; release points of modification agents, method of modification and characteristics of flares, rockets, or other delivery systems employed; temperature at release altitude; and, for aircraft: the type of aircraft, its identification number, the airport or airports used, and the names and addresses of crew members and the person responsible for operating the weather modification apparatus; and the altitude and type of weather phenomenon subjected to weather modification activity during each operational period (e.g., cumulus clouds between 10,000 and 30,000 feet m.s.l.; ground fog).

(d) The following records shall also be maintained, whenever applicable, but need not be made a part of the daily log. Only data specifically collected for the reported activity need be retained; data available from other sources need not be included.

(1) Any descriptions that were recorded of meteorological conditions in target and control areas during the periods of operation; for example: percent of cloud cover, temperature, humidity, the presence of lightning, hail, funnel clouds, heavy rain or snow, and unusual radar patterns.

(2) All measurements made of precipitation in target and control areas.

(3) Any unusual results.

§ 908.9 Retention of records.

Records required under § 908.8 shall be retained and available for inspection by the Administrator or his designated representatives for 5 years after completion of the activity to which they relate. Such records shall be required to be produced for inspection only at the place where normally kept. The Administrator shall have the right to make copies of such records, if he deems necessary.

[1] Filed as part of the original document.

§ 908.10 Penalties.

Knowing and willful violation of any rule adopted under the authority of section 2 of Public Law 92-205 shall subject the person violating such rule to a fine of not more than $10,000, upon conviction thereof.

§ 908.11 Maintenance of records of related activities.

(a) Persons whose activities relate to weather modification activities, other than persons engaged in weather modification activities, shall maintain records concerning the identities of purchasers or users of weather modification apparatus or materials, the quantities or numbers of items purchased, and the times of such purchases. Such information shall be retained for at least 5 years.

(b) In addition, persons whose activities relate to weather modification shall be required, under the authority of section 4 of Public Law 92-205, to provide the Administrator, on his request, with information he deems necessary to carry out the purposes of this act.

§ 908.12 Public disclosure of information.

(a) Any records or other information obtained by the Administrator under these rules or otherwise under the authority of Public Law 92-205 shall be made publicly available to the fullest practicable extent. Such records or information may be inspected on written request to the Administrator. However, the Administrator will not disclose any information referred to in section 1905 of title 18, United States Code, and that is otherwise unavailable to the public, except that such information shall be disclosed—

(1) To other Federal Government departments, agencies, and officials for official use upon request;

(2) In any judicial proceeding under a court order formulated to preserve the confidentiality of such information without impairing the proceeding; and

(3) To the public, if necessary to protect their health and safety.

(b) Certified copies of such reports and information, to the extent publicly disclosable, may be obtained from the Administrator at cost in accordance with the Department of Commerce implementation of the Freedom of Information Act.

(c) Persons reporting on weather modification projects or related activities shall specifically identify all information that they consider not to be subject to public disclosure under the terms of Public Law 92-205 and provide reasons in support thereof. A determination

as to whether or not reported information is subject to public dissemination shall be made by the Administrator.

§ 908.13 Address of letters.

Letters and other communications intended for the Administrator, in connection with weather modification reporting or activities, shall be addressed to: The Administrator, National Oceanic and Atmospheric Administration, Office of Environmental Modification, Rockville, Md. 20852.

§ 908.14 Business to be transacted in writing.

All business transacted with the National Oceanic and Atmospheric Administration with regard to reports of weather modification activities should be transacted in writing. Actions of the National Oceanic and Atmospheric Administration will be based exclusively on the written record.

§ 908.15 Times for taking action; expiration on Saturday, Sunday, or holiday.

Whenever periods of time are specified in these rules in days, calendar days are intended. When the day, or the last day, fixed under these rules for taking any action falls on a Saturday, Sunday, or on a Federal holiday, the action may be taken on the next succeeding day which is not a Saturday, Sunday, or Federal holiday.

§ 908.16 Signature.

All reports filed with the National Oceanic and Atmospheric Administration must be dated and signed by or on behalf of the person conducting or intending to conduct the weather modification activities referred to therein by such person, individually or, in the case of a person other than an individual, by a partner, officer, or other person having corresponding functions and authority. For this purpose "officer" means a president, vice president, treasurer, secretary, or comptroller. Notwithstanding the foregoing, such reports may also be signed by the duly authorized agent or attorney of the person whose activities are being reported. Proof of such authorization shall be furnished to the Administrator when filing a report, unless previously furnished.

§ 908.17 Suspension or waiver of rules.

In an extraordinary situation, any requirement of these rules may be suspended or waived by the Administrator on request of the interested party, to the extent such waiver is consistent with the provisions of Public Law 92–205 and subject to such other requirements as may be imposed.

§ 908.18 Matters not specifically provided for in rules.

All matters not specifically provided for or situations not specifically addressed in these rules will be decided in accordance with the merits of each case by or under the authority of the Administrator, and such decision will be communicated in writing to all parties involved in the case.

§ 908.19 Publication of notice of proposed amendments.

Whenever required by law, and in other cases whenever practicable, notice of proposed amendments to these rules will be published in the FEDERAL REGISTER. If not published with the notice, copies of the text of proposed amendments will be furnished to any person requesting the same. All comments, suggestions, and briefs received within the time specified in the notice will be considered before adoption of the proposed amendments, which may be modified in the light thereof. Informal hearings may be held at the discretion of the Administrator.

§ 908.20 Effective date.

These rules are effective November 1, 1972.

(a) Any person engaged in a weather modification activity on the effective date shall furnish the initial report required under § 908.4 within 30 days from the effective date, appropriately modified as circumstances may require.

(b) Any person intending to engage in a weather modification activity scheduled to commence less than 40 days from the effective date of these rules may furnish the required report under § 908.4 as late as 30 days following such effective date.

(c) The explanatory statement required by § 908.4(c), pertaining to late reports, need not be submitted with the initial reports in the above cases.

§ 908.21 Report form.

Public Law 92–205 and these rules should be studied carefully prior to reporting. Reports required by these rules shall be submitted on forms obtainable on request from the Administrator, or on an equivalent format.[2] In special situations, such alterations to the forms as the circumstances thereto may render necessary may be made, provided they do not depart from the requirements of these rules or of Public Law 92–205.

[FR Doc.72–18279 Filed 10–26–72;8:45 am]

[2] Filed as part of the original document.

RULES AND REGULATIONS

Title 15—Commerce and Foreign Trade

CHAPTER IX—NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, DEPARTMENT OF COMMERCE

SUBCHAPTER A—GENERAL REGULATIONS

PART 908—MAINTAINING RECORDS AND SUBMITTING REPORTS ON WEATHER MODIFICATION ACTIVITIES

Provisions for Reporting Additional Information

In a notice published in the FEDERAL REGISTER of November 6, 1973 (38 FR 30563), the Administrator of the National Oceanic and Atmospheric Administration proposed to amend the rules on maintaining records and submitting reports on weather modification activities (37 FR 22974). Interested persons were given until December 6, 1973 to submit written views, objections, recommendations, or suggestions in connection with the proposed amendments. The few comments received in response to the notice have been considered in detail, but they did not provide any basis for revision of the proposed additions to the rules.

The purpose of these amendments to 15 CFR Part 908, is to provide for the reporting of the additional information required by NOAA to carry out the intent of the President's Directive to the Secretary of Commerce:

> * * * to expand his regulations to provide for Federal notification, including recommendations where appropriate, to operators and State officials in cases where a report disclosed that a proposed project may endanger persons, property, or the environment or the success of Federal research projects. Notifications will be available to the public.

Over the past 27 years, weather modification activities have been undertaken to secure benefits for man, and the results have been encouraging. Although there has been no evidence in this period that these activities have significantly endangered persons, property, or the environment, the President's Message recognizes that such activities may have the potential to cause adverse effects, if carried out without appropriate safeguards.

It is almost impossible to predetermine with certainty all of the effects of a given weather modification operation. For that reason, to minimize the possibility of harmful results, planning for weather modification operations usually includes project safeguards and consideration of environmental impact which will eliminate hazards that might be reasonably foreseen. The amendments, which require the reporting of current safety practices and environmental considerations, will provide a single source of information on the safety and environmental precautions used in weather modification activities in the United States. Compilations of these practices may form the basis for later publication of techniques generally used in the industry to avoid potential danger. The reported information will also help operators to anticipate, and hopefully avoid, possible interference of one experiment or operation by another.

Appropriate Federal agencies have agreed to report their weather modification activities to the Secretary of Commerce. This Federal reporting complements the reporting of non-Federal sponsored projects and provides for a central source of information on all weather modification activities in the United States.

The actions of the Department of Commerce under these amendments are not intended as, nor do they constitute, approval, disapproval, or regulation of weather modification operations. Any notification that may be made to operators and State officials on the basis of information received will be advisory only.

Therefore, pursuant to the authority contained in 15 U.S.C. 330–330e and 15 U.S.C. 313, and pursuant to a Directive to the Secretary of Commerce reflected in the President's February 15, 1973 State of the Union Message on Natural Resources and Environment, and the Fact Sheet accompanying the Message, the National Oceanic and Atmospheric Administration (NOAA) amends 15 CFR by additions to Part 908, adopting the rules set forth below. These rules will be administered by the Administrator, National Oceanic and Atmospheric Administration, on behalf of the Secretary of Commerce, pursuant to the Secretary's delegation of authority in section 3, subparagraph .01t of the Department of Commerce Organization Order 25–5A.

The amendments are as follows:

1. Change § 908.4(a)(7) by deleting the word "and" after the semi-colon.

2. Change § 908.4(a)(8) to § 908.4(a)(9).

3. Add § 908.4(a)(8) as follows:

§ 908.4 Initial report.

(a) * * *

(8) Answers to the following questions on project safeguards:

(i) Has an Environmental Impact Statement, Federal or State, been filed: Yes ____ No _____. If Yes, please furnish a copy as applicable.

(ii) Have provisions been made to acquire the latest forecasts, advisories, warnings, etc. of the National Weather Service, Forest Service, or others when issued prior to and during operations? Yes ____ No _____. If Yes, please specify on a separate sheet.

(iii) Have any safety procedures (operational constraints, provisions for suspension of operations, monitoring methods, etc.) and any environmental guidelines (related to the possible effects of the operations) been included in the operational plans? Yes ____ No _____. If Yes, please furnish copies or a description of the specific procedures and guidelines.

4. Add § 908.12(d) to read as follows:

§ 908.12 Public disclosure of information.

* * * * *

(d) When consideration of a weather modification activity report and related information indicates that a proposed project may significantly depart from the practices or procedures generally employed in similar circumstances to avoid danger to persons, property, or the environment, or indicates that the success of Federal research projects may be adversely affected if the proposed project is carried out as described, the Administrator will notify the operator(s) and State officials of such possibility and make recommendations where appropriate. The purpose of such notification shall be to inform those notified of existing practices and procedures or Federal research projects known to NOAA. Notification or recommendation, or failure to notify or recommend, shall not be construed as approval or disapproval of a proposed project or as an indication that, if carried out as proposed or recommended it may, in any way, protect or endanger persons, property, or the environment or affect the success of any Federal research project. Any advisory notification issued by the Administrator shall be available to the public and be included in the pertinent activity report file.

Effective date. These amendments shall be effective on February 15, 1974.

ROBERT M. WHITE,
Administrator.

[FR Doc.74-1077 Filed 1-14-74;8:45 am]

APPENDIX D. Federal Reporting Rules

Ground Rules for the Reporting of Federal Weather Modification Activities

BACKGROUND

In 1958, the National Science Foundation began collecting reports on weather modification activities under Public Law 85-510. Ten years later in 1968, Congress enacted Public Law 90-407, which repealed the posers of the Foundation to require persons to report. Until 1971, no Federal department or agency had been authorized to collect activity reports. On December 18, 1971, Public Law 92-205 was enacted; it requires that nonfederally sponsored weather modification activities be reported to the Secretary of Commerce. Rules for implementing this legislation were published by the National Oceanic and Atmospheric Administration, Department of Commerce, in the Federal Register, Vol. 37, No. 208, October 27, 1972, with an effective date of November 1, 1972. The ground rules that follow for the reporting of Federal weather modification activities complement the current reporting requirement for nonfederal activities.

AGENCY RESPONSIBILITIES

Each agency or department of the Federal Government engaged in, or actively planning to engage in, a weather modification activity which affects or may affect weather over the United States, whether carried out on its behalf by employees, agents, independent contractors or otherwise, shall assure that records thereof be kept and that reports of such activities be submitted to the Secretary of Commerce. In a weather modification project where more than one agency is involved in a project, only the lead agency shall have the responsibility for reporting. However, the lead agency shall identify all the agencies involved in the project.

INTERNATIONAL ASPECTS

The National Security Council's Under Secretaries' Committee will continue to be responsible for the review of the international aspects of weather modification generally and for the review of all civil weather modification activities of each agency or department of the Federal Government affecting other countries or conducted outside U.S. territory.

DEFINITIONS AND REPORTING RULES

Except as herein otherwise defined or provided, the definitions and rules adopted by the Secretary of Commerce pursuant to Public Law 92-205, 85 Stat. 735 (December 18, 1971), to cover the reporting of nonfederally sponsored weather modification activities, shall apply to any weather

modification activity in which an agency or department of the Federal Government is engaged, or plans to engage.

PENALTY EXEMPTION

No criminal penalty, as provided for in such rules or in Public Law 92-205, shall apply to an agency or department of the Federal Government, its employees, agents, independent contractors, or others, in regard to a weather modification activity carried out by or for the account of such agency or department.

PUBLIC DISCLOSURE OF INFORMATION

Reports of weather modification activities of agencies or departments of the Federal Government shall be preserved by the Secretary of Commerce who shall act upon such reports in a similar manner and under similar conditions as other records of weather modification activities reported pursuant to Public Law 92-205 and the reporting rules cited above.

Records of weather modification activities of an agency or department which are retained by that agency or department, shall be made publicly available to the extent provided for under the Freedom of Information Act (5 U.S.C. 552).

No agency or department of the Federal Government shall be required to furnish any information or material to the Secretary of Commerce or make the same publicly available when such information or material requires protection in the interest of national security.

APPENDIX E. Initial Report

FORM APPROVED: O.M.B. NO. 41-R2664
APPROVAL EXPIRES 12-31-77

Complete in accordance with instructions on on reverse and forward copy:

TO: Environmental Modification Office
National Oceanic and Atmospheric Admin.
Rockville, Maryland 20852

NOAA FORM 17-4 (12-73)
U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

INITIAL REPORT ON WEATHER MODIFICATION ACTIVITIES

PUBLIC LAW 205, 92ND. CONGRESS

1. PROJECT OR ACTIVITY DESIGNATION, IF ANY

2. DATES OF PROJECT

a. DATE OF FIRST ACTUAL WEATHER MODIFICATION ACTIVITY

b. EXPECTED TERMINATION DATE OF WEATHER MODIFICATION ACTIVITIES

3. PERSON FOR WHOM PROJECT OR ACTIVITY IS PERFORMED

NAME AND AFFILIATION OF SPONSOR	PHONE NUMBER

STREET ADDRESS

CITY	STATE	ZIP CODE

4. PURPOSE OF PROJECT OR ACTIVITY

5. TARGET AND CONTROL AREAS *(See Instructions)*

TARGET AREA		CONTROL AREA	
LOCATION	SIZE OF AREA SQ. MI.	LOCATION	SIZE OF AREA SQ. MI.

6. DESCRIPTION OF WEATHER MODIFICATION APPARATUS, MODIFICATION AGENTS AND THEIR DISPERSAL RATES, THE TECHNIQUES EMPLOYED, ETC. *(See Instructions)*

7. LOG BOOKS:

Enter name, address, and telephone number of responsible individual from whom log books or other records may be obtained.

NAME AND AFFILIATION		PHONE NUMBER
STREET ADDRESS		
CITY	STATE	ZIP CODE

8. SAFETY AND ENVIRONMENT

☐ YES ☐ NO Has an Environmental Impact Statement, Federal or State been filed? If yes, please furnish a copy as applicable.

☐ YES ☐ NO Have provisions been made to acquire the latest forecasts, advisories, warnings, etc. of the National Weather Service, Forest Service, or others when issued prior to and during operations? If yes, please specify on a separate sheet.

☐ YES ☐ NO Have any safety procedures *(operational constraints, provisions for suspension of operations, monitoring methods, etc.)* and any environmental guidelines *(related to the possible effects of the operations)* been included in the operational plans? If yes, please furnish copies or a description of the specific procedures and guidelines.

9. OPTIONAL REMARKS *(See Instructions)*

CERTIFICATION: I certify that the above statements are true, complete, and correct to the best of my knowledge and belief.

NAME OF REPORTING PERSON AND AFFILIATION			SIGNATURE	
STREET ADDRESS			OFFICIAL TITLE	
CITY	STATE	ZIP CODE	DATE	PHONE NUMBER

INSTRUCTIONS FOR INITIAL REPORT ON WEATHER MODIFICATION ACTIVITIES

One completed copy of this form is to be received 10 days* or more prior to actual modification activities. A NOAA file number will be assigned by the Administrator after receipt of the initial report for each project or activity.

A supplemental report in a letter form referring to the appropriate NOAA file number must be made to the Administrator if the "Initial Report" is found to contain any material inaccuracies, misstatements, and omissions, or if there are changes in plans for the project or activity.

*For exceptions, see Sections 908.4(b) and (c), Part 908 of Title 15, Code of Federal Regulations.

Item 1. Enter designation, if any, used by operator for the project or activity.

Item 2. Enter: (a) Date first actual weather modification activity is to be undertaken;

(b) Date on which final weather modification activity is expected to occur.

Item 3. Enter name, affiliation, and address of the person for whom the project is to be performed (sponsor).

Item 4. Enter the purpose of the project or activity: e.g., rainfall increase, hail suppression, cold fog dispersal, etc.

Item 5. A map should be attached showing size and location of target area, control area, coded number and location of each item of ground-based weather modification apparatus and coded number and location of key raingages, radars, or other precipitation measuring devices. Also show location of airport for airborne operations.

Item 6. Describe the weather modification apparatus, modification agents, and the techniques to be used. This would include type of ground or airborne apparatus to be used, type of modification material to be dispensed, rate of dispensing material in grams per hour or other appropriate units, type of precipitation gages to be used in target and control areas, and any other pertinent information such as type of radars, type of aircraft to be used, techniques to be employed, (e.g., cloud base seeding at 10,000 feet msl).

Item 7. List name, affiliation, and address of the responsible individual from whom log books or other records may be obtained. Phone number should be included if possible.

Item 8. Provide applicable answers to questions as indicated.

Item 9. This item is to permit the reporting person to include any information not covered by items 1 through 8 but which he feels is significant or of interest. It is also to be used to include any information not covered elsewhere that the Administrator may request.

FORM APPROVED: O.M.B. NO. 41-R2664
APPROVAL EXPIRES 12-31-77

NOAA FORM 17-4A (11-72)

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NOAA FILE NUMBER

INTERIM ACTIVITY REPORTS AND FINAL REPORT

☐ INTERIM REPORT
☐ FINAL REPORT

Complete in accordance with instructions on reverse and forward one copy:

TO: Office of Environmental Modification
National Oceanic and Atmospheric Administration
Rockville, Maryland 20852

REPORTING PERIOD

FROM	TO

MONTH	(a) NUMBER OF MODIFICATION DAYS	(b) NUMBER OF MODIFICATION DAYS PER PHENOMENON				(c) NUMBER OF MODIFICATION MISSIONS	(d) HOURS OF APPARATUS OPERATION BY TYPE		(e) TYPE AND AMOUNT OF AGENT USED				
		CLOUDS			OTHER		AIR-BORNE	GROUND	SILVER IODIDE	CARBON DIOXIDE	UREA	SODIUM CHLORIDE	OTHER
		STRATIFORM	CUMULIFORM ISOLATED	CUMULIFORM ORGANIZED									
OCTOBER													
NOVEMBER													
DECEMBER													
JANUARY													
FEBRUARY													
MARCH													
APRIL													
MAY													
JUNE													
JULY													
AUGUST													
SEPTEMBER													
TOTAL													
TOTALS FOR FINAL REPORT													

DATE ON WHICH FINAL WEATHER MODIFICATION ACTIVITY OCCURRED *(For Final Report Only)*

CERTIFICATION: I certify that all statements in this report on this weather modification project are complete and correct to the best of my knowledge and are made in good faith.

NAME OF REPORTING PERSON			SIGNATURE
STREET ADDRESS			OFFICIAL TITLE
CITY	STATE	ZIP CODE	DATE

F-1

INSTRUCTIONS FOR INTERIM AND FINAL REPORTS

Any person engaged in any weather modification project or activity in the United States on October 1 in any year shall submit one copy of this form setting forth as of such date the information required with respect to each such continuing project or activity not previously furnished in a prior interim report. The box indicating "Interim Report" should be checked. The October 1 date shall not apply if other arrangements have previously been made with the written approval of the Administrator of NOAA. The report shall be received by NOAA not later than 90 days following the end of the reported period.

Upon completion of a project or activity one copy of this report shall be submitted and the box checked indicating "Final Report." The final report shall be received by NOAA not later than 90 days after the completion of the project or activity.

The NOAA File Number should be filled in for any project for which the Administrator has assigned a file number.

A supplemental report in letter form referring to the appropriate NOAA file number must be made to the Administrator if the "Interim" or "Final" reports are found to contain any material inaccuracies, misstatements, and omissions.

INTERIM REPORT

The information in Items (a) through (e) on the report form should be provided as prescribed below for the months to which the report pertains. If no data are applicable for any given item in any month, enter zero.

Item (a). Enter number of days on which actual weather modification activities took place.

Item (b). Enter in the appropriate column number of days on which modification activities were conducted, segregated by each of the predominant types of weather phenomena. Normally, the total of entries in (b) would equal total in (a).

Item (c). Enter number of modification missions that were carried out.

Item (d). Enter in the appropriate column total number of hours of operation of each type of weather modification apparatus, (i.e., net hours of agent release). If the form does not contain sufficient space, report additional types on a separate sheet.

Item (e). Enter in the appropriate column total amount of agent used, by type. If the form does not contain sufficient space, report additional types on a separate sheet.

The totals for these items shall be provided for the period covered by the interim report.

FINAL REPORT

The final report shall contain the information required for interim reports, to the extent not previously reported. In addition, the items designated as "Totals for Final Report" should be reported. This information should pertain to the entire project or activity period, rather than only the period since the last interim report. At the space at the end of the form, enter the date on which final weather modification activity occurred.

FORM APPROVED: O.M.B. NO. 41-R2664
APPROVAL EXPIRES 12-31-77

NOAA FORM 17-4B
(11-72)

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

DAILY LOG DURING WEATHER MODIFICATION ACTIVITIES

MONTH AND YEAR

NOAA FILE NUMBER

DESIGNATION OF APPARATUS

NAME OF OPERATOR

CAREFULLY READ INSTRUCTIONS ON REVERSE BEFORE ENTERING DATA ON FORM

DATE	POSITION OR LOCATION	LOCAL TIME			MODIFICATION AGENT			TYPE OF PHENOMENA MODIFIED			
								CLOUDS			OTHER (fog, etc.)
									CUMULIFORM		
1	2	START 3	STOP 4	TOTAL 5	TYPE 6	RATE 7	AMOUNT 8	STRATIFORM 9	ISOLATED 10	ORGANIZED 11	12
MONTHLY TOTAL											

INSTRUCTIONS FOR COMPLETING DAILY LOG FORM

DAILY LOG OF ACTIVITIES

This is a suggested form to be used in recording the information required to be kept by Section 908.8, Part 908 of Title 15, Code of Federal Regulations. Other logs may be used, providing they contain the information required. A tabular form is provided on which to report a daily log of activities for each unit of weather modification apparatus. The form is suitable for recording operation of individual items of ground or airborne apparatus. In the spaces provided above the columns, write the designation of the weather modification apparatus, coded to refer to the description required by Sections 908.8 (b) (1) and 908.8 (c). Part 908 of Title 15, Code of Federal Regulations, the month and year of daily record, the name of the operator, and the NOAA file number.

Explanation of columns follows:

Col. (1) State date of the weather modification activity.

Col. (2) Give each aircraft position or location of each item of weather modification apparatus during each modification mission. Maps may be used.

Col. (3) and (4) State local time when modification activity began and ended. Use 24-hour clock time (e.g., 0100 signifies 1:00 A.M. and 2300 signifies 11:00 P.M.). For intermittent operations, the start and end of the total sequence are acceptable.

Col. (5) Give duration of operation of each unit of weather modification apparatus, in hours and minutes. (Col. 5 = Col. 4 - Col. 3).

Col. (6) Describe type of modification agent used.

Col. (7) Give rate of dispersal of agent during the period of actual operation of weather modification apparatus, by hour or other appropriate time period.

Col. (8) Give total amount of modification agent used. If more than one agent was used, report total for each type separately.

Col. (9), (10), (11), & (12) Check once for each day on which modification activities were conducted, segregated by each of the predominant types of weather phenomena.

On the daily log sheet for the last day of each month, give monthly totals, for Columns (5), (8), (9), (10), (11), and (12).

INTERNATIONAL CONFERENCE ON WEATHER MODIFICATION

October 1-7, 1973

Tashkent, USSR

Highlights compiled by H. Weickmann

The Conference was subdivided into the following sessions:

Session 1 - Fog Dispersal

Session 2 - Rain Enhancement

Session 3 - Snowfall Enhancement

Session 4 - Hail Suppression

Session 5 - Other Aspects of Weather Modification

Session 6 - Technical and Operational Aspects of Weather Modification.

Session 7 - Physical, Statistical and Economic Evaluations of Weather Modification

Session 8 - Ice Nuclei Technology

In the following review of the Conference proceedings, we try to highlight some of the important facets of the discussions. The text contains information for personal notes taken during the Conference and the reader is requested to take into consideration that they may contain unavoidable errors due to language barriers and the difficulties of simultaneous translation. Also important contributions may be left out due to the author's occasional absences from the Conference.

SESSION ONE - FOG DISPERSAL

The review paper was given by L. Facy (France). He discussed the French system of warm fog dispersal with jet engines. Along the runway and buried underneath to the sides of the runway are horizontally installed jet engines whose exhaust is vented upwards. The system requires 600 liters of gas per hour for standby power per engine and 2,500 liters per hour for full power. Test results are encouraging.

Bakhanova and Silayev (USSR) discussed a method (originating with Derjaguin) of poisoning condensation nuclei with mono layers of surface active agents (SAA). Adsorptive layers of alcohol were used in connection with hygroscopic nuclei. Atmospheric tests were conducted at a cloud base temperature of 10C and the dispersal of 10 kg of cetyl alcohol per km^3.

It was observed that the drops growing on treated condensation nuclei did so at a 4 times slower rate than the drops without SAA layers. The authors believe that with this method fog formation can be prevented. At a cloud temperature of OC, 5.5 kg alcohol is needed per km^3 of which 2 kg are needed to form adsorptive layers and 3.5 kg to saturate the atmosphere. In the discussion, Dr. J. Warner (Australia) called attention to the possibility that when applied in nature, cooling due to the evaporating alcohol may perhaps cause an even more dense fog than without alcohol.

Smith and Latham (United Kingdom) discussed the possibility of fog dispersal by electrical forces where monodispersed droplets are passed through an ion gun and become very highly charged so that the coalescence efficiency with cloud droplets becomes increased. They found an extremely high collection efficiency. In a typical experiment when the collecting drop radius is about 130 μ and the cloud droplets 20 μ and at a liquid water content of 2.5 gm/m^3 each collecting droplet collected about 150 cloud droplets during descent through the cloud. The corresponding effective collection efficiency is about 7.

Derjaguin et. al., (USSR) discussed further experiments with cetyl alcohol and higher orders of alcohol C_{17} to C_{23} as a means of preventing condensation on hygroscopic nuclei during the formation of radiation fogs. In all experimental cases, thin layers of radiation fog up to 10 m did not form in areas where the poisoned nuclei were present. In the case of thicker fog layers, a considerable reduction in density was observed within the treatment zone. Additional research was reported on fog dispersal with hygroscopic substances. Numerical simulation of the processes involved showed that the most efficient mean diameter of the hygroscopic droplet material is within the range of 10-20 μ. The most efficient approach appeared to be through the use of multi-component hygroscopic substances rather than that of a single hygroscopic reagent.

Krasnovskaya et. al., (USSR) reported on the use of propane for the dispersal of supercooled fogs near and even at temperatures slightly above 0^oC. Propane reacts with water to form clathrate compounds whose equilibrium water vapor pressure is lower than saturation relative to water or ice at temperatures between -3C and OC. Presently, the action of these agents is under study.

SESSION TWO - RAIN ENHANCEMENT

The review paper by J. Warner (Australia) on rain augmentation was a very down-to-earth appraisal on where we stand now in this endeavor. The author gave a definition of unconvincing and good experiments. Under unconvincing experiments he mentioned among some Australian experiments the Indian salt seeding experiment in which a large rain increase had been analyzed based upon a very high significance level. The unconvincing part of the experiment was the physical design which could not produce the rainfall analyzed even if each artificial NaCl nucleus had entered the cloud and produced the rain drop. The author also mentioned a number of other experiments as well. He found only three convincing rain making experi-

ments: 1) the CLIMAX experiments, 2) the Israeli experiments, and 3) the Tasmanian experiments. He mentioned five criteria which must be fulfilled for a good experiment: 1) good statistical design and analysis, 2) long term continuity, 3) universality of cloud characteristics, 4) clouds susceptible to seeding techniques, and 5) background knowledge on microphysics and dynamics of clouds. The author also was of the opinion that the poor experiments have brought cloud seeding into ill repute. In the discussion, Dr. Hobbs and the undersigned took issue on the emphasis placed on statistics. The statistical approach is valuable only in the presence of a good physical concept, while in the presence of a poor physical concept even the best statistical approach will not make it a better experiment.

Furman et. al., (USSR) disucssed results of convective cloud seeding in the Ukraine. In the summer of 1972 field experiments with cumulonimbus clouds were performed over the meteorological polygon in the vicinity of Krivoi Rog. Seeding was carried out by means of an airborne generator of AgI at the cloud base and at the updraft area. The rainfall from each cloud was measured by means of the rain gage meters of the polygon while other cloud parameters were measured with a weather radar. The analysis was done with a target control area designed and the computation of a multi-variate regression of rainfall. Seventeen clouds were seeded in the summer of 1972. The average rainfall was double the value computed by the regression line equation.

Serpolay and Andro (France) discussed the possibility of decreasing high humidity atmospheric layers by salt seeding. Drizzle rains which were quite similar to those falling from cloudy layers have been initiated.

Gagin (Israel) discussed the precipitation mechanism in the cloud systems which produce additional rain after seeding. He did not find any type of ice crystal multiplication. Cloud drops with temperatures warmer than -14C have ice crystal concentrations which are always lower than one per liter. Clouds that are warmer than -10C did not have any detectable concentration of ice crystals. About 35% of the total number of clouds on a rainy day had radar echo top temperatures of about -14C or warmer. These findings seem to confirm the physical basis for the statistically significant results of the Israel rain making project.

SESSION THREE - SNOWFALL ENHANCEMENT

The review paper was given by the undersigned. It was shown that in any precipitation systems, nature furnishes between 5-40 crystals per liter which means indeed that any artificial crystal number smaller than this concentration is likely to give no additional precipitation. Problems of targeting the artificial snowfall of diffusion of the seeding material through the clouds under conditions of wind shear and the physical background of seeding have been discussed. The structure of winter cloud systems and their seeding potential is being deduced.

Leskov (USSR) discussed seeding experiments of frontal clouds in winter. Between 1960 and 1972, 77 experiments were carried out. Sixty-one

precipitating nimbostratus-altostratus systems were seeded, of which in 16 cases precipitation was stimulated. The target area was 3/4 hours downwind (30-40 km) from the seeding area. The main relative increase of precipitation was about 100%. It appears that no dedistribution of precipitation took place. The seeding effects could be observed two to three hours downwind from the seeding line. During the operations a series of physical measurements were carried out. Crystal concentration in nimbostratus and altostratus were artificially increased to concentrations of 1-100 per cc. It is possible that interpretation errors during the simulation translation may have entered into these numbers. The seeding rate was 700 grams of dry ice per km or about 1 kg per km^3. The efficiency was 3×10^{13} per gram at -8 to 10C or 3×10^{16} per km^3 which is 30 per cc. In general, the crystal concentrations in his experiments were somewhere between 1 and 100 per cc. He estimates that precipitation during the cold winter period can be increased by 30 to 35% over areas of 1000-2000 km^2.

Ramachandra Murty et. al. (India) reported on ground based cloud seeding experiments using AgI at Delhi during winter. The experiment has been in progress since 1968 using the dense rain gage network in the environment of Delhi. The amount of AgI vaporized per day varied from 1 to 1.5 kg. Results from the first four years of the planned 5-year program suggest a net increase of 52% in rainfall in the target sector. This increase is not statistically significant.

Hobbs and Radke (USA) discussed the artificial modification of clouds and precipitation in the mountainous region and showed that under certain conditions the orographic clouds can be over seeded so that the precipitation can be lifted across mountain ranges. Case studies were represented.

Jiusto (USA) discussed the microphysical mechanisms of snowfall and showed the significance in connection with snow storm modeling of the Great Lakes, as well as snowfall targeting and hail suppression. A new large scale weather modification project -- the pyramid polot cloud seeding project in Nevada -- was discussed by Warburton, USA. It is planned for a three-year duration with randomized seeding using remotely controlled airborne AgI generators. The terrain is mountainous and the analysis of seeding effects relies heavily on the observations with an x-band radar system incorporating real time digital processing.

SESSION FOUR - HAIL SUPPRESSION

The review paper on hail suppression was by Burtsev, Gaivoronsky and Kartsivadze (USSR). The paper was presented by Burtsev who gave an excellent up-to-date review of our knowledge and understanding of hailstorms, and their precipitation mechanism. The review included the accomplishments of the USSR hail suppression projects. He mentioned that at the present time, 3,770,000 hectares are under protection and that over this area hail fall was diminished by a factor of 3 to 4.

Admirat (France) presented a very interesting paper on the structure of hail precipitation. On one location within the hailstreak, he made

very interesting observations with respect to the number-diameter relationship of hailstones. Essentially two types were observed:
1. The study of this relationship from one stage to another indicated that the total number of hailstones per m^2 and the maximum diameter would grow at the same time. 2. When observed at the same location the number of hailstones of a given diameter is in inverse relation to this diameter. This observation suggests that seeding may even increase the hail fall in some cases.

Zaitchenko et. al. (USSR) reported on additional observations of the hail process and the results of hail suppression activities in Moldavia. The authors studied particularly temperature, humidity, and wind conditions in the atmosphere for cases in which hailstorms developed. A relationship between the intensity of hailstorms and the rate of horizontal air flow in the upper cloud level was observed. For this analysis four radar stations 250 km apart were used. Presently 400,000 hectares are being protected in the Moldavian SSR. The average of statistical data since 1966 using two controlled areas and one target area indicates a reduction in damage by a factor of 10 to 30.

Bartishvili et. al. (USSR) discussed the hail suppression activities of the Trans-caucasian Hydrometeorological Institute and the efforts of this institute. Two seeding agents are being used -- NaCl, 1.89 gm; AgI, 0.29 gm. The total consumption for the protection of 2,500,000 hectares was consequencly NaCl, 370.12 kilograms, and AgI, 58.42 kilograms; throughout the past 5 years the method of using a mixed seeding agent was reliable and efficient.

Kachurin et. al. (USSR) discussed a numerical model of cumulonimbus clouds. The significance of this paper can be fully assessed only after the publication of the proceedings. In Kachurin's model, the hail cloud is defined by 6 to 8 parameters and the variability of these parameters for natural and seeded conditions has been investigated. The height of the cloud top, vertical updraft velocities, rate of maximum radar reflectivity as well as size and concentration of hailstones were in satisfactory agreement with the values of these parameters measured in natural conditions. The paper stimulated lively discussions from the floor. It's publication must be awaited with great interest.

SESSION FIVE - OTHER ASPECTS OF WEATHER MODIFICATION

Gentry (USA) presented a review paper on the experimental program to modify hurricanes. The review paper discussed hurricane dynamics observed and derived from numerical modeling and reviewed the various approaches of hurricane modification. The rationale for seeding the wall clouds as well as radial cloud bands was discussed along with future plans of the experiments.

The use of artificial jets for convective cloud modification was discussed by Vulfson and Levin (USSR). Following the idea of Dessen's "meteotron," a modern "meteotron" was constructed using 12 jet engines which

generate updraft velocities of 350 m/sec and an air temperature of 45OC for a total of 500,000 kw. Field experimentation was carried out from 1967-1969 in the Ukraine. Results indicate that for condensation levels at about 1000 m above the ground precipitating clouds were generated. Cumulonimbus developed only under conditions where cumulonimbus clouds form naturally. But the jets allowed the formation of such clouds over a certain site. The present plans call for a new design using six jet engines in a star-like arrangement whose exhaust is directed towards the center and upward. This arrangement will yield 600 m/sec updraft and a temperature of 110OC. The first experiments are planned to be conducted in 1974. Convective clouds were dissipated through the generation of downdrafts by the use of dust discharged into the clouds such as Portland cement. Another method was to explode shells in the upper cloud parts. Between 1961 and 1965 more than 100 experiments were conducted to generate downward directed jets in clouds. The methods were essentially four different ones:

1. By flying an aircraft through the cloud,
2. By releasing dust or water,
3. By a jet aircraft climbing vertically in the cloud, and
4. By explosives.

Both types of clouds - warm or supercolled- were modified. The clouds were 5-6 km deep; in general shallow as well as deep clouds were destroyed likewise. In the discussion, Soulage pointed out that the French experience with the meteotron resulted in essentially little precipitation. Bibilashvili suggested that cloud dissipation by exploding shells may not be a direct shock wave effect, but that downward motion could be stimulated by the debris of the shells or by the possibility that the explosion creates artificial nuclei. It appears that a strict randomization of these experiments would be a primary requirement for providing confidence in the results.

An interesting discussion was given by Artsybashev et. al. (USSR) on the result of extinguishing forest fires through artificial precipitation. The method applied makes use of redistributing the natural precipitation to occur over forest fires. Convective clouds were seeded from an aircraft using pyrotechnic cartridges. The research was accomplished by the Main Geophysical Observatory and the Research Institute of Forestry. During the period 1970 to 1972, 121 forest fires were extinguished over a total area of about 80,000 hectares in the territories of Khabarovsk and Yakut, and the Irkutsk regions. Scanning IR radiometers are used to survey the fires. By method of targeting the precipitation extinguished 77% of the forest fires. In the discussion that followed, Elizabeth Scott mentioned that lack of statistical control and the possibility that new thunderstorms develop due to the seeding which may generate more lightning. Goldsmith mentioned that generally 10% increase of rainfall is being caused after seeding, which may be insufficient to affect the fires, and he mentioned the possibility that the fire itself may change the atmosphere more than would be accomplished by the AgI seeding. He, therefore, agreed with Scott for the need of strict statistical control. Kornienko mentioned that seedable convective clouds gave three times more rain and that indeed even weak precipitation will extinguish a forest fire.

Gaivoronsky, et. al. (USSR) reported on 12 randomized experiments in Moldavia with intensive AgI seeding of thunderstorms. The seeding agent was injected using the Oblako rocket along an 8 km path. The results indicated that clouds with tops warmer than -30C did grow after seeding and clouds with tops colder than -30C did not grow. The lightning frequency was also studied for these thunderstorms. The normal lightning frequency measured with lightning detectors was 3.8 to 4 lightning strokes per minute. The detectors were sensitive in the frequency band of 52-62 kilocycles and had a useful range of 21 km. For lightning suppression the cloud was seeded with 6-18 kg of cement and in three typical experiments lightning frequencies per minute were as follows:

1) before seeding - .8; after seeding - .4
2) before seeding - 2.5; after seeding - 1.4
3) before seeding - 3.0; after seeding - 0.1

On the average the reduction of lightning frequencies was by a factor of 2.5. Thunderstorm centers were treated with up to 30 kg of cement. Air mass thunderstorms dissipated on the average in 15 minutes after the seeding.

Khorguany (USSR) reported on laboratory experiments conducted on the effect of releasing 10 lbs of cement powder from balloons at an elevation of 50-160 meters. It was observed that the powder generated a general downdraft on the order of 10 m/sec which was a higher velocity than an individual particle would assume. A lively discussion arose on the physical mechanism of cloud dissipation by the relatively small amounts of cement dust applied. At the request from the floor, Dr. Seregin reiterated the results of the experiments: A few hundred experiments had been conducted with clouds more than 9 km thick which also included clusters of storm clouds. Result with the smaller clouds: Under unstable lapse rate conditions seeding experiments with more than 10 kg per cloud core were always successful. Seeding of air mass thunderstorms resulted in the dissipation of 80%. Frontal clouds made up 17 cases out of the 60 and most of the 17 were unsuccessful.

Djachuk (USSR) spoke about the possibility of lightning suppression by stimulating corona discharge from small ice crystals which according to the author exist in the tops of cumulonimbus clouds in form of needles and plane crystals. It was observed that in fields of one to two thousand volts per cm these particles are turning from a horizontal to a vertical position. The critical electric field strengths for reorientation is a function of their sizes. It was suggested that corona discharge generated on the long ice particles after their reorientation will trigger the lightning discharge.

Kasemir (USA) reported on his experiments related to the initiation of corona discharge for lightning suppression using metallized chaff fibers. At a field strength of about 60,000 volts per meter, a corona current of about 1 microampere is generated at the ends of each fiber. If 2 million fibers are seeded in a thunderstorm, they should be able to discharge a current of about 2 amperes which is compatible with the charge generation

of an average thunderstorm. He reported on field experiments which were carried out in Boulder, Colorado, in 1972 and which indicated that the electric field measured near the cloud vase of a thunderstorm decays faster by a factor of about 5-6 after chaff has been released, if compared to the natural decay of the field in an unseeded storm.

Sax (USA) reported on the field activities of the 1973 phase of the Florida area cumulus experiments. The experiments involved the coordination of surface, radar, and aircraft measurements including the measurement of raindrop size distribution, of aerosol and rain water collection for silver analysis and of randomized seeding. Results were as yet not available.

SESSION 8 - ICE NUCLEATION TECHNOLOGY

A method for the production of pure AgI by evaporating pure silver and exposing it to Iodine vapor was discussed by Poc and Roulleau (France).

P. A. Allee (USA) discussed the instrumentation of an ice nuclei network consisting of 19 stations spread over the western USA. The instrumentation makes use of the millipore filter method. The sampling equipment is installed at the measuring stations and a timer governs the sampling period such that 5 minutes out of each hour are being sampled. After 24 hours the filter is replaced and the exposed filter is mailed to the central analysis location. The first results were discussed. They indicated an increase of nuclei concentrations from the Pacific coastline toward the central USA. From this increase a production rate of 2 ice nuclei per minute and m^2 surface area can be derived.

An interesting paper on the scavenging of tracer substances by convective clouds was given by A. N. Dingle (USA). Trace substances which were placed from an aircraft into the updraft below and in front of the convective system were found at distances of some 50 km from the location of release. The paper was received with great interest.

Fukuta (USA) discussed the technology of ice nuclei generators and Hicks and Vali (USA) gave results of seeding with propane spray at the base of the outdoor laboratory on the Elk Mountain in Wyoming. Crystal habits and crystal growth rates were studied 200 meters downwind of the release point.

A few final remarks: The spirit of the conference was highly motivated and produced a good understanding of the approach to the problem of weather modification which is used in various countries. Generally one can say that the approach in the Soviet Union is physical rather than statistical, while in the USA the approach is more strongly governed by statistical controls. One may say that what is sometimes exaggerated with strict statistical control in one country is being underestimated in the other country. Lively discussions concerned with the differences of approach highlighted the conference repeatedly and produced a healthy cross fertilization of ideas. This type of cross fertilization is the

invaluable net gain of such conferences.

In the concluding conference session the motion was accepted to make these conferences a regular international endeavor. The second conference, again jointly sponsored by WMO and IAMAP, is planned for 1976 in Boulder, Colorado, in close coordination with the IAMAP International Conference on Cloud Physics, which is planned for the same year in the same location.

LIST OF CONTRIBUTIONS DISCUSSED ABOVE:

Dispersal of fog. L. Facy

On a method of fog modification by the passivation of condensation nuclei. R. A. Bakhanova and A. V. Silayev

The dispersal of fogs by electrical forces. M. H. Smith and J. Latham

Problems of preventing the formation of radiation fogs. Dissipation of warm fogs. B. V. Derjaguin, I. N. Grigorenko, V. A. Ershov, I. A. Zolotarev, Yu. S. Kurgin, L. F. Leonov, B. A. Malikov, P. S. Prokhorov. V. A. Fedoseev, E. I. Shaglij, V. A. Shustov, S. B. Kudritskij.

Some data on the dissipation mechanisms of supercooled fogs by propane gas. L. I. Krasnovskaya, T. I. Shevaldina and A. N. Khijnyak

Rain Augmentation. J. Warner

Results of seeding cumulonimbus clouds aimed regulating precipitation in the Ukraine. A. I. Furman, S. B. Husid, E. E. Kornienko, I. A. Kurejko and F. Ya. Voit

Salt drizzles extracted from under-saturated air layers by seeding with hygroscopic nuclei. R. Serpolay and M. Andro

Quick inducement of precipitation by seeding layers of stratified air. R. Serpolay and M. Andro

The role of solid precipitation elements in natural and artificial production of rain in Israel. A. Gagin

Snowfall enhancement. H. Weickmann

Experimental seeding of frontal clouds in winter to stimulate precipitation. B. N. Leskov

Ground-based cloud seeding experiment at Delhi during winter. R. K. Kapoor, R. N. Chatterjee, K. K. Kanuga, S. K. Paul and Bh. V. Ramana Murty

The artificial modification of clouds and precipitation in a mountainous region. P. V. Hobbs and L. F. Radke

Seeding requirements for rapid glaciation or stimulation of a mixed-phase cloud. J. E. Jiusto

The Pyramid pilot cloud-seeding project. J. A. Warburton

Recent advances in studies of the physical processes producing hail, and results of anti-hail operations in the USSR. I. I. Burtsev, I. I. Gaivoronsky, and A. I. Kartsivadze

Natural "hailcores" and their abilities to estimate the efficiency of the hail prevention system. P. Admirat

Hail process investigation and results of hail protection measures in Moldavia. N. M. Zaitchenko, I. I. Gaivoronsky and L. A. Kinevitch

Results of operations over the five years 1969-1973 to protect agricultural crops from hail damage applied by the Transcaucasian Hydrometeorological Institute. V. P. Lominadze, I. T. Bartishvili and Sh. Gudushauri.

A model of natural hailstone growth process and its transformation under the influence of artificial crystallization. L. G. Kachurin, A. I. Kartsivadze, P. I. Makharashvili, C. Stojanov, M. Tecle

The experimental programme to modify hurricanes. R. C. Gentry

Dynamic methods of convective cloud modification by means of artificial vertical jets. N. I. Vulfson and L. M. Levin

The results of experimental work on extinguishing forest fires with artificial precipitation. E. S. Artsybashev, P. A. Gubin, A. I. Sidorov, Yu. P. Simin and N. S. Shishkin

Convective cloud modification to reduce thunderstorm activity. I. I. Gaivoronsky, L. P. Zatsepine and B. I. Zimin

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INTERNATIONAL CONFERENCE ON WEATHER MODIFICATION

October 1-7, 1973

Tashkent, USSR

Highlights compiled by H. Weickmann

The Conference was subdivided into the following sessions:

Session 1 - Fog Dispersal

Session 2 - Rain Enhancement

Session 3 - Snowfall Enhancement

Session 4 - Hail Suppression

Session 5 - Other Aspects of Weather Modification

Session 6 - Technical and Operational Aspects of Weather Modification.

Session 7 - Physical, Statistical and Economic Evaluations of Weather Modification

Session 8 - Ice Nuclei Technology

In the following review of the Conference proceedings, we try to highlight some of the important facets of the discussions. The text contains information for personal notes taken during the Conference and the reader is requested to take into consideration that they may contain unavoidable errors due to language barriers and the difficulties of simultaneous translation. Also important contributions may be left out due to the author's occasional absences from the Conference.

SESSION ONE - FOG DISPERSAL

The review paper was given by L. Facy (France). He discussed the French system of warm fog dispersal with jet engines. Along the runway and buried underneath to the sides of the runway are horizontally installed jet engines whose exhaust is vented upwards. The system requires 600 liters of gas per hour for standby power per engine and 2,500 liters per hour for full power. Test results are encouraging.

Bakhanova and Silayev (USSR) discussed a method (originating with Derjaguin) of poisoning condensation nuclei with mono layers of surface active agents (SAA). Adsorptive layers of alcohol were used in connection with hygroscopic nuclei. Atmospheric tests were conducted at a cloud base temperature of 10C and the dispersal of 10 kg of cetyl alcohol per km^3.

It was observed that the drops growing on treated condensation nuclei did so at a 4 times slower rate than the drops without SAA layers. The authors believe that with this method fog formation can be prevented. At a cloud temperature of OC, 5.5 kg alcohol is needed per km^3 of which 2 kg are needed to form adsorptive layers and 3.5 kg to saturate the atmosphere. In the discussion, Dr. J. Warner (Australia) called attention to the possibility that when applied in nature, cooling due to the evaporating alcohol may perhaps cause an even more dense fog than without alcohol.

Smith and Latham (United Kingdom) discussed the possibility of fog dispersal by electrical forces where monodispersed droplets are passed through an ion gun and become very highly charged so that the coalescence efficiency with cloud droplets becomes increased. They found an extremely high collection efficiency. In a typical experiment when the collecting drop radius is about 130 μ and the cloud droplets 20 μ and at a liquid water content of 2.5 gm/m^3 each collecting droplet collected about 150 cloud droplets during descent through the cloud. The corresponding effective collection efficiency is about 7.

Derjaguin et. al., (USSR) discussed further experiments with cetyl alcohol and higher orders of alcohol C_{17} to C_{23} as a means of preventing condensation on hygroscopic nuclei during the formation of radiation fogs. In all experimental cases, thin layers of radiation fog up to 10 m did not form in areas where the poisoned nuclei were present. In the case of thicker fog layers, a considerable reduction in density was observed within the treatment zone. Additional research was reported on fog dispersal with hygroscopic substances. Numerical simulation of the processes involved showed that the most efficient mean diameter of the hygroscopic droplet material is within the range of 10-20 μ. The most efficient approach appeared to be through the use of multi-component hygroscopic substances rather than that of a single hygroscopic reagent.

Krasnovskaya et. al., (USSR) reported on the use of propane for the dispersal of supercooled fogs near and even at temperatures slightly above 0^oC. Propane reacts with water to form clathrate compounds whose equilibrium water vapor pressure is lower than saturation relative to water or ice at temperatures between -3C and OC. Presently, the action of these agents is under study.

SESSION TWO - RAIN ENHANCEMENT

The review paper by J. Warner (Australia) on rain augmentation was a very down-to-earth appraisal on where we stand now in this endeavor. The author gave a definition of unconvincing and good experiments. Under unconvincing experiments he mentioned among some Australian experiments the Indian salt seeding experiment in which a large rain increase had been analyzed based upon a very high significance level. The unconvincing part of the experiment was the physical design which could not produce the rainfall analyzed even if each artificial NaCl nucleus had entered the cloud and produced the rain drop. The author also mentioned a number of other experiments as well. He found only three convincing rain making experi-

ments: 1) the CLIMAX experiments, 2) the Israeli experiments, and 3) the Tasmanian experiments. He mentioned five criteria which must be fulfilled for a good experiment: 1) good statistical design and analysis, 2) long term continuity, 3) universality of cloud characteristics, 4) clouds susceptible to seeding techniques, and 5) background knowledge on microphysics and dynamics of clouds. The author also was of the opinion that the poor experiments have brought cloud seeding into ill repute. In the discussion, Dr. Hobbs and the undersigned took issue on the emphasis placed on statistics. The statistical approach is valuable only in the presence of a good physical concept, while in the presence of a poor physical concept even the best statistical approach will not make it a better experiment.

Furman et. al., (USSR) disucssed results of convective cloud seeding in the Ukraine. In the summer of 1972 field experiments with cumulonimbus clouds were performed over the meteorological polygon in the vicinity of Krivoi Rog. Seeding was carried out by means of an airborne generator of AgI at the cloud base and at the updraft area. The rainfall from each cloud was measured by means of the rain gage meters of the polygon while other cloud parameters were measured with a weather radar. The analysis was done with a target control area designed and the computation of a multi-variate regression of rainfall. Seventeen clouds were seeded in the summer of 1972. The average rainfall was double the value computed by the regression line equation.

Serpolay and Andro (France) discussed the possibility of decreasing high humidity atmospheric layers by salt seeding. Drizzle rains which were quite similar to those falling from cloudy layers have been initiated.

Gagin (Israel) discussed the precipitation mechanism in the cloud systems which produce additional rain after seeding. He did not find any type of ice crystal multiplication. Cloud drops with temperatures warmer than -14C have ice crystal concentrations which are always lower than one per liter. Clouds that are warmer than -10C did not have any detectable concentration of ice crystals. About 35% of the total number of clouds on a rainy day had radar echo top temperatures of about -14C or warmer. These findings seem to confirm the physical basis for the statistically significant results of the Israel rain making project.

SESSION THREE - SNOWFALL ENHANCEMENT

The review paper was given by the undersigned. It was shown that in any precipitation systems, nature furnishes between 5-40 crystals per liter which means indeed that any artificial crystal number smaller than this concentration is likely to give no additional precipitation. Problems of targeting the artificial snowfall of diffusion of the seeding material through the clouds under conditions of wind shear and the physical background of seeding have been discussed. The structure of winter cloud systems and their seeding potential is being deduced.

Leskov (USSR) discussed seeding experiments of frontal clouds in winter. Between 1960 and 1972, 77 experiments were carried out. Sixty-one

precipitating nimbostratus-altostratus systems were seeded, of which in 16 cases precipitation was stimulated. The target area was 3/4 hours downwind (30-40 km) from the seeding area. The main relative increase of precipitation was about 100%. It appears that no dedistribution of precipitation took place. The seeding effects could be observed two to three hours downwind from the seeding line. During the operations a series of physical measurements were carried out. Crystal concentration in nimbostratus and altostratus were artificially increased to concentrations of 1-100 per cc. It is possible that interpretation errors during the simulation translation may have entered into these numbers. The seeding rate was 700 grams of dry ice per km or about 1 kg per km^3. The efficiency was 3×10^{13} per gram at -8 to 10C or 3×10^{16} per km^3 which is 30 per cc. In general, the crystal concentrations in his experiments were somewhere between 1 and 100 per cc. He estimates that precipitation during the cold winter period can be increased by 30 to 35% over areas of 1000-2000 km^2.

Ramachandra Murty et. al. (India) reported on ground based cloud seeding experiments using AgI at Delhi during winter. The experiment has been in progress since 1968 using the dense rain gage network in the environment of Delhi. The amount of AgI vaporized per day varied from 1 to 1.5 kg. Results from the first four years of the planned 5-year program suggest a net increase of 52% in rainfall in the target sector. This increase is not statistically significant.

Hobbs and Radke (USA) discussed the artificial modification of clouds and precipitation in the mountainous region and showed that under certain conditions the orographic clouds can be over seeded so that the precipitation can be lifted across mountain ranges. Case studies were represented.

Jiusto (USA) discussed the microphysical mechanisms of snowfall and showed the significance in connection with snow storm modeling of the Great Lakes, as well as snowfall targeting and hail suppression. A new large scale weather modification project -- the pyramid polot cloud seeding project in Nevada -- was discussed by Warburton, USA. It is planned for a three-year duration with randomized seeding using remotely controlled airborne AgI generators. The terrain is mountainous and the analysis of seeding effects relies heavily on the observations with an x-band radar system incorporating real time digital processing.

SESSION FOUR - HAIL SUPPRESSION

The review paper on hail suppression was by Burtsev, Gaivoronsky and Kartsivadze (USSR). The paper was presented by Burtsev who gave an excellent up-to-date review of our knowledge and understanding of hailstorms, and their precipitation mechanism. The review included the accomplishments of the USSR hail suppression projects. He mentioned that at the present time, 3,770,000 hectares are under protection and that over this area hail fall was diminished by a factor of 3 to 4.

Admirat (France) presented a very interesting paper on the structure of hail precipitation. On one location within the hailstreak, he made

very interesting observations with respect to the number-diameter relationship of hailstones. Essentially two types were observed:
1. The study of this relationship from one stage to another indicated that the total number of hailstones per m^2 and the maximum diameter would grow at the same time. 2. When observed at the same location the number of hailstones of a given diameter is in inverse relation to this diameter. This observation suggests that seeding may even increase the hail fall in some cases.

Zaitchenko et. al. (USSR) reported on additional observations of the hail process and the results of hail suppression activities in Moldavia. The authors studied particularly temperature, humidity, and wind conditions in the atmosphere for cases in which hailstorms developed. A relationship between the intensity of hailstorms and the rate of horizontal air flow in the upper cloud level was observed. For this analysis four radar stations 250 km apart were used. Presently 400,000 hectares are being protected in the Moldavian SSR. The average of statistical data since 1966 using two controlled areas and one target area indicates a reduction in damage by a factor of 10 to 30.

Bartishvili et. al. (USSR) discussed the hail suppression activities of the Trans-caucasian Hydrometeorological Institute and the efforts of this institute. Two seeding agents are being used -- NaCl, 1.89 gm; AgI, 0.29 gm. The total consumption for the protection of 2,500,000 hectares was consequencly NaCl, 370.12 kilograms, and AgI, 58.42 kilograms; throughout the past 5 years the method of using a mixed seeding agent was reliable and efficient.

Kachurin et. al. (USSR) discussed a numerical model of cumulonimbus clouds. The significance of this paper can be fully assessed only after the publication of the proceedings. In Kachurin's model, the hail cloud is defined by 6 to 8 parameters and the variability of these parameters for natural and seeded conditions has been investigated. The height of the cloud top, vertical updraft velocities, rate of maximum radar reflectivity as well as size and concentration of hailstones were in satisfactory agreement with the values of these parameters measured in natural conditions. The paper stimulated lively discussions from the floor. It's publication must be awaited with great interest.

SESSION FIVE - OTHER ASPECTS OF WEATHER MODIFICATION

Gentry (USA) presented a review paper on the experimental program to modify hurricanes. The review paper discussed hurricane dynamics observed and derived from numerical modeling and reviewed the various approaches of hurricane modification. The rationale for seeding the wall clouds as well as radial cloud bands was discussed along with future plans of the experiments.

The use of artificial jets for convective cloud modification was discussed by Vulfson and Levin (USSR). Following the idea of Dessen's "meteotron," a modern "meteotron" was constructed using 12 jet engines which

generate updraft velocities of 350 m/sec and an air temperature of 45OC for a total of 500,000 kw. Field experimentation was carried out from 1967-1969 in the Ukraine. Results indicate that for condensation levels at about 1000 m above the ground precipitating clouds were generated. Cumulonimbus developed only under conditions where cumulonimbus clouds form naturally. But the jets allowed the formation of such clouds over a certain site. The present plans call for a new design using six jet engines in a star-like arrangement whose exhaust is directed towards the center and upward. This arrangement will yield 600 m/sec updraft and a temperature of 110OC. The first experiments are planned to be conducted in 1974. Convective clouds were dissipated through the generation of downdrafts by the use of dust discharged into the clouds such as Portland cement. Another method was to explode shells in the upper cloud parts. Between 1961 and 1965 more than 100 experiments were conducted to generate downward directed jets in clouds. The methods were essentially four different ones:

1. By flying an aircraft through the cloud,
2. By releasing dust or water,
3. By a jet aircraft climbing vertically in the cloud, and
4. By explosives.

Both types of clouds - warm or supercolled- were modified. The clouds were 5-6 km deep; in general shallow as well as deep clouds were destroyed likewise. In the discussion, Soulage pointed out that the French experience with the meteotron resulted in essentially little precipitation. Bibilashvili suggested that cloud dissipation by exploding shells may not be a direct shock wave effect, but that downward motion could be stimulated by the debris of the shells or by the possibility that the explosion creates artificial nuclei. It appears that a strict randomization of these experiments would be a primary requirement for providing confidence in the results.

An interesting discussion was given by Artsybashev et. al. (USSR) on the result of extinguishing forest fires through artificial precipitation. The method applied makes use of redistributing the natural precipitation to occur over forest fires. Convective clouds were seeded from an aircraft using pyrotechnic cartridges. The research was accomplished by the Main Geophysical Observatory and the Research Institute of Forestry. During the period 1970 to 1972, 121 forest fires were extinguished over a total area of about 80,000 hectares in the territories of Khabarovsk and Yakut, and the Irkutsk regions. Scanning IR radiometers are used to survey the fires. By method of targeting the precipitation extinguished 77% of the forest fires. In the discussion that followed, Elizabeth Scott mentioned that lack of statistical control and the possibility that new thunderstorms develop due to the seeding which may generate more lightning. Goldsmith mentioned that generally 10% increase of rainfall is being caused after seeding, which may be insufficient to affect the fires, and he mentioned the possibility that the fire itself may change the atmosphere more than would be accomplished by the AgI seeding. He, therefore, agreed with Scott for the need of strict statistical control. Kornienko mentioned that seedable convective clouds gave three times more rain and that indeed even weak precipitation will extinguish a forest fire.

Gaivoronsky, et. al. (USSR) reported on 12 randomized experiments in Moldavia with intensive AgI seeding of thunderstorms. The seeding agent was injected using the Oblako rocket along an 8 km path. The results indicated that clouds with tops warmer than -30C did grow after seeding and clouds with tops colder than -30C did not grow. The lightning frequency was also studied for these thunderstorms. The normal lightning frequency measured with lightning detectors was 3.8 to 4 lightning strokes per minute. The detectors were sensitive in the frequency band of 52-62 kilocycles and had a useful range of 21 km. For lightning suppression the cloud was seeded with 6-18 kg of cement and in three typical experiments lightning frequencies per minute were as follows:

1) before seeding - .8; after seeding - .4
2) before seeding - 2.5; after seeding - 1.4
3) before seeding - 3.0; after seeding - 0.1

On the average the reduction of lightning frequencies was by a factor of 2.5. Thunderstorm centers were treated with up to 30 kg of cement. Air mass thunderstorms dissipated on the average in 15 minutes after the seeding.

Khorguany (USSR) reported on laboratory experiments conducted on the effect of releasing 10 lbs of cement powder from balloons at an elevation of 50-160 meters. It was observed that the powder generated a general downdraft on the order of 10 m/sec which was a higher velocity than an individual particle would assume. A lively discussion arose on the physical mechanism of cloud dissipation by the relatively small amounts of cement dust applied. At the request from the floor, Dr. Seregin reiterated the results of the experiments: A few hundred experiments had been conducted with clouds more than 9 km thick which also included clusters of storm clouds. Result with the smaller clouds: Under unstable lapse rate conditions seeding experiments with more than 10 kg per cloud core were always successful. Seeding of air mass thunderstorms resulted in the dissipation of 80%. Frontal clouds made up 17 cases out of the 60 and most of the 17 were unsuccessful.

Djachuk (USSR) spoke about the possibility of lightning suppression by stimulating corona discharge from small ice crystals which according to the author exist in the tops of cumulonimbus clouds in form of needles and plane crystals. It was observed that in fields of one to two thousand volts per cm these particles are turning from a horizontal to a vertical position. The critical electric field strengths for reorientation is a function of their sizes. It was suggested that corona discharge generated on the long ice particles after their reorientation will trigger the lightning discharge.

Kasemir (USA) reported on his experiments related to the initiation of corona discharge for lightning suppression using metallized chaff fibers. At a field strength of about 60,000 volts per meter, a corona current of about 1 microampere is generated at the ends of each fiber. If 2 million fibers are seeded in a thunderstorm, they should be able to discharge a current of about 2 amperes which is compatible with the charge generation

of an average thunderstorm. He reported on field experiments which were carried out in Boulder, Colorado, in 1972 and which indicated that the electric field measured near the cloud vase of a thunderstorm decays faster by a factor of about 5-6 after chaff has been released, if compared to the natural decay of the field in an unseeded storm.

Sax (USA) reported on the field activities of the 1973 phase of the Florida area cumulus experiments. The experiments involved the coordination of surface, radar, and aircraft measurements including the measurement of raindrop size distribution, of aerosol and rain water collection for silver analysis and of randomized seeding. Results were as yet not available.

SESSION 8 - ICE NUCLEATION TECHNOLOGY

A method for the production of pure AgI by evaporating pure silver and exposing it to Iodine vapor was discussed by Poc and Roulleau (France).

P. A. Allee (USA) discussed the instrumentation of an ice nuclei network consisting of 19 stations spread over the western USA. The instrumentation makes use of the millipore filter method. The sampling equipment is installed at the measuring stations and a timer governs the sampling period such that 5 minutes out of each hour are being sampled. After 24 hours the filter is replaced and the exposed filter is mailed to the central analysis location. The first results were discussed. They indicated an increase of nuclei concentrations from the Pacific coastline toward the central USA. From this increase a production rate of 2 ice nuclei per minute and m^2 surface area can be derived.

An interesting paper on the scavenging of tracer substances by convective clouds was given by A. N. Dingle (USA). Trace substances which were placed from an aircraft into the updraft below and in front of the convective system were found at distances of some 50 km from the location of release. The paper was received with great interest.

Fukuta (USA) discussed the technology of ice nuclei generators and Hicks and Vali (USA) gave results of seeding with propane spray at the base of the outdoor laboratory on the Elk Mountain in Wyoming. Crystal habits and crystal growth rates were studied 200 meters downwind of the release point.

A few final remarks: The spirit of the conference was highly motivated and produced a good understanding of the approach to the problem of weather modification which is used in various countries. Generally one can say that the approach in the Soviet Union is physical rather than statistical, while in the USA the approach is more strongly governed by statistical controls. One may say that what is sometimes exaggerated with strict statistical control in one country is being underestimated in the other country. Lively discussions concerned with the differences of approach highlighted the conference repeatedly and produced a healthy cross fertilization of ideas. This type of cross fertilization is the

invaluable net gain of such conferences.

In the concluding conference session the motion was accepted to make these conferences a regular international endeavor. The second conference, again jointly sponsored by WMO and IAMAP, is planned for 1976 in Boulder, Colorado, in close coordination with the IAMAP International Conference on Cloud Physics, which is planned for the same year in the same location.

LIST OF CONTRIBUTIONS DISCUSSED ABOVE:

Dispersal of fog. L. Facy

On a method of fog modification by the passivation of condensation nuclei. R. A. Bakhanova and A. V. Silayev

The dispersal of fogs by electrical forces. M. H. Smith and J. Latham

Problems of preventing the formation of radiation fogs. Dissipation of warm fogs. B. V. Derjaguin, I. N. Grigorenko, V. A. Ershov, I. A. Zolotarev, Yu. S. Kurgin, L. F. Leonov, B. A. Malikov, P. S. Prokhorov. V. A. Fedoseev, E. I. Shaglij, V. A. Shustov, S. B. Kudritskij.

Some data on the dissipation mechanisms of supercooled fogs by propane gas. L. I. Krasnovskaya, T. I. Shevaldina and A. N. Khijnyak

Rain Augmentation. J. Warner

Results of seeding cumulonimbus clouds aimed regulating precipitation in the Ukraine. A. I. Furman, S. B. Husid, E. E. Kornienko, I. A. Kurejko and F. Ya. Voit

Salt drizzles extracted from under-saturated air layers by seeding with hygroscopic nuclei. R. Serpolay and M. Andro

Quick inducement of precipitation by seeding layers of stratified air. R. Serpolay and M. Andro

The role of solid precipitation elements in natural and artificial production of rain in Israel. A. Gagin

Snowfall enhancement. H. Weickmann

Experimental seeding of frontal clouds in winter to stimulate precipitation. B. N. Leskov

Ground-based cloud seeding experiment at Delhi during winter. R. K. Kapoor, R. N. Chatterjee, K. K. Kanuga, S. K. Paul and Bh. V. Ramana Murty

The artificial modification of clouds and precipitation in a mountainous region. P. V. Hobbs and L. F. Radke

Seeding requirements for rapid glaciation or stimulation of a mixed-phase cloud. J. E. Jiusto

The Pyramid pilot cloud-seeding project. J. A. Warburton

Recent advances in studies of the physical processes producing hail, and results of anti-hail operations in the USSR. I. I. Burtsev, I. I. Gaivoronsky, and A. I. Kartsivadze

Natural "hailcores" and their abilities to estimate the efficiency of the hail prevention system. P. Admirat

Hail process investigation and results of hail protection measures in Moldavia. N. M. Zaitchenko, I. I. Gaivoronsky and L. A. Kinevitch

Results of operations over the five years 1969-1973 to protect agricultural crops from hail damage applied by the Transcaucasian Hydrometeorological Institute. V. P. Lominadze, I. T. Bartishvili and Sh. Gudushauri.

A model of natural hailstone growth process and its transformation under the influence of artificial crystallization. L. G. Kachurin, A. I. Kartsivadze, P. I. Makharashvili, C. Stojanov, M. Tecle

The experimental programme to modify hurricanes. R. C. Gentry

Dynamic methods of convective cloud modification by means of artificial vertical jets. N. I. Vulfson and L. M. Levin

The results of experimental work on extinguishing forest fires with artificial precipitation. E. S. Artsybashev, P. A. Gubin, A. I. Sidorov, Yu. P. Simin and N. S. Shishkin

Convective cloud modification to reduce thunderstorm activity. I. I. Gaivoronsky, L. P. Zatsepine and B. I. Zimin

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RESEARCH NEEDS FOR

LARGE SCALE, APPLIED WEATHER MODIFICATION PROGRAMS

Merlin C. Williams and D. Ray Booker

INTRODUCTION

The development of large scale, applied weather modification programs in the past few years has increased to the point where they now form a significant portion of the overall weather modification effort. State, county and local governmental programs are proposed or underway in large portions of the western U.S. and Canada. More critical than the reason for such expansion is the characteristic determination with which this trend has proceeded.

An examination of the history of such developments should provide some thought provoking material for the weather modification field as a whole. Too often such developments are viewed by researchers with contempt and hostility. An immediate attempt is made to put a stop to such "Irresponsible" acts without really bothering to become acquainted with the goals, problems and attitudes of the groups proposing applied programs. Such applications tend to be viewed as a threat to the existence of the research program. On the other hand, those groups proposing or engaging in applications have come to distrust the "scientist" who insists that only pure research can be tolerated.

It is time that a more positive approach to coexistence of programs is recognized, and made a part of the planning for future programs. In a time of shrinking federal budgets, wise use of funds is essential. The expansion of state and local funding represents an opportunity to stretch shrinking budgets. Like most opportunities, it must be recognized and grasped.

DEMONSTRATED NEED

The development of large scale programs poses a new set of problems both of virtue of the type and size of operations required. The methods used to operate large scale programs places requirements on the field for new and improved tools. On the other hand, seeding over large areas can be expected to have effects not considered by past investigations. These factors, then, generate new research requirements.

A case in point is represented by the South Dakota Weather Modification Program. This activity was developed in 1971 on the basis of cooperative State - county efforts. Funding for the program is provided totally by the state and counties on a cost-share basis. Overall policy for the program is provided by the Weather Modification Commission, appointed by the Governor. The administration and operations are conducted by the Division of Weather

Modification (DWM), Department of Natural Resources Development. Decision-making for conduct of the field activities is shared by the DWM and county representatives. Actual field operations are conducted by commercial groups under contract to the DWM (1).

Since its beginning in 1971, the program has grown steadily from a budget of $100,000 to an approved budget of approximately $1,000,000 for operations in FY 1975. This budget expansion has provided for growth in area of the state covered from 26 counties (16,000 square miles) in 1972 to 42 counties (41,000 square miles) in 1973 to a proposed 46 counties (47,000 square miles) in 1974. Thus, the program has reached the stage where the area being treated is of the order of 200 miles by 200 miles. In actuality the shape of the participating area is such that the area is more like 150 miles by 300 miles.

Support for the program has been monitored on various levels through the program. Sociological studies of individual attitudes have indicated public support for the program of the order of three to one. Legislative support has been demonstrated through the funding provided to the program annually. Finally, the budget for FY 1975 was, for the first time, included as a part of the regular, operating budget of the state denoting recognition as an established program.

The initial impetus for the development of the applied effort was generated on the basis of research results indicating that 10% to 20% increases in precipitation and 40% to 60% decreases in hail could be achieved by seeding under selected conditions. Target and control comparisons for the 1972 operational season indicates that approximately 20% more rainfall was observed in the seeded area than in unseeded areas. More detailed target and control analysis of 1973 operations again indicate approximately 20% more rainfall in seeded than unseeded areas. Similar analysis of hail losses for the two years indicate 25% to 60% less hail in seeded than in unseeded areas. Overall, the effect of these evaluations is to tend to verify the earlier research results.

Neither the results nor the program techniques are as clear-cut as might be indicated by such a brief description. It is fully recognized that continuation of the program will depend not only on performance of field activities, but on the effects of the program on all scales. This means technological improvement to effect efficiency and economy, and sound, technical evaluations are needed. Thus, a concurrent research effort which seeks to address itself to the problems of such applied programs is not a hope, but a requirement.

IMMEDIATE RESEARCH NEEDS

This discussion is not intended to provide a complete list of research projects needed. Such a list would be impossible to compile, since development of each program generates unique needs of its own. However, the experience gained during two years of operation of the South Dakota Program has provided the basis for identifying some research needs.

One of the most obvious problem areas (and opportunities) results from the size of the program. Questions of the effect of seeding over areas varying from single clouds to systems covering 25,000 square miles in a single period are of concern not only in determining effects within that area, but also in decision making for operations in adjacent areas. Since the overall operations are conducted on the basis of six districts, each approximately 100 miles square, the decision in a particular district may well depend on activities previously conducted in another district. (In the past, this problem was viewed with alarm as possible "interference" rather than an opportunity to learn from field applications). Viewing the situation in reverse, it is equally important to understand the effect of the cloud environment on the treated cloud.

These considerations lead to the requirement for an effort to study the dynamic effects of large scale programs - a project that will be termed mesoscale cloud dynamics. Such a project should consider the relationship of seeded and unseeded clouds and their meso-scale environment. It will require both field measurement and laboratory modelling. The project is too big? It certainly is, if you never start.

Related to the meso-scale problem is one of nuclei considerations. Answering the question of spread and activity of material released over large areas is essential not only for operational purposes, but to provide answers to an increasingly critical public. A project to measure nuclei counts under various conditions ranging from natural conditions to intensive seeding over various areas should be initiated as soon as possible. Development of large scale coal resources to alleviate the energy crisis will contribute to the nuclei problem and adds urgency to the need for such a program now. A program of combined airborne and ground based nuclei counters should be established in areas of existing and proposed programs as an integral part of a meso-scale cloud dynamics program.

During the past few years, the use of silver iodide as a seeding material has become increasingly difficult. Increasing costs occasioned by a dwindling supply of silver pose one set of problems to large scale use. More recently, dwindling energy sources have made acetone almost unavailable. Objections to the use of silver iodide by environmentalist groups, justified or not, continue. All of these factors point to a limit to the use of silver iodide in the future.

To the concern for the limited supply for silver iodide should be added the lack of utility under certain cloud conditions. A significant (but unknown) portion of clouds occurring in South Dakota are of a "warm" type, unsuitable for silver iodide treatment. The use of hygroscopic materials has been under development for a period of years, but a number of questions regarding effective techniques remain. Answers to these questions should be sought to provide an expanded seeding capability. All of these considerations point to a need for a concerted effort to develop new materials, new methods and new equipment for production of seeding nuclei in 1972 (before the crisis hits in 1974!)

Field research in the high plains has been almost entirely conducted during daylight hours on weekdays only. In the same area, most of the

increase opportunities and much of the hail damage occur in darkness. Obviously, the weather modification operator must work whenever opportunities or threats occur. The problem is that the dynamic aspects and the physics of nocturnal storms appear to be different from the more convenient daytime storms. This leaves the user in a position of having to do his own research or to extrapolate what may have been learned in the daytime research programs.

When asked why research is restricted only to daylight hours, one research leader gave the following reasons:

1. Funding is inadequate to support round-the-clock observations,
2. Nighttime operations are too difficult,
3. Research scientists are more interested in doing their work during regular working hours.

If these are the real reasons, and we compare the existing research needs with research goals, we may begin to understand the softness of public support for research.

There is a great need for research to be conducted on cloud populations which are representative of these encountered by user groups. Are the people well advised to pay millions of dollars for research on a handful of test clouds which may not be representative of the ones they are concerned about? Perhaps research would be better directed in studying the clouds weather modification operators work with. They are the ones the people are really concerned about.

Another area of concern is represented by prediction techniques. Specialized prediction techniques are required to provide for both real-time decision making and post operational evaluation. It is no longer adequate to rely on a general forecast with 85% (at best) reliability when conducting operations for a public that demands more. The necessity to combine classical techniques of predictions with all of the available satellite, computer, model, radar and special observing capabilities is obvious to those who have been involved with actual field operations. Of course the problem is not new! It is, however, highlighted by the development of more and larger scale applied programs for which the luxury of saying "Oh well, if I miss this test case, I'll catch the next one", does not exist. That philosophy does not impress the farmer who has been hailed out.

Finally, the necessity exists to develop evaluation techniques for applied programs, The results cited above for the South Dakota Program provide strong indications of effects, but the reliability of the results does not meet the critical requirements of the scientific community as absolute proof. Certainly, user groups do not require the degree of statistical proof needed by researchers (in fact, they are quite suspicious of such "number plugging".) However, a sound technical approach that recognizes both the needs and capabilities of user and scientific groups is needed. It can be speculated at this point that, if as many efforts and resources had been spent on development of evaluation techniques specifically designed for atmospheric science as has been spent on trying

to adapt a method developed to test the effectiveness of fertilizer to an infinitely more variable system such as the atmosphere, a solution to the problem would be available. This does not, however, negate the requirement for an evaluation system that is effective in as near real time as possible, is repeatable and meets the needs of the various groups.

COOPERATIVE ACTIVITIES

One way to solve some of the research problems posed by large scale applied programs is to take advantage of what is already taking place. Research groups too often demand certain non-negotiable conditions that must be met before the research can be involved with the applied program. The response to this approach by the user has been to outline in detail where he would like to see the research program go, and then attempt to proceed on his own.

The opportunities available for such cooperative approaches are practically unlimited. In the case of South Dakota, approximately $1,000,000 will be spent in FY 1975 for personnel, equipment and supplies in the conduct of seeding operations. During the summer of 1973 alone over 900 seeding flights were flown amounting to nearly 2,000 hours of aircraft seeding time. The area covered by the seeding was approximately 26,000,000 acres. The opportunities for observation, analysis and research in conjunction with this effort are limited only by the imagination of the researcher.

Similar opportunities are available in conjunction with applied orographic programs in the Sierra Nevada, Pacific Northwest and parts of the Rocky Mountains. Summer cumulus projects are underway in parts of the High Plains from Texas to North Dakota. Summer programs have been developed in Michigan and various other midwestern locations. It is to be seriously doubted, however, that these groups will all come beating on the door asking for research. Nevertheless, they represent an opportunity for conducting research which the people should be willing to support.

The most suitable cooperative approach appears to be a combination of user - federal - university interests. The important point is that all groups share equally in the research program. Attempts to give lip-service to the integrity of one group by another will simply hamper further efforts by all parties. Paternalistic attitudes implying superior knowledge will contribute further to the mistrust already existent between the public and "scientists".

SUMMARY AND CONCLUSIONS

Events of the past few years leave little question that new, imaginative research efforts are needed to keep pace with developing, applied programs. The question becomes one of whether or not the research community is willing to accept the challenge, opportunity and responsibility offered by these new programs. If so, this group must take the first

step, and make a conscious effort to adjust to the new situation. The opportunities for joint programs to provide mutual benefit exist as never before. If the decision is to proceed, then in the words of Vincent Schaefer, "Let's get on with the job." If the decision is in favor of caution, delay and more argument, prepare for one of those cyclic recessions in weather modification activity that has been observed in the past year!

An Interesting Early Reference Received from

Dr. Arnold Court
Professor of Climatology
California State University
Northridge, California 91324

THE AMERICAN METEOROLOGICAL JOURNAL

December 1893: Volume 10, No. 8, Page 357

Artificial Rainmaking in Kansas. An attempt to produce rain by artificial means was made in Kansas on May 26. A press dispatch from Wichita, of that date, described the event as follows:

"By preconcerted arrangement between the mayors of the towns of Wellington, Winfield, Arkansas City, South Haven, Caldwell, Hutchinson, and Newton, a simultaneous bombardment of the heavens began at noon yesterday. Cannon and every explosive within reach were brought into requisition, and hundreds of men and boys with guns blasted away at the skies till 2 P.M., when the clouds opened their reservoirs and drenched the earth, the rain continuing four hours. All the country for some miles beyond the radius of these towns was deluged by the heaviest rainfall in eight months. The crop prospects in the eight counties over which the rain fell are wonderfully improved."

The cause of the rain is readily seen on an examination of the weather map for the same morning. An area of low pressure was hanging over the southwestern United States, and the forecast for the day was for "showers." Rain fell, not only in the section where the bombardment was going on, but over all the region roundabout, and to the westward. The whole of Eastern Kansas, and a large part of Nebraska, Missouri, Iowa, and Illinois received abundant rains.

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THE AMERICAN METEOROLOGICAL JOURNAL

September 1894: Volume 11, No. 5, page 196-197

The Rainmakers at Work* - The rainmakers have been industriously plying their trade in Kansas and Nebraska since the opening of the crop season, and it is reported that they have at least succeeded in convincing a good many people that they possess the ability to draw moisture from the most arid skies under the sun. The Kansas City Star of recent date devoted a column to this subject, arriving at the conclusion that "the rainmaker seems to have a peculiar faculty for commencing his experiments just about the time a rain is due, and there have been many remarkable coincidences due to this

*From the Monthly Review of the Iowa Weather and Crop Service, May 1894.

fact, or else many remarkably successful experiments at rainmaking. The faith of the western people in the processes is based on the seeming success of them."

The Rock Island Railroad Company, the Star says, maintains a rainmaking department, for which special cars have been fitted up. The chief assistant rainmaker, in a recent interview, said: "We do not claim to be absolutely able to produce rain. We merely assist nature in the work. At times a certain element is lacking in the atmosphere, and by the use of gases and electricity we believe we are able to furnish what is lacking. What that element is we decline to say."

Down in Kansas, it is said, while the operators were at work, there occurred a destructive rain and hail storm, and now the people whose property was injured are about to bring suits against the Rock Island Company for damages. On the basis of the theory that the company's agents produced the disturbance, the people have a just cause of action. But... if the cases come to trial there will be no trouble in procuring a great cloud of witnesses, scientific experts at that, to swear that the so-called rainmakers are in no wise responsible.

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HOW WEATHER ENGINEERING WILL EASE THE ENERGY CRISIS

Irving P. Krick
Palm Springs, California

INTRODUCTION

Man has been and is the greatest changer and innovator of all earthly creatures. No others have so altered earth, in so many ways. Some changes have been extremely wise, others unwise, and many others are still in the balance and yet to be evaluated. Of these creatures of change, Man has been the first to extract from Nature and create his own environment, while others tend to adjust their habits to fit natural surroundings and trends.

Today an article on this subject isn't considered timely or relevant unless there are two words contained therein and emphasized -- those words being "ecology" and "environment." This paper deals with two basic scientific processes involving ecology and environment. They may be of primary importance in Man's struggle to relate to his "ecological spaceship" in a manner that capitalizes upon physical and natural laws, providing social and economic benefits without altering or harming his environment or causing ecological damage. Some may argue this point of view, but it is based upon long experience in the practical application of these principles in many parts of the globe. Reference here is to (1) long range weather prediction, and (2) weather modification.

Both long range weather projections and weather modification have become two related aspects of the science of ecology. Both deal with interactions between living organisms on earth, which we might term "life-forms." The human "life-form" is fully dependent upon the atmospheric envelope within the earth spacecraft. Further, the interrelated physical factors may include the earth's soil and composition, land forms, temperature conditions, water in its varied forms such as atmospheric humidity, rainfall, snowfall, drainage, evapotranspiration, air movement over land surfaces and the winds acting as the transport mechanism for our life-support systems, air and water. When one studiously analyzes the two factors of long range weather forecasting and weather modification, one cannot arrive at any other conclusion but that these two are interdependent and that one without the other is less than optimum. Further, it is necessary to understand that "ecologically speaking" the science of ecology is representative of a "constant state of change." So, too, are the atmospheric phenomena to which I refer, being unified and working within the broad living cycle of all natural phenomena.

Current world conditions have forced Man into a face-to-face confrontation with ecology and environment. And here I refer to what we term the Energy Crisis. For the first time in decades the opulent society of the United States is facing a severe crisis in an environment Man holds so dear -- one that may be called the "automotive environment," where an indi-

vidual's prized possession is his car. The shock of being without his transport-slave, on a moment's notice, is really boggling Man's thinking and causing a dilemma. The related steps between Man's automobile and the fields of weather forecasting and weather modification help one to realize the marriage that must exist in harmony in an ecological sense.

As Chairman J. K. Jamieson of Exxon Corporation has stated: "World energy relationships are now at a turning point. The earth is not running out of potential sources of energy, but it will take a major effort and considerable lead time to develop resources to meet our future needs." I take the stand that Man is overlooking, during this crisis, one vital means of helping him plug the hole, tide him over into the next energy generation period, and do so without turmoil, massive investment or great self-sacrifice. I believe the full application of long range weather forecasting and weather modification offers a means of alleviating the present Energy Crisis, and to a major degree.

WEATHER KNOWLEDGE WILL INCREASE HYDROPOWER PRODUCTION

In his hysterical thinking of the present, Man may be forgetting the wonderful ecological balance contained in hydropower production. Isn't this one means of clean power production, a non-polluting means of power acquisition, as well as a non-depleting resource? Also with all the energy developed from hydropower we are forestalling the depletion of fossil fuels for this purpose and making such fuels available for other needed applications. Recent developments have made us vitally cognizant of the depletable factors of fossil fuels. Magnification of effort and full utilization of hydropower become a means to an end in this difficult period.

In assessing the impact of weather on the development of electrical energy, it is obvious that any effort to increase river flows through cloud-seeding can become significant. One can cite the situation in the Pacific Northwest during the fall of 1973 as an example. Flows along the Columbia River and its tributaries were at virtually all-time lows, and both the power producers and industrial users were hard pressed because of the curtailments that were inevitable. Even though a respite occurred from rains after late October, the situation will become critical again in 1974-75. (Figures 1 - 8).

If weather projections supplied to interests in the Northwest in 1969 for low flows in 1974-75 and reiterated in 1972 are validated, the crisis can become compounded. This is due to the fact that most of the energy, perhaps 90 percent of electrical power supplied to the Pacific Northwest, is generated in hydroelectric plants in Canada and the U. S. It is distributed by the Bonneville Power Administration under contract to both the private utility groups in the Pacific Northwest and the industrial users, particularly aluminum companies. These latter companies are in a critical position because they were invited to develop facilities in the Pacific Northwest with promises of large blocks of inexpensive power -- a prerequisite for aluminum production. Now they are faced with heavy

curtailment in upcoming years, and production will fall, unemployment will increase, and in other segments of industrial activity in the Northwest related economic difficulties could ensue.

Much of this problem could be alleviated through the application of long range precipitation projections together with regional weather modification programs along the Columbia River on both sides of the U. S. - Canadian border. This is not a hypothetical suggestion, but is based on the evaluation of actual operations which have been conducted both for the government of the U. S. through the Bonneville Power Administration in September 1951 and for a group of private power companies and one of the large aluminum companies later in the '50s, when conditions similar to those of 1973 threatened the area. Figure 9 depicts target-control streamflow relationships prepared by BPA following the September 1951 weather modification operation which was sufficient to overcome the critical situation.

Proposals of this nature have been presented from time to time, but pressure from environmentalists, cumbersome government procedures, and the difficulties in working out formulae for allocating power produced by additional water have delayed activation of broad programs. However, such programs should be pursued, initiated and established on a permanent basis, not only on the Columbia but on other major river basins supplying hydroelectrical energy, irrigation water or municipal water supplies throughout the Western states. Indeed, such a program has even broader implications. It would appear appropriate to reassess all hydropower potential throughout the world as a function of existing cloudseeding capabilities. The author has advocated a combination of long range weather forecasting and weather modification practices as an economical source of such power for many years. To emphasize this statement, a bibliography is cited at the end of this paper.

Controversies surrounding cloudseeding principles and operational procedures, usually inspired by those in government or research groups unfamiliar with techniques engineered and applied within the private sector, have slowed widespread use of known methods. Perhaps more attention can now be focused on these inexpensive yet effective methods to maintain optimum hydropower operations on many river basins throughout areas of the world adaptable to their application.

It should be noted that cloudseeding to augment power production requires neither a large capital outlay nor long periods to set up an operation. Therefore it can be an immediate remedy as well as a long-term one in getting at the problem, and new construction of thermal capacity or reservoir and hydro plant facilities becomes less pressing. For example, new capacity need not be developed on rivers such as the Columbia, as additional river flows can be utilized effectively at existing installations to augment energy resources in some years simply by putting more water through existing plants.

The prerequisite to a useful contribution to river flows from cloudseeding, of course, is the occurrence of seedable storms. Preoperational

analyses incorporating a prediction of seasonal weather patterns, and indeed conditions for some years ahead, can now be studied to plan operations and water management procedures to prevent any emergencies which may arise due to water shortages.

Fortunately some of the state agencies responsible for water and power management have taken the initiative in this respect and are progressing studies along these lines. California's Project Hydrospect, in which the talents of long-range weather forecasters and hydrologists are combined, is one such example, and in time may form a basis for similar work in other areas.

WEATHER KNOWLEDGE WILL HELP HEAT OUR HOMES

Only recently has it become possible to estimate with reliability the heating degree-day values in advance for one or more seasons so that oil refinery runs, bulk storage and distribution systems can be geared to upcoming seasonal weather patterns as they depart from historical averages.

Fuel oil supply and demand in various markets are closely related to heating degree-days as they accumulate at these cities. In the past a base of 65°F has been used to develop quantitative relationships which can serve to measure consumption. Each oil company will find its own level in the various markets through studies developed from historical temperature data and their past heating oil sales.

In the summer of 1973 one of the major oil companies opted to test the usefulness of such forecasts in their present stage of development. The purpose, of course, was to assess their reliability for future planning. Naturally the idea was greeted with considerable skepticism at management decision-making levels because past experience had not been encouraging, and government sources were quite frank to admit that any projections of a month or more prepared by the National Weather Service must still be regarded as experimental. Furthermore, such experimental forecasts could not be quantified in terms of monthly degree-day accumulations and therefore would be unusable from a decision-making standpoint where commitments of millions of dollars might be involved.

As of this writing (February 1974) the forecasts issued in the summer of 1973 for the heating season of October 1973 - March 1974 have proven valid within the ranges considered acceptable to management. (Table 1). The basic forecast called for degree-day deficiencies through February 1974 generally east of a north-south line bisecting the states of Minnesota, Iowa and Missouri. The forecast was particularly helpful along the eastern seaboard following the Arab embargo on oil shipments to the U. S., as this oil is most important to consumers there.

Many applications for long-range forecasts of this nature are currently available to assist in alleviating numerous weather-oriented problems the Nation is facing as our resources dwindle. Oil is only one

commodity for which weather knowledge can be used effectively to better plan the logistics of supply and demand.

WEATHER KNOWLEDGE WILL ASSIST AGRICULTURE

Forecasting weather for long periods ahead is useful to agricultural interests in estimating weather related crop yields and in determining acreage to be planted to maintain production at optimum levels. If the U. S. is to maintain a favorable export posture as an aid to the balance of trade, we must do all possible to this respect. For this reason the U. S. Department of Agriculture has encouraged the farming community to go all out to produce at maximum levels. Now the energy crisis threatens curtailment of fertilizer production. How can this be offset? By identifying areas of deficient rainfall through long range forecasts, known cloudseeding techniques can be employed to not only offset short supplies of fertilizer by adding to rainfall, but also to optimize crop production. Work of this nature is currently in progress in Oklahoma, where recurrent drought has been a way of life in the past. It need not be in the future.

Even in areas normally under irrigation, or where normal rainfall is usually adequate, cloudseeding is useful in producing crops at maximum levels year after year. Some farm groups in the eastern U. S. have already become familiar with this potentiality and are establishing continuous cloudseeding operations from year to year. During excessive rainfall regimes, operations are temporarily suspended. The use of a ground generator network for cloudseeding, which is inexpensive to maintain, has proved to be a most efficient method of working in such cases. Furthermore rainfall from cloudseeding, coupled with accurate forecasts for a week or so, frequently permits farmers to skip an irrigation schedule. Such reductions in irrigation costs during a season pays for the cloudseeding program several times over. The saving of energy required for pumping and other phases of an irrigation operation where large amounts of power are consumed is a fringe benefit from such practices. Any energy conservation measures are certainly to be given serious consideration henceforth and all avenues explored which offer savings. Cloudseeding is one such approach.

CONCLUSION

Thus it would appear that long range weather forecasting and widespread cloudseeding should be actively pursued worldwide in the upcoming years as another means of developing and conserving energy resources. At present there are very few qualified practitioners with proven experience in both of these fields. In government and university circles too little attention is being given to the engineering aspects of the subject necessary for sound and practical economic applications. Hopefully the realization that such possibilities are currently at the leading edge of science and technology will produce a wider interest in these two scientific disciplines and the incentive to vigorously progress their wide applica-

tion. Certainly they represent a necessary and useful contribution to all Mankind, and should become as routine as many earlier technological advances.

The development of solar sources of thermal and electrical energy or wind-driven systems have weather-related aspects. Naturally, climatic conditions in various parts of the world will dictate the efficiency of such programs as a function of the hours of usable sunlight or wind. The location of earth stations will be dependent on an assessment of this potential. Space stations for the production of solar power and its transmission to earth may in time partially overcome this limitation.

Power plant siting to minimize air pollution and yet permit the establishment of flexible electrical transmission systems is also related to atmospheric conditions and justifies more study then has been apparent in the past. The alternate use of low and high sulphur fuel oil can be regulated with weather forecasts as sensors to automate controls at power plants in relation to atmospheric conditions. On smog-free days fuels with high sulphur content can be burned without fear of environmental damage. These conditions currently are predictable within useful limits.

All in all, it seems evident that the weather and its manipulation can become a powerful tool in handling the problems of our world as our non-renewable resources run short. Let us regard the Energy Crisis as an opportunity, not a danger. Now is the time to be thinking and planning ahead to make optimum use of this life-support system of ours -- the Atmosphere -- and its multiple ramifications.

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FIGURE 1
FORECAST - 1973-74 Water Year (October-December)

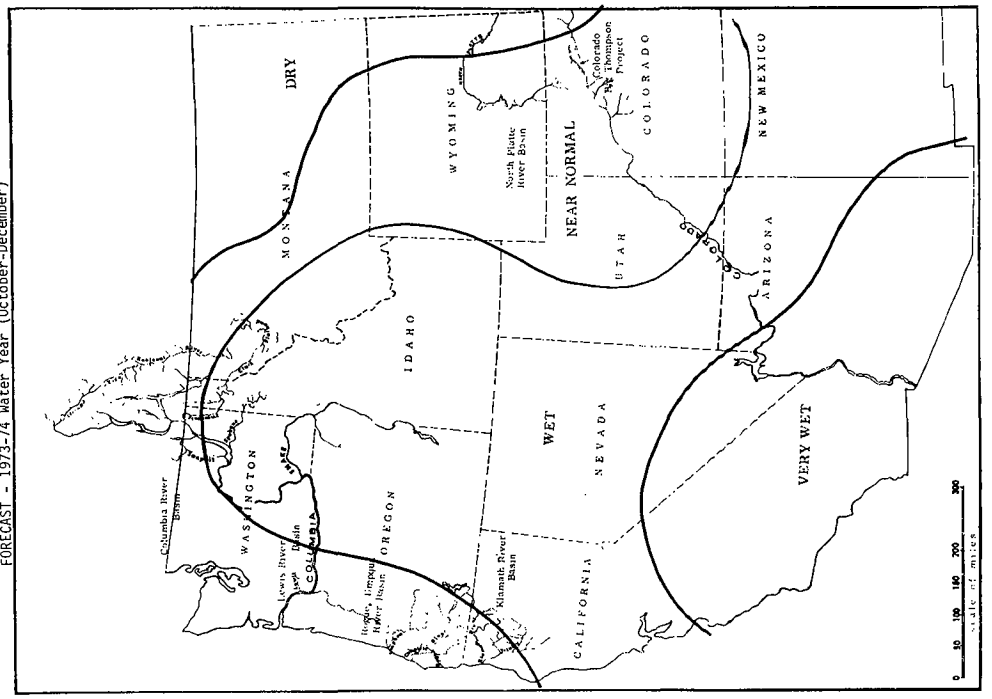
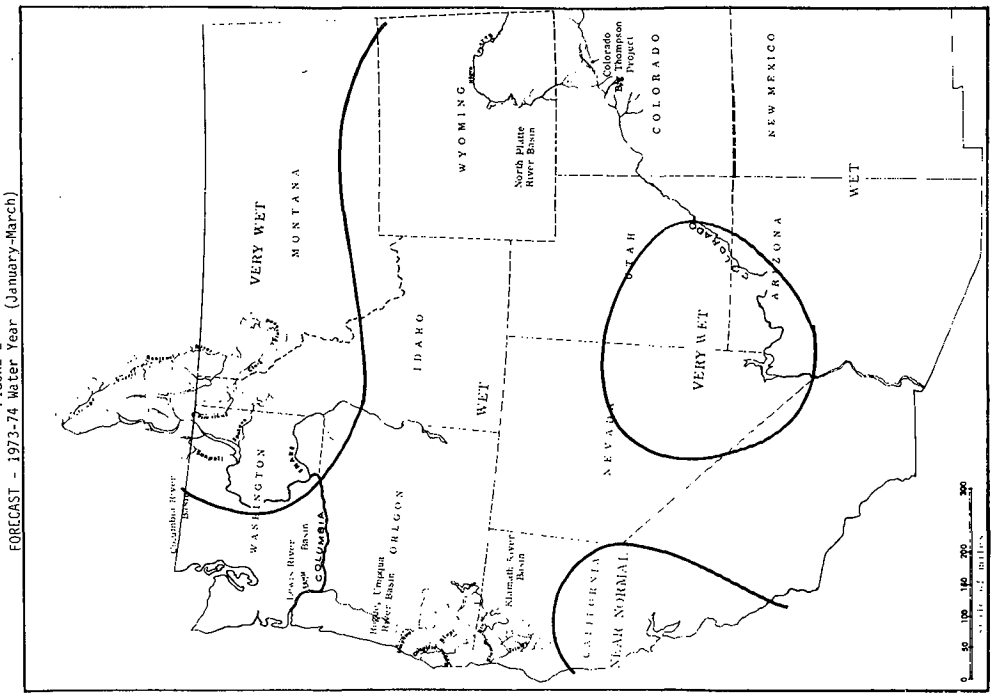


FIGURE 2
FORECAST - 1973-74 Water Year (January-March)



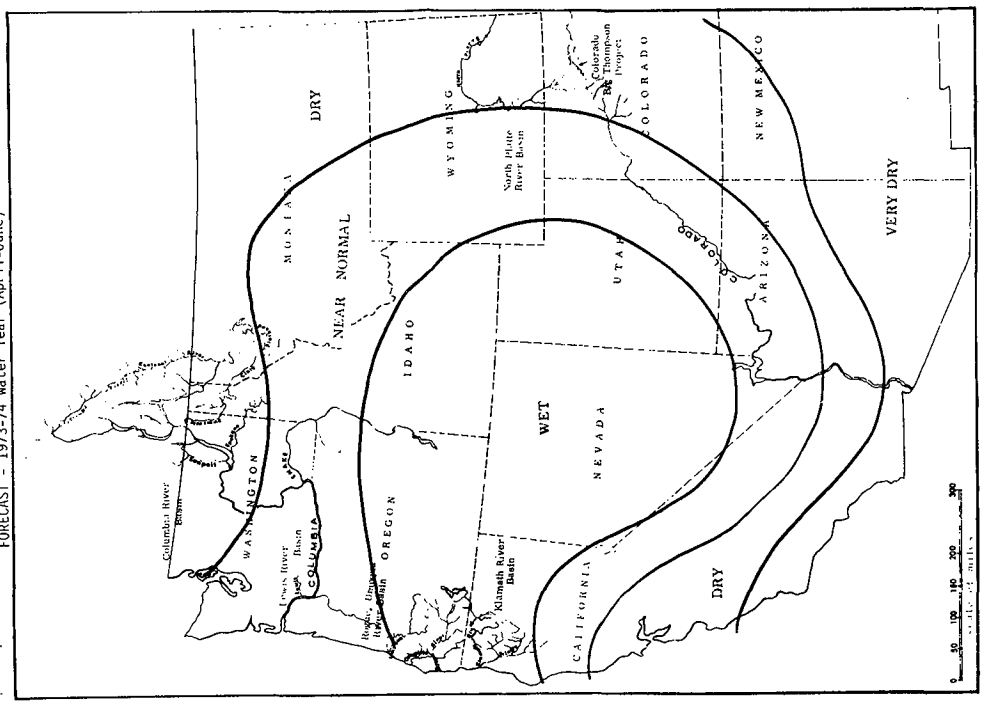


FIGURE 3
FORECAST - 1973-74 Water Year (April-June)

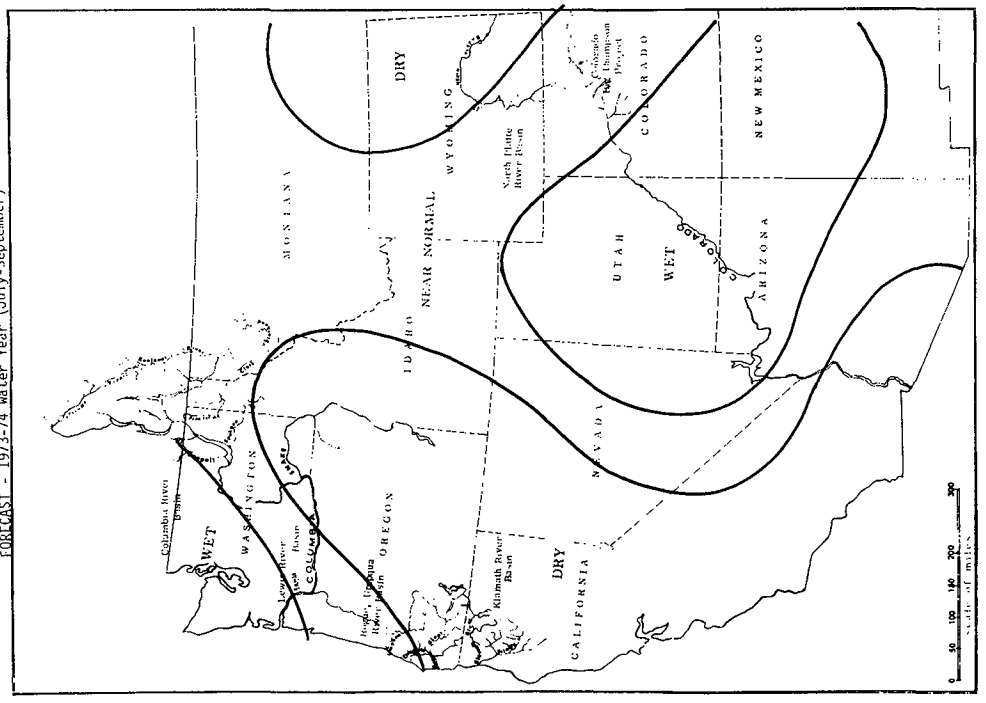


FIGURE 4
FORECAST - 1973-74 Water Year (July-September)

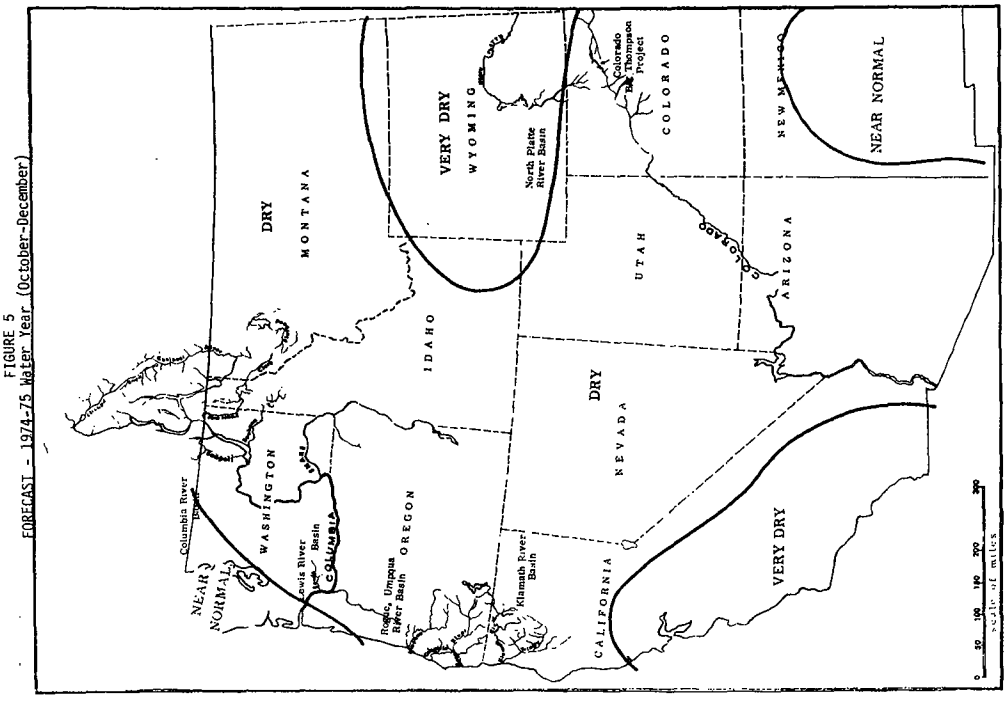


FIGURE 5
FORECAST - 1974-75 Water Year (October-December)

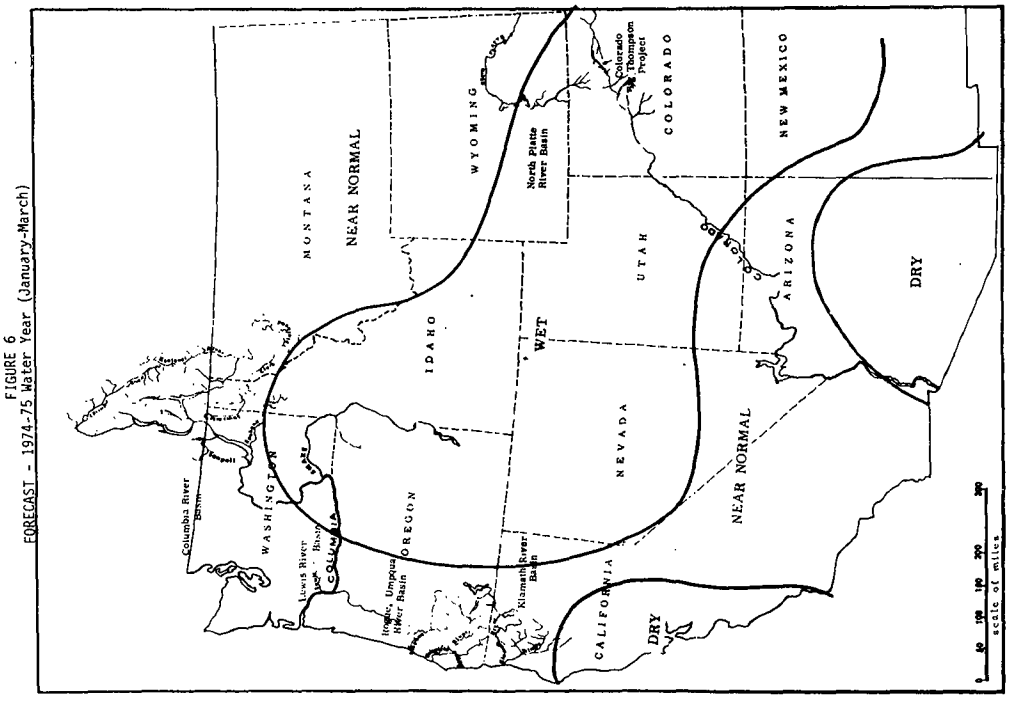


FIGURE 6
FORECAST - 1974-75 Water Year (January-March)

FIGURE 8
FORECAST - 1974-75 Water Year (July-September)

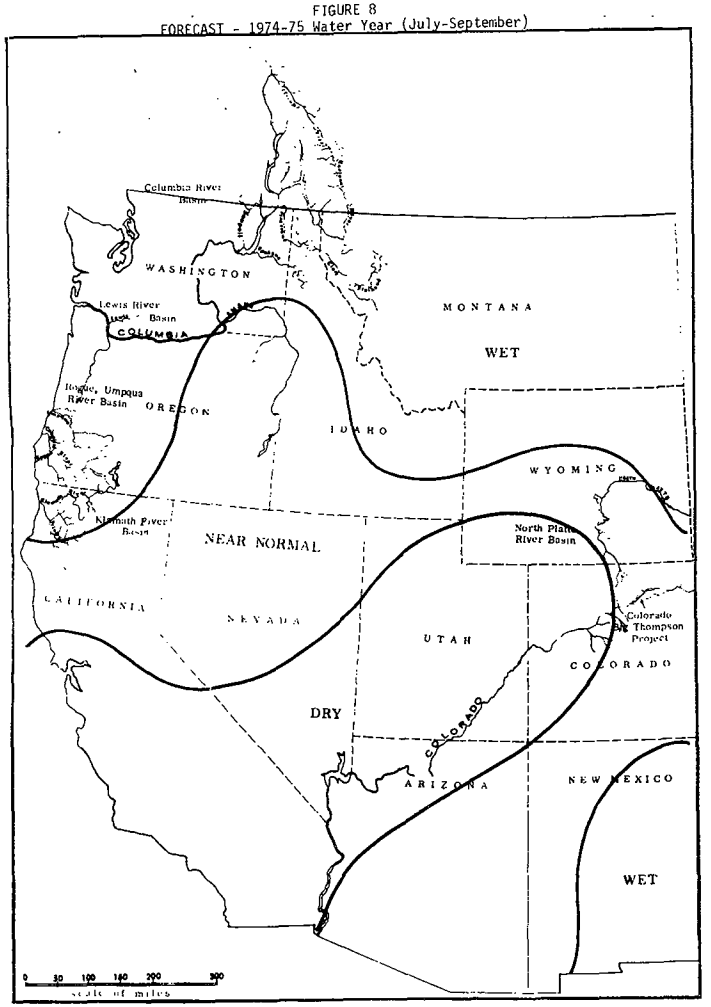


FIGURE 7
FORECAST - 1974-75 Water Year (April-June)

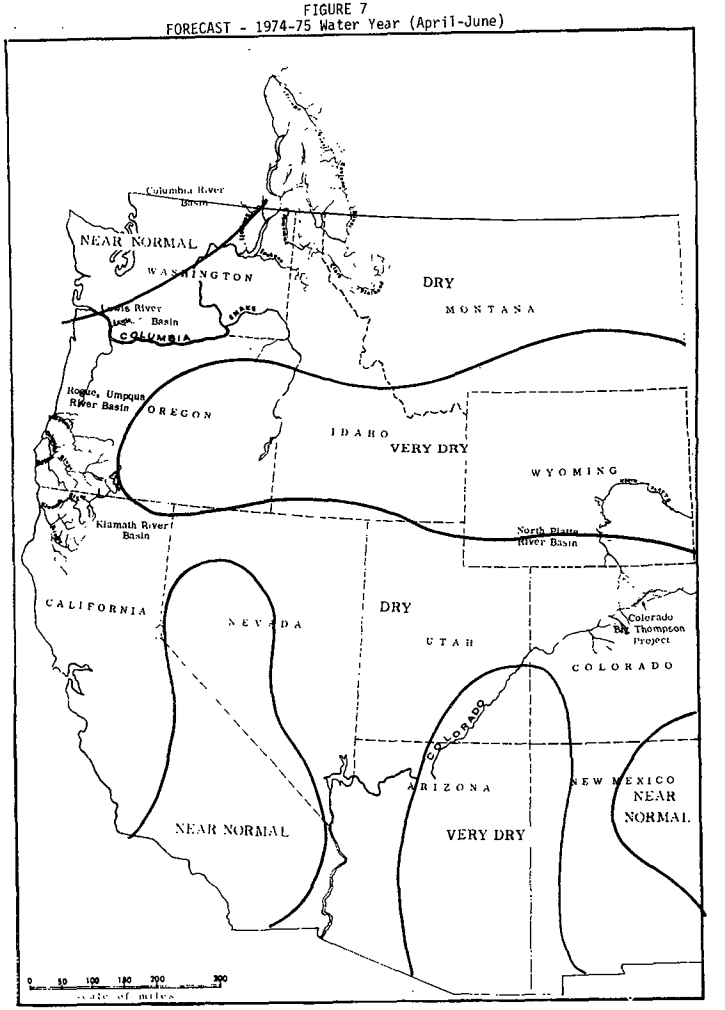


FIGURE 9

COMPARISON OF STATISTICALLY COMPUTED WITH ACTUAL DISCHARGE FLATHEAD RIVER AT COLUMBIA FALLS, MONTANA

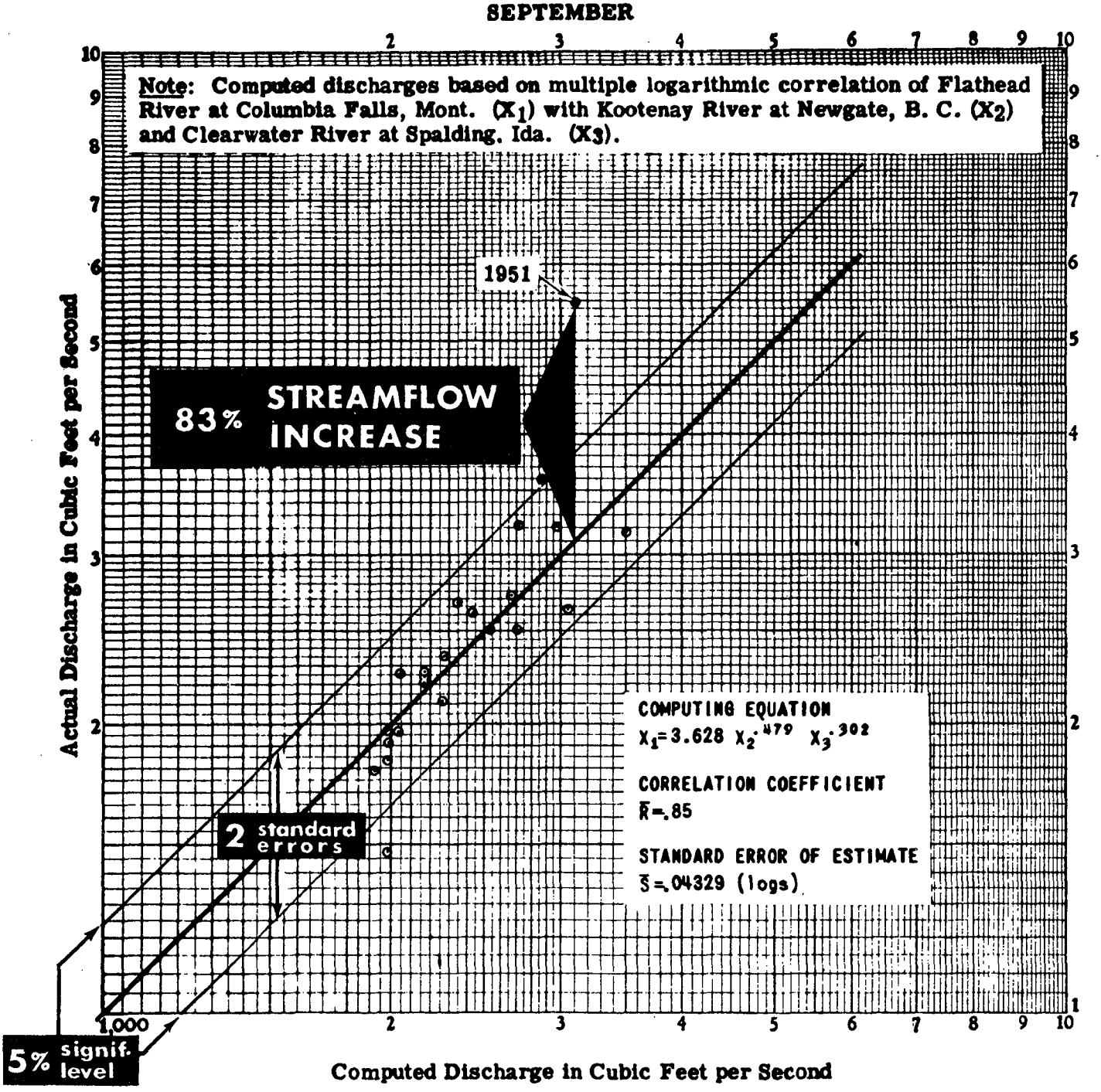


TABLE 1

1973-74 FALL AND EARLY WINTER CUMULATIVE DEGREE DAY COMPARISONS

(October through Fabruary)

CITIES	NORM	FCST	ACTUAL
Minneapolis	5984	5570	5744
Des Moines	4994	4575	4692
Detroit	4425	4000	4328
St. Louis	3688	3460	3684
Pittsburgh	4285	3835	3808
Rochester	4644	4375	4348
New York	3709	3335	3490
Philadelphia	3780	3455	3336
Boston	3968	3605	3650

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2. Long Range Weather Forecasting and Cloud Seeding for the VIIIth Olympic Games, Squaw Valley, California. February 18-28, 1960, by Irving P. Krick Associates Inc., January 1958.

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4. Long Range Weather Forecasting as a Water Supply Tool, by Irving P. Krick. Reprinted from and copyrighted as a part of Journal of American Water Works Association, Vol. 51, No. 11. Nov. 1959.

5. Weather and Streamflow Estimates for Selected River Basins. Water Years 1961-62 through 1965-66. Prepared for The Pacific Power and Light Company. December 1961.

6. Doing Something about the Weather, outline of remarks by Irving P. Krick at the University of California, San Diego, Symposium on California and the Challenge of Growth: The Impact of Science. June 1963.

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8. Water Supply Projections for 1972-73, Water Year (for San Joaquin, Kings, Kaweah, Tule and Kern Rivers). Report No. 1, December 1, 1972.

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11. Trained Rain in Spain Boosts Hydro Output, Electrical World, June 18, 1956.

12. Results of Cloud-seeding Operations to Augment Municipal Water Supplied, Journal of American Water Works Association, Vol. 48, No. 10, October 1956.

13. Rapport d'Activité (weather modification activities for years 1956-1957-1958), Société de Développement des Techniques de Pluie Provoquee, 17 November 1958.

14. The Forecasting and Modification of Weather, by F. E. LeBras, l'Atlantique Nord (official publication of the North Atlantic Treaty Organization), June 1957.

15. Is Another Drought on the Way? The Farmer-Stockman Magazine, October 1969.

16. We're Sorry Our Prediction of Drought is Proving True! The Farmer-Stockman Magazine, April 1971.

17. Verification prepared by Client (Pacific Northwest Hydro Power Company). Private correspondence dated May 2, 1967.

18. Weather and Streamflow Estimates for Selected River Basins -- Water Years 1971-75. Prepared for The Pacific Power and Light Company, August 1969, Report No. 664.