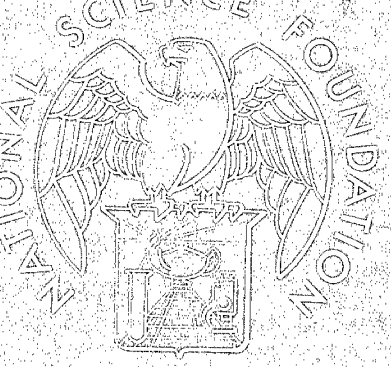
# Weather Modification




SEVENTH ANNUAL REPORT, 1965



NSF 66-

NATIONAL SCIENCE FOUNDATION

# Weather Modification




*SEVENTH ANNUAL REPORT FOR*

*FISCAL YEAR ENDED JUNE 30, 1965*

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## LETTER OF TRANSMITTAL

WASHINGTON, D.C.,
*January 12.*

MY DEAR MR. PRESIDENT:

I have the honor to transmit herewith the Seventh Annual Report on Weather Modification (for fiscal year 1965) for submission to the Congress as required by section 3(a), paragraph 9, the National Science Foundation Act of 1950, as amended by Public Law 85–510, July 11, 1958.

Respectfully,

LELAND J. HAWORTH,
*Director, National Science Foundation.*

*The Honorable*
*The President of the United States.*

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# A NATIONAL APPROACH TO WEATHER MODIFICATION

Each year mankind relearns the lesson that weather and climate can deal destruction no less severe than war or pestilence. In 1965, we were furnished with an unwelcome bumper crop of such reminders—ranging from the erratic, twisting devastation of Hurricane Betsy in Florida and Louisiana and the winter floods in California, to the continuing, bewildering drought plaguing the entire northeastern section of the Nation. No wonder, therefore, that Americans want whatever action is possible to alleviate adverse effects of weather and to improve climate, and they want it as soon as possible.

Until this year, we can fairly say that the major debate over weather modification has centered on whether an intensive and expanded national program was a suitable risk investment in terms of cost and potential benefit.

In 1965, key words are no longer "whether" and "when." They are "what" and "how" and "who." Both within and without the Government, the scientific and political worlds are the scenes of debate as to how an expanded national program can be organized in order that applications of various kinds can be established as feasible, and then reached in the shortest possible time.

When President Johnson last spring transmitted to the Congress the Foundation's Sixth Annual Report on Weather and Climate Modification, he said:

> The development of methods for altering weather and climate to the benefit of mankind is a subject of quickening interest in the Congress and the executive branch of the Government of the United States—as it is to all of the human race * * *
>
> We hope someday to acquire the knowledge permitting us to minimize the incidence and severity of hurricanes, tornadoes, and other violent storms and, also, to be able to improve the temperature and rainfall conditions in agricultural and industrial regions * * *
>
> Substantial progress has been made * * * But the pace has been slow. To advance the rate of progress, an effort of larger scope and direction is needed both in conducting basic research and in developing means to put the knowledge to work * * *
>
> If the day is distant and dim when the benefits of weather modification will become real, tangible and universally enjoyed, it is no longer possible for any to argue justifiably that such a day is beyond the reach of man at all.

On the gray Monday following the assault of Hurricane Betsy on New Orleans, Secretary of Commerce John T. Connor, in a memorandum to the President, said: "A vigorous national program to explore the possibilities of weather modification should now be mounted * * * If we in the United States were to acquire the ability to modify the weather in a substantial way * * * we would be able to expand our national economy and to improve the well-being of the American people in ways and to a degree that are now inconceivable."

To which the President, following Secretary Connor's presentation to the Cabinet, replied by letter: "This is a field in which I want us to move ahead to make a breakthrough I am convinced is possible for us."

Weather modification research and engineering thus has taken its place as a priority item on the national agenda. It is time to convert this concept into an active long-range program.

## A Broad-Based National Program

The term weather modification, of course, covers a broad range of possible activities, with varying probabilities of success and varying time scales for the essential preliminary research and development. It includes the dispersion of supercooled fogs, which on a pilot basis has already been accomplished at airports. It includes cloud seeding of most air masses as they are lifted by mountain ranges, a technique which appears to produce at least modest increases in winter snowfall, despite the fact that we do not yet sufficiently understand why. It includes the suppression of hail, a field in which a national program of research and development is now being planned. It includes an attempt to modify hurricanes, for which there is as yet no evidence of feasibility. It includes attempts to increase precipitation from summer showers and thunderstorms, which have been tried with thus far equivocal results, but in which recent evaluations present more optomistic prospects than previously. It includes attempts to influence the paths of storm tracks to help alleviate drought—a field of inquiry in which the path toward applications is sufficiently long, and the possibilities are so diffuse, that a decade or more may be required to determine whether or not such large-scale efforts are economically feasible. It includes determining the extent of inadvertent modification that is now in process through the exhausting of fossil fuel gasses into the atmosphere, the conversion of large rural areas to cities and suburbs, and the injection of jet aircraft exhausts into the atmosphere at jet-stream altitudes.

At the present time a realistic weather modification program must therefore be evolved from a whole range of potentialities, each of which must be approached individually in terms of scientific planning and research; technical development; the odds for, and value of, ultimate successful application: and the time, effort, money, and manpower required.

In designing a national program built on these diverse potentialities, the critical task is to preserve the proper balance among them, utilizing the proper proportions of scarce manpower and dollars in: (1) making the best use of current knowledge; (2) continuing the vigorous acquisition of basic knowledge and engineering capabilities that will lead to subsequent applications; (3) continuing the expansion of the reservoir of trained manpower upon which, a decade or two hence, the execution of a major national effort will depend; (4) foreseeing and finding ways to avoid or solve the social and economic problems, both national and international, that successful weather modification techniques can create.

Too much emphasis on short-range objectives would make it more difficult to reach such longer range objectives as determining the feasibility of large-scale climate modification that may prove to be of far greater value. Too little emphasis on such short-range objectives as improving methods of orographic cloud seeding would delay the beneficial application of current knowledge.

The existing national effort in weather modification has emerged piecemeal from the interests of various groups within the scientific community, various commercial operators, and various Federal agencies. Nonetheless, a rough, healthy balance, such as described above, has emerged. In the national interest, therefore, the future task should be to build on this modest but sound beginning by increasing coordination among Federal agencies (through such instrumentalities as the Interdepartmental Committee for Atmospheric Sciences, a subgroup of the Federal Council on Science and Technology), and by improving interactions among the scientific community (especially the universities), private industry, the Federal agencies that must play the leading role of sponsorship, and all the economic and political bodies which will be the users of weather modification techniques as they are developed.

## The Scientific Manpower Problem

If the Nation is to realize the full potential of weather modification, a long complex effort is necessary, lasting a generation or more in some of its aspects. It requires harnessing available scientific talent, and the training of a much larger next generation of atmospheric scientists. It requires complex interweaving of the interests of a dozen or more Federal departments or agencies which can use the techniques produced. It requires international cooperation among scientists and among governments. The vigor and extent of current planning efforts are evidence of both genuine public needs and genuine optimism about the prospects for success in satisfying them to a significant extent.

These broad, long-range considerations involve forethought and planning of a type which may sometimes be lost sight of in the pressure to reach decisions regarding specific problems, such as the priorities to be placed

on various scientific problems. It may be useful, therefore, to consider some of these wider problems in a little more detail.

How can we involve the necessary scientific talent in the most productive way? What kind of organization of the national effort will most effectively link the scientist and the problems to be solved, in both the short and long term? How do we increase the flow of first-rate scientists into the atmospheric sciences?

There are many related questions, some of which are:

How can we wed basic research and engineering so as to reduce the time lapse between acquisition of basic knowledge and its application from the usual 10 or 20 years to the practical minimum? How can we make the best use of the experience of the many excellent people who are engaged in commercial weather modification activities? How can we most effectively organize attacks on large scientific problems, such as the study of the global circulation?

In this general area, one question is closely linked to the central mission of the NSF: How can we most effectively link the university community, where much of the basic research talent resides, with the Government agencies which will fund weather modification research and development, which can provide or make available necessary facilities, and which have the largest interest in the techniques that will emerge?

This question has no easy answer. We cannot "draft" scientists as we did during World War II, for example, to develop nuclear weapons. The scientific problems are still too diffuse, the psychological motivations of national emergency are lacking. We cannot deprive the universities of their creative scientists for still another very practical reason: By doing so, we would undermine the training of younger people and thus endanger the supply of future scientists in a field where the number of scientists must grow rapidly to meet the scientific and technical opportunities of coming decades.

We must therefore encourage the ablest scientists in the universities to remain there, and build better bridges between them and priority problems of national interest. To some extent, this process has already begun. The Foundation's weather modification program itself has had modest success in drawing scientists in the universities toward research problems connected with prospective weather modification methods. In a broader sense, all Government support of atmospheric research in the universities constitutes a wise long-range investment in future applications, and this connection should not be underrated.

But new bridges must also be built to increase the flow of ideas between research and potential applications. One such mechanism is now in being, founded and operated by a group of universities themselves, and sponsored by the Foundation. This is the National Center for Atmospheric Research (NCAR), at Boulder, Colo., operated under contract with the Foundation

by a nonprofit corporation to which 21 universities belong. The Center, founded in 1960, has built an effective research staff and is making steady progress toward focusing on large, fundamental atmospheric problems, most of which can already be recognized as having direct relevance to future weather modification possibilities. Through the interchange of visitors, postdoctoral appointments, and graduate fellowships (the latter funded privately), as well as through the provision of research facilities, the Center has become an effective force in promoting breadth and excellence in the atmospheric research effort of the Nation.

The Foundation believes that mechanisms like NCAR will draw university scientists toward problems of critical importance to future applications, without upsetting the proper balance between basic and applied research, and without debilitating the graduate education capabilities of the universities. The ultimate solution to the current manpower shortage will, of course, come chiefly through an increase in the number of students being trained through the Ph. D. level. Any method of organizing research that would tend to stem the production of new Ph. D.'s in the atmospheric sciences would mean increased difficulty in reaching the long-range applications that may ultimately prove to be of the greatest practical value to mankind.

Capabilities could be built up rapidly, of course, by importing atmospheric scientists from other fields, but educational goals should not be sacrificed to short range objectives. We must build up operational capabilities in weather modification without preempting basic meteorology. The key limiting factor to this is that weather modification is only just beginning to achieve full recognition as a promising field of effort.

It is our hope that the other principal Federal sponsors of weather modification research will develop further their modes of bringing university scientists into the arena of applied research while allowing them to continue to participate fully in university affairs, especially the training of additional able scientists. The Bureau of Reclamation's research program is making headway along the same line. We should never forget that the important breakthrough in weather modification may well be produced by young men and women who are not yet in college.

The total national approach is one of a broad, diversified effort which, while in need of expansion and continued improved leadership, is healthy and sound. The Nation is understandably impatient for results. That impatience provides an opportunity and challenge for both the scientific and the governmental communities in the years ahead.

# SIGNIFICANT NATIONAL DEVELOPMENTS IN WEATHER MODIFICATION

Federal activities in weather modification during fiscal year 1965 touched on nearly every aspect of this complex subject, ranging from what might be called short-range objectives (those objectives to which the paths are relatively clear, and which can, with adequate effort, be reached within the next few years) to broad surveys of how an attack on long-range problems can best be organized.

## Interdepartmental Committee on Atmospheric Sciences

The Interdepartmental Committee on Atmospheric Sciences, which serves as a forum and coordinator for Federal atmospheric research program activities, turned special attention in weather modification during the past year to shorter range objectives where, as J. Herbert Hollomon, ICAS chairman, put it, "special opportunity" exists. These objectives are hail suppression and fog dispersal.

"A comprehensive hail-suppression research project enjoys high priority in research planning and can be justified now," an ICAS report to Dr. Donald F. Hornig, chairman of the Federal Council for Science and Technology, stated. ICAS, therefore, recommended that "expert groups in Government laboratories, in industry, in the universities, and related organizations," mount an "experimental program on the modification of hail-producing clouds," including "an extensive observation and analysis effort * * * to document the life cycle of hail-cloud cells."

ICAS recommended further that the National Science Foundation, in consultation with other interested Government agencies, should develop a national plan for hail suppression research, including the scientific and technical details, a framework for coordination, the selection of a suitable experimental site, and manpower and funding estimates.

As a first step in the planning process, the Foundation and the National Center for Atmospheric Research cosponsored the First National Hail Suppression Symposium at Dillon, Colo., October 14–16, 1965.

With regard to fog dispersal, the ICAS recommendations concerned themselves with two types of fog—cold fog, where the fog droplets are supercooled, and warm fog, where the fog droplets have temperatures above freezing. It has already been demonstrated on a limited scale that cold fog can be dispersed by dropping crushed dry ice into fogbound areas (such as

airport runways). ICAS, therefore, recommended that the Federal Aviation Agency, in consultation with other interested agencies, should develop a technical plan for cold fog dispersal, including an evaluation of operational feasibility and of the supporting research and development required. A recommendation on what role the Federal Government should play in cold fog dispersal activities was also called for.

Warm fog, the report found, requires much systematic and intensive research into possible techniques for its dispersal, such as forcing coalescence of the tiny fog droplets into drops large enough to fall out. This might be accomplished by injecting electrical charges, or by seeding with condensation nuclei. It was recommended that NSF undertake to develop a plan for this kind of research. The Foundation has invited the Air Force to participate in the preparation of such a plan based upon its extensive experience and interests in this problem. The Air Force Cambridge Research Laboratories has expressed its desire to work with NSF in the preparation of a plan for accelerated research on warm fog dispersal, to be submitted to ICAS in the spring or early summer of 1966.

## Atmospheric Water Resources Research Program

The major new program in weather modification during fiscal year 1965 is that of the Bureau of Reclamation, Department of the Interior, carried out through the Bureau's Office of Atmospheric Water Resources, based in Denver. The program, funded at a level of $1.1 million in fiscal year 1965 and further increased in 1966, is intended "to ascertain whether or not it is economically feasible to increase the water supply available to reclamation projects, through the application of weather modification techniques, for the purpose of increasing the precipitation into the headwaters of drainage basins providing the inflow to reclamation reservoirs * * *."

"Although the physical process or processes of precipitation are not completely understood," a Bureau of Reclamation report to ICAS states, "there is sufficient evidence that cloud seeding affects the production of precipitation to justify a program of engineering research designed to learn how to use cloud seeding to increase inflow into reservoirs."

In the first year of its expanded program, the Office of Atmospheric Water Resources has concentrated on: (1) finding experimental areas representative of major portions of the regions in which the Bureau operates; (2) providing support to groups that are presently involved, or will ultimately be drawn into, the major experiments to be performed; (3) fostering the development of "well-instrumented outdoor laboratories in areas where the potential for learning is high."

The major area of current Bureau of Reclamation activity is in the Upper Colorado River Basin, with a significant effort during fiscal year 1965 concentrated in the Park Range, an area east of Steamboat Springs, Colo. Preparations were made for a major physical experiment in silver-

iodide seeding of winter storms to be carried out in 1966 and 1967. The experiment is designed not only to test to what extent seeding is effective in increasing snowfall, but also to determine how accurately the effects of seeding can be measured. The next largest portion of Bureau funding was devoted to a contract with the Institute of Atmospheric Sciences of the South Dakota School of Mines, Rapid City, S. Dak., for studies leading to the modification of convective cloud processes.

## Project Stormfury

The major weather modification activity of the Weather Bureau-Navy over the past 3 years has been Project Stormfury, designed to explore the structure and dynamics of hurricanes through field experiments. The purpose is to achieve better understanding of hurricanes, as a basis for improved prediction and for assessing the feasibility of modfying various aspects of hurricanes.

Planned activity during 1965 included a hurricane seeding experiment of a more intensive nature, involving seeding a hurricane's eyewall five times at 2-hour intervals. The project's rigid operational rules prohibit seeding of any hurricane that could strike a populated area within 36 hours. Unfortunately, no hurricanes in Project Stormfury's theater of operations—the Atlantic east of Florida and the Antilles chain—met the necessary conditions during fiscal year 1965.

Since hurricane energy depends upon tropical convective processes, field experiments were conducted in the Caribbean by the Weather Bureau-Navy project between July 28 and August 11, 1965, to observe 22 selected cumulus clouds in detail. Fifteen of these clouds were seeded by dropping 16 Alecto seeding units each into the cold tops of likely looking cumulus towers, and the other 7 clouds were not seeded but were observed as controls. Data are now being analyzed to determine the effect of seeding on the rate of growth and peak height of these clouds.

## Commercial Cloud Modification

State and municipal activity in cloud modification in fiscal year 1965 was confined to two counties in California. Under these two programs, 1,220 square miles of territory were seeded with silver-iodide generators for rainfall augmentation.

Activity by commercial seeding operators, under the sponsorship of individual ranchers, farmers, farm cooperatives, etc., showed a very significant increase in fiscal year 1965 due to the prevailing drought conditions. The number of commercial companies reporting active seeding operations for 1965 is 15, which is approximately the same as in 1964. The reported area seeded, however, totals 98,000 square miles, or an increase of 72 percent over the area treated in 1964. Some 59 individual projects were reported for 1965 compared to 30 in 1964, and the number of States in

which these operations were conducted rose from 17 in 1964 to 26 in 1965. The fiscal year 1965 commercial projects may be summarized as follows:

| Purpose | Area treated (square miles) | Projects | States | Operators |
|---|---|---|---|---|
| Rain augmentation | 89,000 | 44 | 26 | 11 |
| Snow pack | 2,800 | 5 | 3 | 3 |
| Hail suppression | 6,200 | 3 | 5 | 3 |
| Fog suppression (7 airports) | ..... | 7 | 6 | 3 |
| Total | 98,000 | 59 | 26 | 15 |

In general, reported results on rain augmentation have shown average increases of 10 percent to 15 percent when the seeding was performed by qualified meteorologists on cloud systems which were already producing natural rain or were about to produce natural rain. Stream runoff increases of 6 to 10 percent were reported. The percentage of success in augmenting natural rainfall by seeding seems to be about the same for both orographic and convective systems. A majority of the commercial operators employ ground silver-iodide generators, and at times up to 100 generators have been used to cover large areas. Ground seeding in a few cases has been augmented by airborne silver-iodide generators, but the commercial operators appear to find ground-based seeding more practical and economical.

There were a few cases of unusual seeding techniques being tried by the commercial operators such as secret powders and salts, but there is no way to assess the success of these ventures. One project uses ions injected into the atmosphere by a span of fine wire stretched between telegraph poles and energized by high-voltage direct current. The value of this method as a means of stimulating rainfall is still highly controversial. Some use continues to be made of dry ice, but this is usually confined to supercooled fog dispersal at airports. The method has generally been successful when meteorological conditions are right. The use of secret salts to disperse warm fog has been claimed to be successful by several operators, but no scientific evaluation is known to exist at the present time to back up these claims. Reports claim visual clearing of fog after use of these secret processes within 20 minutes or so, but there is no assurance that clearing would not have occurred naturally.

In general, silver iodide still appears to be the favorite seeding material of commercial operators, and appears to have produced significant increases in precipitation when used intelligently by qualified personnel. Many of the small operators with no suitable technical training are finding it difficult to obtain seeding contracts, and the larger commercial operators with staffs

of competent trained professionals are obtaining a bulk of the work. There continues to be a small number of "do it yourself" operations, but most farmers and orchardists now contract out their operations to the professional groups where the yield per dollar is expected to be higher. At the present time, there is no analytical evidence from commercial operations that seeding will reduce natural rainfall, and there does appear to be some evidence that existing rainfall can be augmented by seeding. No one has yet devised a scheme for producing rainfall where natural moisture is lacking in the atmosphere, and it is unlikely that seeding can produce rainfall where drought conditions are produced by large-scale movements of dry air.

## Proposed New Federal Regulation on Reporting Weather Modification Activities

In September 1965, a proposed new Federal regulation was published in the Federal Register by the National Science Foundation inviting comments from interested parties. (These comments are currently being evaluated.) The regulation would require all weather modification efforts to be reported in advance. (Reports upon completion of projects had already been required by NSF.) As a result, it should be easier in the future to avoid conflicts of aims among weather modification projects and thus protect both Government and private investment in such experiments or operations.

Commenting on the need for this regulation, an ICAS report stated: "A major expansion of federally supported field projects is under way, some of which will operate over a period of 10 years or more. Such allocations of public funds must be adequately protected. A first step is the systematic collection of information needed to protect the validity of field experiments * * * In addition to providing a much-needed service, such information would be invaluable in advancing research, development, and operations in weather modification, and insuring that Government and other research efforts are better protected from contamination than they are today."

The text of the proposed regulation is contained in appendix D.

## Studies of the Present Status and Future Goals of the Nation's Weather Modification Program

Three groups have been at work during 1965 in efforts to define weather modification goals; scientific paths; methods of organization; division of responsibilities; and emerging legal, economic, and social problems. The Committee on Government Operations of the House of Representatives constituted a fourth group which was especially concerned with Federal Government weather activities.

## NATIONAL SCIENCE FOUNDATION SPECIAL COMMISSION ON WEATHER MODIFICATION

The group with the broadest assignment is the NSF Special Commission on Weather Modification,[1] formed in response to a request from the Federal Council for Science and Technology, transmitted through ICAS. The Council asked for an analysis of the present status and future potential of weather modification, covering a broad range of aspects of the problem—scientific, economic, social, legal, international. The request came at a time when the Foundation itself felt the need for a thorough reevaluation of the Foundation's own role in this field. The National Science Board, policymaking body of the Foundation, thereupon created the Commission.

Composed of 11 members with specialties that include meteorology and other physical sciences, ecology, law, economics, and international affairs, the Commission was asked by the Director of the Foundation to "speak on the preparations needed by the Federal Government, and society as a whole, to cope with the great power that an ability to alter the weather and climate would place in our hands," so that "as our ability to interfere effectively with the natural processes of the atmosphere continues to grow, it will not too far outstrip our ability to cope with the consequences."

The Commission has established subcommittees to probe the economic, social, legal, legislative, and international consequences of being able to modify weather and climate over large and small areas; to recommend ways to determine the effects of potential weather modification schemes on human life and ecological conditions; to consider generally how to design laboratory and field experiments so as to produce statistically reliable results; and to help formulate the basis for an accurate assessment of the scientific and technical problems still to be solved.

The Commission's report, expected in January 1966, is intended to contribute to an overall blueprint for the national effort in the years to come. It will suggest what benefits may be anticipated; what new programs need to be instituted; how to maintain the proper balance between basic research and development work; what patterns of long-range support should be established; what legal, social, economic, and political problems are likely to be encountered; and how they should be anticipated and later dealt with. Finally, it will more clearly distinguish knowns from unknowns as a guide for realistic national decisions and expectations.

## NATIONAL ACADEMY OF SCIENCES PANEL ON WEATHER AND CLIMATE MODIFICATION

A second major report, to be published nearly simultaneously with that of the NSF Special Commission, is being written by the Panel on Weather and Climate Modification of the National Academy of Sciences. The

[1] See app. C for list of members.

Panel's preliminary report, described in the Foundation's fiscal year 1964 weather modification annual report, stated that its objective was "to promote effective weather modification at the earliest possible date."

The Panel's final report will analyze what is now possible and establish rough priorities of scientific problems to be solved as steps toward various modes of weather modification. It will also recommend specific immediate actions in support of weather modification research, list urgently needed facilities and major field projects, and comment on the usefulness of an adequate global observing network in providing data for simulated experiments involving large-scale circulations.

The report will thus present a rough outline of scientific endeavor in the years ahead, and together with the NSF Special Commission report, should provide a firm basis for national planning and the setting of national priorities.

## U.S. WEATHER BUREAU

"Weather and Climate Modification," a report by staff members to the Chief of the U.S. Weather Bureau, was published July 10, 1965. This report assessed the state of weather modification research as well as socio-economic, legal, and legislative aspects of man's growing power to influence weather and climate.

In its evaluation of prospects for the future, the report assigned rough probabilities to the chances of success in various kinds of weather modification efforts. Highest probability of success (more than 50 percent) was assigned to modestly increasing precipitation from winter orographic precipitation, resulting from the lifting of moist air up the flanks of mountain ranges, and to suppressing hail and modifying hurricanes. Less likely, the report held, was the long-range prospect for purposeful (as distinguished from inadvertent) modification of climate (a possibility of inestimable potential value whose realization is also clearly much farther away in time).

The report then surveys major research options, recommending the doubling or tripling of the present annual rate of Federal expenditure on weather modification research for a period of about 5 years, after which the effort should be reappraised. The report places current emphasis on expanding research efforts into physics and physical chemistry of fine particles droplets and thin liquid films, which "appear to provide the major and perhaps only prospective tools for modifying the weather on a scale larger than a few miles." Equal emphasis is also placed on research on the dynamics and microphysics of cumulus convection as the first step in possible methods of ameliorating such atmospheric catastrophes as lightning, tornadoes, hail, torrential rains, and hurricanes. The report takes note of the current Federal effort (principally through the Bureau of Reclamation) to increase orographic precipitation from winter mountain storms. It also notes the progress being made in theoretical studies of the

dynamics of global and hemispheric circulations. It recommends a moderate increase in funding for such research, under the assumption that computer efficiencies will continue to increase and that "the present plans for global collection of meteorological data will come to fruition."

## COMMITTEE ON GOVERNMENT OPERATIONS, HOUSE OF REPRESENTATIVES

"Government Weather Programs, Military and Civilian Operations and Research," House Publication No. 177, 89th Congress, was published May 17, 1965, by the Committee on Government Operations of the House of Representatives. It describes briefly all Federal Government weather activities, in both operations and research, and presents tables showing the funding pattern of these activities. A concluding section is devoted to "Questions of Potential Congressional Concern" in 18 areas:

1. National programs
2. Mechanisms for Federal coordination
3. Coordination of atmospheric sciences and meteorological services
4. Authorizations and appropriations
5. Fragmentation of atmospheric sciences and meteorological services
6. Objectives and long-range planning
7. Congressional review
8. Air-sea interaction program
9. Weather modification program
10. Meteorological satellites
11. Climatology
12. Communication of weather data
13. Facilities
14. Manpower and education
15. Information transfer
16. Computers
17. International programs
18. Research and development

Weather modification activities of the various agencies could of course only be mentioned. "Questions of potential Congressional concern" were raised.

The Government Operations Committee forwarded copies of the report to all interested agencies, asking for whatever comments agency heads wished to make. The answers were subsequently published in "Responses of the Executive Agencies to House Report No. 177, 89th Congress." The request for comments was not interpreted as a means of seeking the answers to "Questions of Congressional Concern," nor did the 23 respondents directly deal with them. Most comments were aimed at clarifying, expanding, or placing in perspective various sections of the original report.

In his response to the Honorable Chet Holifield, chairman of the Military

Operations Subcommittee under whose aegis the report was written, the Director of the Foundation commented in part:

> Broadly speaking, the Foundation feels that major scientific progress supported by the Government must continue to be developed and to be focused on the improvement of our understanding of the atmospheric environment, which in completeness must range far beyond the operational needs of the weather services. The basic requirement to be placed on this research program is that it be vigorously directed toward developing an understanding of our finite physical environment sufficiently comprehensive to guarantee the ability to detect changes resulting from cultural influences upon the air environment before they become a signficant factor to the future of our culture; and to assure our ability to predict the influence of mankind's activities upon the physical environment well enough that the evaluations and predictions of our scientists can be accepted as being sufficient upon which to base decisions with respect to land usage, the disposal of waste materials and energy, and the conscious attempts to modify weather and climatic factors for the benefit of mankind. Therefore, such fundamental understanding must of necessity go far beyond the needs of the weather services for improvements in forecasting and of the health services for the abatement of air and water pollution.
>
> The National Science Foundation believes that the strength and vigor of our national scientific effort in this field can be best assured by insisting that it be supported from many places within the Government. This leads to the important question of how the program is to be reviewed and coordinated. Here we believe the Federal Council for Science and Technology has done an outstanding job, particularly through its Interdepartmental Committee on Atmospheric Sciences (ICAS), in focusing on the problems of the atmospheric sciences and in effecting the necessary coordination. We are satisfied that the ICAS can continue to give the needed national emphasis for the atmospheric sciences and can guard against unwarranted duplication among programs funded by many agencies.

These comments have relevance for the Foundation's program in weather modification as well as its activities in the atmospheric sciences generally.

## Legal and Legislative Problems

Weather modification has already, of course, met its first legal and legislative problems. The State of Maryland, for example, has placed a moratorium on cloud seeding for a 2-year period. In other States, weather modification operators have been sued for damage which they are alleged to have caused. There are possibilities of interference and contamination among the various commercial operators and research scientists, many of whom are working on Federal grants or contracts.

As the number of weather modification activities becomes greater, and as the techniques for modification become more powerful, a far greater need is sure to emerge for clarification and elaboration of existing State and Federal law for effective collection and dissemination of information concerning modification activities, and for some sort of Federal regulation.

Two factors make the proper course in the legal and legislative area difficult to foresee. First, of course, we cannot now predict which specific weather modification techniques will be developed, how reliable they will be, or what size areas they will affect. Second, legal history shows that the law has difficulty preparing to meet problems before they are actualities. The central question that must be answered in this area is: What legislative and regulatory steps can be taken to create a legal environment conducive both to the development of the science and the protection of the public welfare.

Accumulation of information is obviously a first step, and the way to better dissemination of current information will be helped by the proposed new reporting regulation of the Foundation, contained in appendix D.

Other legal and legislative aspects are now under consideration by the NSF Special Commission on Weather Modification, which has analyzed and summarized responses to its questionnaires addressed to the 50 States and 64 commercial operators and research groups (including Federal agencies). The legal and legislative aspects of the report of the Commission are expected to be based upon a comprehensive study and analysis of the responses.

## International Cooperation

International contacts among scientists have developed rapidly during recent years, and those interested in the potential of weather modification are no exception. As is described in the section, "Weather Modification Activities of other Nations," more than half a dozen countries are engaged in extensive field tests of weather modification techniques. A similar number of other nations have scientists involved in theoretical, laboratory, or field observing work closely related to weather modification problems.

U.S. scientists, often with the encouragement of the Foundation, have vigorously pursued contacts among scientists here and abroad as a means of accelerating research progress. Interchanges take many forms, including visiting appointments at foreign universities or research organizations; official international organizations such as the International Union of Geodesy and Geophysics; joint projects such as the recently completed International Indian Ocean Expedition; large symposia such as the International Symposium on Cloud Physics, held in Tokyo in May–June 1965, and attended by 250 scientists from 16 nations; and small working groups such as the 25 scientists who will attend the First National Symposium on Hail Suppression at Dillon, Colo., in October 1965, where scientists from 4 foreign countries will join U.S. scientists to outline a long-range program to develop hail suppression methods in this country.

No weather modification field experiments or operations have yet been undertaken that can be clearly recognized as international in character (though inadvertent modification—the spread of air pollution—has created international problems in Western Europe). As we move closer to the possibility of large-scale weather or climate modification experiments, however, scientific cooperation among nations and agreements among governments will be necessary.

The report of the Foundation's Special Commission on Weather Modification will include a discussion of first steps in such international cooperation. Clearly it is imperative to forge international understandings on both the scientific and diplomatic levels while large-scale weather modification is still deep in the research phase. The closer we are to proven application, the more difficult such international agreement will be, unless a solid foundation has been laid well in advance.

If large-scale weather modification becomes a reality, it will be due in part to the development of a truly adequate global observing network, which will supply data essential to more accurate prediction of weather, both natural and artifically modified. For the last year, a group within the Federal Government, the Interagency Committee for International Meteorological Programs (ICIMP), has been developing a U.S. International Meteorology Program Plan, by which the various interested agencies and research groups in the United States will participate with other nations in the development of a global observing experiment to test the feasibility of such a system. The experiment, to be performed in the late 1960's, will make use of tools, such as satellites, constant-level balloons, free-floating ocean buoys, unmanned land stations, and advanced computers, building on the currently operated world-observing network. The product of such a system would be a comprehensive three-dimensional picture of the global atmosphere, including observations from the three-quarters of the globe that are covered either by water or ice, and where few observations are now taken.

The ICIMP effort, which was initiated through a request from President Johnson to the Secretary of Commerce, is being closely coordinated with the World Meteorological Organization through Robert M. White, Administrator of the Environmental Science Services Administration and a member of the World Meteorological Organization (WMO) Executive Committee. The preliminary concept of a global-observing experiment has been endorsed by a joint committee of WMO and the International Union of Geodesy and Geophysics.

Without adequate global data, scientists cannot draw an accurate picture of the global atmosphere at a given time. This inability to describe the state of the atmosphere is now deemed one of the major roadblocks to extending accurate weather predictions from the present 2 days to perhaps 2 weeks or longer. It is also a major roadblock to understanding the feasibility of large-scale weather modification schemes.

# EVALUATION OF THE STATE OF THE ART IN WEATHER MODIFICATION

## Introduction

It is now 20 years since the early experiments of Langmuir, Schaefer, and Vonnegut planted the seed of credibility that man could modify the clouds and the weather. The bright hopes of 1946–1947 have been tempered with the recognition that the weather processes are much more complex than originally thought. The challenge of the atmosphere in recent years has attracted an increasing number of trained analytical minds from many disciplines of science and engineering, and progress is now being made in substituting fact for fiction through systematic research. The scientific assessment for the future of weather modification is no less bright than the dreams of the earlier experimenters, but it is tempered by a sober realization of the magnitude of the task remaining.

Weather modification, like any emerging science and technology, has been principally divided into two schools of thought. One school of thought is represented by the basic researcher in search for scientific fact who is best satisfied with the logical progression of proven scientific evidence obtained in the laboratory, fully supported by theoretical reasoning, and verified in the atmosphere by a series of critical experiments. It was by such deductive process that atomic energy was developed and made available to mankind today. It is a proven approach and has demonstrated its efficacy many times in the physical, chemical, and mathematical sciences.

The second school of thought consists of those who are concerned with the realization that the atmosphere is a complex and large entity containing many variables, some of which are beyond the understanding of man today or in the near future. This group feels that the laboratory approach can never adequately simulate the environment of the earth's atmosphere, and that the best approach is to conduct experiments on the natural atmosphere and then attempt to assess results through statistical evaluation and the formulation of theoretical models.

There is, of course, a third position which maintains that, for best progress, both schools of thought must be preserved and fostered, and that good exchange should take place between them. This is the position selected by the National Science Foundation. Over the past 7 years the NSF has stimulated and supported research projects following both schools of thought. NSF has also encouraged personal contacts, sponsored symposia and conferences, and disseminated information and reports to provide the cross-fertilization required. The fruits of these efforts are evident in the program of

the Bureau of Reclamation for increasing precipitation over water sheds of its reservoir systems in the Western States.

Much scientific work remains to be done. Nonetheless, steady progress has been made along many lines in the understanding of atmospheric processes looking toward beneficial weather modification.

## Fog and Cloud Modification

The modification of fogs or clouds is usually attempted either to dissipate them to improve visibility or to cause more rapid cloud development so that natural precipitation may result.

The dissipation of cold fog for the improvement of visibility is already a proven technique using either dry ice or the release of propane gas through expansion nozzles to produce local freezing. It is being used in pilot operations by the U.S. Air Force, by United Airlines, and in several foreign countries, including Russia and France. The Federal Aviation Agency is searching out the broad operational significance of the cold fog dissipation methods.

The dissipation of warm fogs (fog particle temperatures above freezing) has not yet been satisfactorily achieved. Four general approaches are now being pursued. One technique attempts to evaporate the fog droplets by the introduction of massive quantities of heat from open flames or infrared burners. This is the mechanism used by the British in World War II to clear landing strips for military aircraft, and is generally known as the FIDO system. It is a successful system, provided that sufficient heat can be provided and maintained in the runway area. It is expensive to install and operate and is localized to the treated runway areas. Unless taxi strips, maintenance areas, loading ramps, etc., are included in the ring of heat, air traffic may bottleneck as soon as it leaves the runway area. Pilots feel uneasy in landing between the walls of fire. Landing problems can also be complicated by the turbulence created by the hot thermals at critical control points before touch down on the runway.

A second method involves the use of fans to draw dry air from above into the fog. When sufficient dry air is mixed into the fog, the fog particles will evaporate. The U.S. Army has successfully used helicopter downwash to produce such mixing where the fog layer was shallow and dry air was available aloft.

The third technique attempts to sweep out the fog droplets by releasing a water spray from an aircraft flying over the fog deck and mechnically driving the fog particles to the ground. This works successfully if sufficient water can be released by the spray aircraft; however, this is not a practical system because the quantities of water needed are too large. Charged sand and concentrated salt brine have also been tried with no major improvement in practical application.

A fourth method attempts to stimulate coagulation of the fog particles into large enough droplets to fall out as a drizzle. The injection of elec-

trical charges into the fog to produce attraction between fog droplets holds some promise for success, but a successful way of introducing charged ions without developing space charge barriers has not yet been developed. The coagulation of fog droplets in sound beams using sirens, whistles, loudspeakers, etc., has been successfully demonstrated in laboratory enclosures but, in the free atmosphere where standing waves cannot be produced by reflections from solid surfaces such as walls, the amount of energy required is prohibitive. The use of finely ground deliquescent salt particles blown into the fog by fans has been successful in some cases by producing droplet growth centers which accumulate liquid water from the saturated water vapor in the air and causing the fog droplets to evaporate. The drizzle of brine droplets which results, however, is corrosive to metal and produces stains on grass, runways, and buildings.

Overall, there appears to be sufficient success in the dissipation of warm fog to predict that eventually an economical, clean, and practical method can be developed. Possibly the application of several of the above mentioned techniques applied either simultaneously or in sequence will provide the answer.

In the opposite sense to dissipation, there is sometimes the need to preserve a cloud which is in danger of evaporation. Rain shadow areas are common natural occurrences behind mountain chains where downward flowing air can inhibit cloud development. Research has shown that if clouds are seeded with dry ice or silver iodide as they grow and extend above the freezing level over a mountain ridge, ice crystals will be formed and sufficient heat may be released to provide extra buoyancy to the cloud to prevent its dissipation as it passes over to the adjacent valley. Rain may then develop naturally within the cloud and provide moisture in the previous shadow area.

## Precipitation Modification

The problem of artificially stimulating rain to fall from a cloud is largely one of inducing approximately a million or more tiny cloud particles to join together and form a single rain droplet.

Most successful attempts at rain stimulation involve the addition of silver iodide or dry ice to produce freezing of supercooled droplets (supercooling is an unstable condition where the temperature is below freezing but the water is still liquid). Once tiny crystals form, they grow rapidly; as fast as available water vapor turns into ice, cloud droplets evaporate to replace it. When the ice crystals became heavy enough, they fall through the cloud and collide with water droplets, freezing them directly. At this stage they are snowflakes. If the bottom layers of the atmosphere are near freezing a snowfall results. If the bottom layers are warmer, the flakes melt and fall as rain.

It is estimated that in a coastal storm where moist maritime air is lifted up over a coastal mountain range, such as in the Northwestern Pacific

coast range, approximately 25 to 30 percent of the available moisture will fall as natural precipitation on the upslope of the mountain. Ordinary convective thunderstorms, on the other hand, are formed by thermal lifting of air masses and are estimated to deliver approximately 10 percent of the available liquid water as natural precipitation on the ground. While the effect of seeding will vary greatly depending upon the meteorological situation, an average increase of 10 to 15 percent in the amount of rain reaching the ground seems to be indicated. It should be noted that this figure applies only to an increase in rainfall from clouds which are already raining or about to rain.

Most of the water content of air passing over land masses is of maritime origin acquired from long periods of passage over the oceans, and very little water falling upon land areas is recycled back into the clouds again. Rainfall patterns and drought cycles are produced by variations in the global circulation trajectories of large-scale air masses, and cloud seeding is ineffective if the upper level air masses are dry.

Not all rain falls from clouds which contain ice crystals. In the tropics, rain commonly falls from clouds which have not reached the freezing level. The mechanism responsible for the coalescence of the cloud droplets into rain is not well understood. It is known that electrostatic effects, droplet collisions, cloud motions, and natural sea salt nuclei are involved at one time or another.

One theory is based upon the observation that clouds generated over the ocean generally contain larger drop sizes on the average than clouds formed over the continent. The theory suggests that the nuclei upon which the maritime cloud particles condense consists mostly of giant salt nuclei formed by evaporated ocean spray. Since the vapor pressure of a cloud water particle formed on a salt particle is less than that for pure water, the particle will continue to grow as long as the salt content of the cloud drop is highly concentrated. If the salt nucleus were large enough to begin with, the cloud particle may grow quickly to raindrop size. The theory is the basis of an experiment now underway in the Virgin Islands where warm cumulus maritime clouds are being seeded with finely pulverized salts. The salt is released from an aircraft into the updraft of a building cumulus deck. Visual observations to date have indicated excellent results on clouds exceeding 4,000 feet in thickness.

## Hail Suppression

A hailstorm is a severe thundercloud containing violent updrafts which sustain large supercooled liquid water contents at temperatures below freezing. Ice crystals within the cloud are driven violently upwards into the supercooled water accumulation zone. Here they can grow rapidly into hailstones by successive collisions with the supercooled water droplets. Since the updrafts are turbulent, a growing hailstone may pass up and down

through the liquid water accumulation zone many times, building up onionlike layers of ice. A typical hailstorm usually has many individual cells, and hail has been observed to fall in five or six widely separated areas within a short length of time from a single storm. The fact that some hailstones are clear ice and others milky in color indicate that different processes of growth were in operation.

Hail modification attempts in the United States, Russia, Switzerland, and Argentina have utilized seeding by silver iodide. The Russians have been especially careful to pinpoint injections of silver iodide into the collection zone of the storm by using artillery shells and small rockets directed by radar. Their claims of millions of rubles saved each year in crop damage through pinpoint seeding lend credence to this technique.

In Argentina, hail suppression was conducted with ground-based silver-iodide generators. The puzzling results reported indicate that on days when a cold front had just passed, hail damage was reduced by 70 percent due to seeding. However, on nonfrontal days, seeding appeared to double the amount of hail damage. It is apparent that different storm structures were involved on the two types of hail days. Further, it seems possible that on days of cold front pasage, the accumulation zone received enough of the ground released silver iodide to be effective in converting its liquid water content into ice. In any event, there does appear to be great need to study the dynamics of hailstorm structure and considerable reason to believe that hailstone suppression can be attained in the not too distant future.

Interesting hail suppression experiments have been conducted in Italy and in Kenya. Small rockets containing an explosive charge of TNT are fired into hail-bearing clouds in large numbers by local farmers and ranchers. In Kenya it is reported that hail losses on the 1 plantation protected by this rocket firing program have been reduced to less than 1 percent of the damage experienced by 12 nearby plantations which were not protected. The same experience is claimed by the grape growers in Italy. The result is consistent with experiments being conducted in this country and elsewhere on the freezing of supercooled water droplets by shock waves produced by explosions. When balloon-borne explosives are detonated in the center of a cloud of supercooled water droplets, ice crystals are observed to fall from the cloud immediately after the explosion. The use of supersonic military aircraft to project sonic booms into hail clouds is a likely subject of investigation for hail suppression studies in the near future.

## Lightning Modification

The mechanism for the production of electricity in clouds is poorly understood at the present time. Some observations indicate that electrical fields appear in clouds as soon as ice crystals are formed. However, this does not cover the situations where strong electrical fields are observed in warm clouds where no ice is present. Other theories suggest that space charge is carried

from the surface layer of air near the earth into the clouds by the convective updraft of the cloud. Regardless of the slim knowledge about the mechanism involved, the reduction of destructive lightning strokes which damage millions of dollars of forest lands and property each year requires attention from the weather modification expert.

Massive seedings of lightning storms with silver iodide by the U.S. Forest Service shows that a significant reduction in cloud to ground lightning strokes can be obtained. Laboratory tests predict that the presence of ice crystals in a volume of air exposed to breakdown electrical potentials will cause electrical breakdowns to occur at lower potential gradients than in clear air. A higher density of ice crystals in lightning-bearing clouds may well reduce the potential at which lightning strokes can occur and thereby reduce the severity of the lightning. It is also possible that a very high density of ice crystals will drain off sufficient charge internally from the cloud to prevent lightning initiation. Further evidence of the effectiveness of this latter approach was obtained by U.S. Army scientists who released millions of tiny metallic needles into a thunderstorm from an aircraft, and observed a significant reduction in electrical field gradient in the vicinity of the charged cloud when the needles were present.

## Severe Storm Modification

Hurricanes are spawned in the warm tropical waters of the Caribbean by the absorption of warm moist air into the rising convective tower of an active growing cumulus cloud. As the heavily laden moist surface air is sucked into the rising cloud, it is cooled by expansion as it reaches upwards, and the water condenses out in the form of billions of tiny cloud droplets. The condensing process releases the heat of condensation to the surrounding cloud mass and causes the cloud to rise with increasing velocity like a hot air balloon. This in turn sucks up more warm moist surface air which also condenses, and the rising tower grows with ever increasing intensity. The high velocity winds ejected from the top of the cloud tower distribute themselves horizontally in radial trajectories from the center in all directions. After traveling horizontally for many miles from the convective center, these winds lose their momentum and fall back to the surface of the warm ocean where they replenish their heat and moisture supply and are sucked back into the core to repeat the cycle all over again. This circulatory system with the core cloud acting as a pump extends for 60–100 miles or more in radius for a mature storm, and involves energy of the motion of tons of fast moving air exceeding many thousands of megatons of nuclear energy.

In current attempts to modify hurricanes, massive quantities of silver iodide are periodically released over an 8- to 10-hour period into the supercooled portion of the core cloud which drives the storms, and it is believed

that the cool water droplets are converted immediately into ice. The freezing ice liberates its heat of fusion to the surrounding cloud mass and induces a momentary increase in the vertical motion of the cloud. It is hypothesized that this increase in vertical motion forces the rotating wind structure outward to cover a larger area than before. Since the storm is forced to spread out over a larger area but has gained no additional momentum, the average wind velocity is reduced significantly and the storm becomes less damaging. The Navy-Weather Bureau Project Stormfury has conducted a few such massive seeding experiments intended to test the above hypothesis. The results are as yet inconclusive. More research and experimentation are planned.

There are other avenues of approach to hurricane modification. The fuel on which the hurricane feeds is the shallow layer of warm water which lies on the surface of the tropical seas. If effective means can be found to seal off the surface of the ocean, for example by spreading a thin layer of an oily material over the water, then the supply of moisture upon which the hurricane feeds may be cut off. It may also be possible to produce mixing of the warm surface water with the cooler water just a few feet below it and lower the water surface temperature below the critical point. Further, it is conceivable that artificial cirrus clouds can be maintained by aircraft or rockets high above the danger area to reduce solar heating of the sea surface. In any event, the suppression of hurricanes will probably not be achieved by brute force methods, and it seems more profitable to search out the mechanisms by which nature builds up its huge storehouse of hurricane energy, and to interfere with a critical ingredient while the process of build up is still in the formative stage.

The research required to achieve this knowledge is well underway, and mathematical models are being studied on high-speed computers to find the weak link in the chain of hurricane formation. In looking ahead, it is hoped the key will be found, and hurricanes will be starved into submission in their own breeding ground.

The suppression of tornadoes is a problem of even greater difficulty than hurricanes because they appear spontaneously and with very little warning. The tornado is known to contain a significant quantity of electrical energy, but it is not yet apparent whether the electrical activity is a side effect or a dominant driving force in tornado formation. Since the "will of the wisp" appearance of tornadoes has precluded cloud seeding attempts, the approach to this problem is presently confined to laboratory simulation and theoretical computer modeling. It will probably be many years before sufficient insight can be gained into the tornado mechanism to indicate fruitful modification procedures. There is some hope that the severe storms which spawn the tornado may be amenable to treatment rather than the tornado itself, and a more feasible approach would be to prevent the storm from reaching the proportions of tornado generation.

## Climate Modification

Climate modification is distinguished from weather modification by the span of time covered by the modification activity. If the permanent pattern of weather activity is altered by intervention, whether intentional or not, then climate modification has taken place.

The unintentional modification of the atmosphere by man continues due to his pollution of the atmosphere—modification of the surface climate structure through urbanization, deforestation of large wooded areas, building of dams and diversion of rivers, to mention a few. The modification upwards of the mean average surface air temperature by several degrees in heavily populated regions is a matter of record. All such inadvertent modification is cause for serious concern as to future consequences, and deserves careful study.

To date, studies leading to the climate modification have been confined to the electronic computer. The primative equations of the general motion of the earth's atmosphere have been combined into a mathematical model, and hypothetical cases of climate modification have been tested by mathematically removing the arctic ice pack, removing portions of mountain ranges, changing ocean temperatures, etc. While these mathematical models respond well to large-scale modification inputs, they are not yet sensitive enough to detect small-scale changes such as might be produced by cloud seeding.

The possibility of being able to alter the global pattern of atmospheric air masses has been the subject of much speculation. Such large-scale measures as melting the Arctic ice cap, diverting warm ocean currents, artificially producing widespread cirrus cloud cover by rocket or aircraft seeding, injecting reflecting dust or needles into orbit above the earth, etc., are being studied theoretically with respect to their possible effects upon circulation patterns. Actual climate modification attempts cannot be made until the consequences on a worldwide basis can be assessed. There is too much at stake to permit irresponsible tampering of the atmosphere at this time on a global scale. It is anticipated that the next 5–10 years will provide the necessary knowledge and increased computer capacity to permit an accurate assessment of these consequences.

## WEATHER MODIFICATION ACTIVITIES OF FOREIGN NATIONS

The amount and variety of weather modification activities elsewhere in the world are impressive. Research on nucleation, ice crystal growth, coalescence, cloud structure and dynamics, etc., in being conducted in many laboratories in many countries. In Argentina, Australia, Canada, France, Italy, Kenya, Korea, and the Soviet Union field programs in weather modification are being conducted or are now getting under way.

### U.S.S.R.

The Soviet Union's weather modification program is by far the world's largest, exceeding that of the United States by two or three times, it was estimated by members of a U.S. delegation that visited the Soviet Union in May 1964.[2] The major Russian operational efforts are directed at dissipation of supercooled fogs, stimulation of precipitation, and hail suppression. The hail suppression effort is the most elaborate, involving extensive use of aircraft, radar, rockets, artillery, balloons, dense observing networks, and a wide variety of instrumentation—all of which is backed up by a sizable program of theoretical work and laboratory investigation. END p. 31

The major portion of the hail suppression effort is being carried out under G. K. Sulakvelidze of the Alpine Research Institute in Nalchik, with its field program located in the Alazon Valley of Georgia; and under A. I. Kartsivadze of the Georgian Academy of Science. Kartsivadze operates a regular seeding service for farmers in the Transcaucasus on a subscription basis. It is claimed that the program averted 10 million rubles in crop damage in 1964. The hail suppression technique employed by Sulakvelidze involves the detection of hail in the clouds by radar and the subsequent seeding of the clouds at the −5.5° C. level. This is done with artillery shells containing 50–100 grams of silver iodide each, fired at 10–15 minute intervals until the storm is over. The technique used by Kartsivadze is similar, except that rockets are used instead of artillery.

[2] The major portion of this description of Russian activities was taken from a published article of one of the members of the delegation (Battan, Louis J., "A View of Cloud Physics in the Soviet Union," *Bulletin,* AMS, 46, 309, June 1965) and from an unpublished report on a separate trip by David Atlas, of the Air Force Cambridge Research Laboratories.

A very brief summary of other weather modification work in the Soviet Union follows:

*Dry-ice seeding of supercooled fog.*—During the winter of 1963–64, the Soviet Hydrometeorological Service seeded supercooled fog on 31 days at three different airports, with success reported on 30 days. During 1964–65, the Service planned to extend the experiment to nine more airports.

*Cloud-seeding to modify patterns of snowfall.*—The Institute of Applied Geophysics at Obinsk has been seeding clouds with dry ice in an area approximately 125 miles in diameter, in order to determine if snowfall over a small area can be increased, with the subsequent effect of decreasing snowfall downwind. The Soviets are interested not only in the possibility of augmenting precipitation in an agricultural or reservoir area, but also, as a byproduct, decreasing the snow removal job various cities face each winter.

*Increasing precipitation on the plains near Kirovograd.*—The Ukraine Hydrometeorological Research Institute in Kiev has established a large test area (31 miles wide, 46 miles long) near Kirovograd, with approximately 350 rain gages placed therein. Dry-ice seeding, especially of warm-front stratus, has appeared to produce increased precipitation when some rain was already falling naturally from the clouds. Rainfall augmentation was reported to average 10–15 percent in the successful cases.

*Laboratory experimentation—cloud chambers.*—Several institutes have built cloud chambers, one of them 45 feet in diameter and 54 feet high (but without temperature controls) and other smaller, more sophisticated chambers, for studies of condensation, coalescence, ice nucleation, the effect of cloud motions, and other processes affecting precipitation.

*Weather radar development.*—Soviet scientists have worked extensively to develop radars that can detect rainfall rate, parameters measuring the likelihood of hail, etc. "In the last 5 years or so, Soviet capability in radar meteorology appears to have increased markedly," Battan reports.

In addition, many more basic studies of precipitation processes, such as the effectiveness of both condensation and freezing nucleating materials, are being vigorously carried on at more than 10 Soviet institutes and universities.

## Argentina

A 5-year hail-prevention experiment is underway in Mendoza, Argentina, using randomized seeding with silver iodide in an attempt to reduce damage in the vineyards. Classification of test days into two groups, one of which includes all those during which a surface cold front has passed, and the second of which includes all other test days, shows a striking result. On cold front days, the total damage decreases approximately 70 percent for seeded days. On other days, seeding appears to increase the damage by almost 100 percent.

## Australia

In Australia, active research in weather modification is being carried on by Commonwealth Scientific and Industrial Research Organisation (CSIRO) and other research organizations and at universities. Considerable attention is being given to the formation of ice in clouds, and to the mechanisms whereby natural nucleators are introduced into the atmosphere and distributed into clouds. Cloud-seeding experiments have been carried on for a long period of time, and E. G. Bowen of CSIRO summarizes his conclusions as follows: "The experiments have in general not been sufficiently sensitive to give unequivocal results. The factors which appear to have contributed to this are:

"(1) The probability that silver iodide on some occasions increases precipitation and on other occasions decreases it cannot be discounted.

"(2) Seeding may increase the variance of rainfall in the test regions and hence extend the time necessary to achieve a significant result.

"(3) The present design of randomized experiments breaks down or becomes progressively more insensitive if these are persistent or cumulative effects due to seeding."

## Canada

In the past fiscal year, cloud seeding has received much publicity in the Ottawa and Quebec areas of Canada. Rainmaking attempts by Weather Engineering, Inc., and Genie-Metro under sponsorship of local government have coincided with 2 years of downpour and drizzle in the Lac St. Jean area of Northern Quebec, and irate citizens have demanded a cessation of operations. Unfortunately, there is no scientific evidence available either to substantiate or to refute the existence of a casual relationship between the general weather conditions and the cloud seeding. A silver-iodide seeding project being carried out in Canada for the purpose of reducing lightning-induced forest fires has been investigated by Canadian scientists for 4 years. They concluded that it has failed to increase precipitation.

In Alberta, a continuing investigation into hailstorms was begun in 1956. It is being supported by the Research Council of Alberta, the National Research Council of Canada, the Canadian Meteorological Service, and the Stormy Weather Group of McGill University in Montreal. The immediate aim of the project is the elucidation of the causes and behavior of Alberta hailstorms, and the longer term object is that of conducting experiments aimed at developing possible modification techniques. The summer field program is located within Alberta's severe hail belt, where some hail is observed on 2 days out of 3 during the months of June, July, and August. In this sensitive grain-growing area, covering over 25,000 square miles, farmers serve as voluntary hail observers. This survey technique is capable of providing about one report per 2 square miles over large areas.

## France

In France, seedings with silver iodide conducted by Electricite de France in the mountain regions for 10 years have produced no statistically significant increase in precipitation. P. Cachera offers two possible explanations for this lack of success:

(1) Inside the portion of the precipitation really due to the Bergeron-Findeisen ice process, only a little part offers conditions favorable to an artificial action.

(2) In natural clouds, silver iodide has no ice-forming action such as observed in cloud chambers.

## Germany

In Germany, work continues on the physics of clouds and precipitation. Measurement of drop-size spectrum and liquid-water content are being made on the Jungfraujoch in Switzerland by German scientists. The importance of the coalescence processes in the supercooled clouds has been recognized because ice crystal growth alone cannot account for the observed rainfall rates. Attention is also being given to atmospheric electricity and associated charging processes using ground and free-balloon measuring instruments.

## Great Britain

The collision and coalescence of water droplets of sizes occurring in clouds continue to be studied in Great Britain using streak photography. For droplets below 35 microns in diameter, collisions do not very often result in coalescence. The tendency of electrical charge to increase the probability of coalescence has also been confirmed by this work. Research has also been performed on the electrification produced by melting and evaporating ice crystals. In the case of evaporation, it is interesting to note that a positive charge is measured on the specimen if its surface is warmer than its interior, and a negative charge is observed if the surface is colder. These results are being studied from the standpoint of their bearing on charge generation in clouds. Studies of ice crystal growth are also in progress in Great Britain.

## India

Scientists in India are studying condensation nuclei and find that the hygroscopic aerosol-nuclei count at Delhi showed a marked increase during the monsoon with a corresponding decrease in nonhygroscopic aerosol nuclei. Measurements of precipitation electricity from tropical rainstorms have been made, and possible mechanisms of charge separation in tropical thunderstorms are being considered.

## Israel

In Israel, research is being carried on to determine the physical characteristics and possible effects of ice nuclei upon precipitation initiation processes. Examining the frequency distributions of nuclei counts and hourly amounts of rain for various stations, the scientists have found a clear tendency for places with higher nuclei counts to have corresponding higher hourly amounts of rain. The observed dependence of nuclei counts on wind direction was found to correspond to a similar dependence on the hourly amounts of rain. Studies are also being made of the oscillation of solid spheres falling under gravity through a viscous liquid in order to estimate this effect upon the computed collection efficiency of falling raindrops through clouds.

## Italy

In Italy, work continues on the use of small rockets by the grape growers to reduce the intensity of hail in severe storms. Studies are also being made of the electrical charging of dusts in the atmosphere and its possible influence upon the formation of atmospheric water droplets.

## Japan

Japan continues to have a large and competent research capability in cloud physics. Numerical models of convective clouds are being developed and compared to field observations. Studies are being made on the physical structure of fog and stratus clouds, and ice crystal sondes are being flown into clouds on free balloons to bring back to earth formvar impressions of ice crystals encountered. Studies similar to those in progress in Great Britain are also being made on the positive electrification of melting snow crystals. In general, Japan excels in studies of ice crystal formation, growth, and shapes.

Since 1951, the Meteorological Research Institute of the Japanese Meteorological Agency has been conducting artificial rainmaking experiments on behalf of the electric power companies. The experiments utilized ground-based silver iodide generators and resulted in a reported increase in precipitation from 10 to 20 percent during the summer season. Techniques have been used to tag rainfall produced by the artificial seeding, and results appear to show that the increase in rainfall is due to seeding. Work was also done on dry ice seeding, and the results observed with a 3-centimeter radar.

## Kenya

In Kenya, an extremely interesting experiment on hail suppression is now underway using an Italian type of rocket. A network of antihail rocket stations has been set up by the African Highlands Produce Co. on 1 of their 12 tea growing estates in Kenya. There are 13 launching sites approximately one-fourth mile apart from which small rockets with explosive nose cones can

be launched. Rockets are fired only when hail is actually observed, and firing continues until hail ceases. In 1962, at the start of the experiment, 1 of the 12 estates suffered approximately 25 percent of the total hail damage suffered by all 12. This estate was selected for protection by rockets, and by 1964 it was suffering less than 1 percent of the total hail damage. No other estate has shown a comparable decrease, and there is no evidence of any natural decrease in the frequency or severity of hailstorms.

## Korea

Atmospheric scientists in Korea are making a survey of natural-ice nucleus concentration in preparation for a cloud seeding experiment in that country. A silver-iodide generator has been obtained from CSIRO in Australia and tested in the field. Rainwater is collected in a rain-gage network around Seoul and is analyzed for silver-iodide content by the method of Isona and Warburton. To date, results are not sufficient to lead to definite conclusions.

## Switzerland

In Switzerland, efforts are being made to analyze the hail seeding data collected by the late Professor Sanger, and adjacent areas in Germany and France are being considered as possible control areas for the analysis. Work is also being done on the growth of hailstones using 6-mm.-diameter plastic graupel models in a wind tunnel. The growth of natural hailstones is then compared with the results of the wind tunnel experiments.

## Tunisia

In Tunisia, French scientist R. Serpolay is conducting a series of interesting experiments on the dispersal of supercooled ground fog. His technique involves use of a set of sprayers which vaporize liquid propane along a remote perimeter surrounding the entire system of runways. The localized low temperatures produced by the vaporizing propane results in the formation of ice crystals in the vicinity of the nozzles, and these ice crystals are diffused into the fog. This seeding results in the formation of wide holes in the fog in an area extending to approximately 4,500 feet downwind from the spray area. The effect can be sustained as long as the spray nozzles are operating.

## WEATHER MODIFICATION PROGRAM OF THE NATIONAL SCIENCE FOUNDATION

Fiscal year 1965 is the seventh year in which the Foundation has supported a program of weather modification research. While a majority of the research has been carried on through university efforts, the NSF has also enlisted the efforts of outstanding researchers on the staffs of industrial corporations and nonprofit institutes. In addition, NSF has sponsored "in house" efforts in other Government agencies in weather modification to insure that funding is made available to develop worthwhile ideas and talents in this field within the Federal Government's scientific organizations. This program has resulted in a broad research and development effort extending across the entire spectrum of weather modification problems, ranging from the elucidation of the mechanism of ice nucleation to actual field seeding and observational programs employing radar networks and multiple aircraft. Each year has shown advances in our understanding of weather modification processes, and fiscal year 1965 has been particularly important in this respect.

Appendix A contains a summary of NSF grants and contracts made in 1965, as well as those projects continuing from previous years.

### Project Whitetop

The University of Chicago's Project Whitetop has completed its first year of operation at Bemidji, Minn., following 5 years of operation at West Plains, Mo. A preliminary examination of the Bemidji data to date indicates that the droplet coalescence mechanism operates much more slowly in this more northern area than in Missouri, and that the first ice found in cumulus clouds in Minnesota is usually in the form of ice crystals and snow as contrasted with the ice pellets and graupel characteristically found in the Missouri cumulus clouds. This result emphasizes the hazards of postulating universal precipitation mechanisms.

A review of the past 5 years of seeding operations at West Plains has also revealed that the precipitation average taken over a 90-mile downwind strip of terrain over which a seeded plume has passed shows less than normal precipitation as compared to control areas. Paradoxically, however, radar observations of the clouds in the area show quite another story. The analysis to date has shown that seeding results in increased radar echo signals in a region 30–50 miles downwind of the seeding line during

the hours of seeding. Beyond a point about 30–50 miles downwind from the seeded area there is another broad region of 30–50 miles wide from which the radar echo signal is weaker than would be expected in the absence of seeding. The data also suggest that another region of increased precipitation develops about 80 miles further downwind. This evidence suggests that cloud-base seeding has a direct effect only upon the clouds immediately downwind of the seeding line. As a result of the increased growth of clouds in the seeded area, it is hypothesized that a physical perturbation occurs which spreads outward and downstream, creating a region unfavorable for cloud growth.

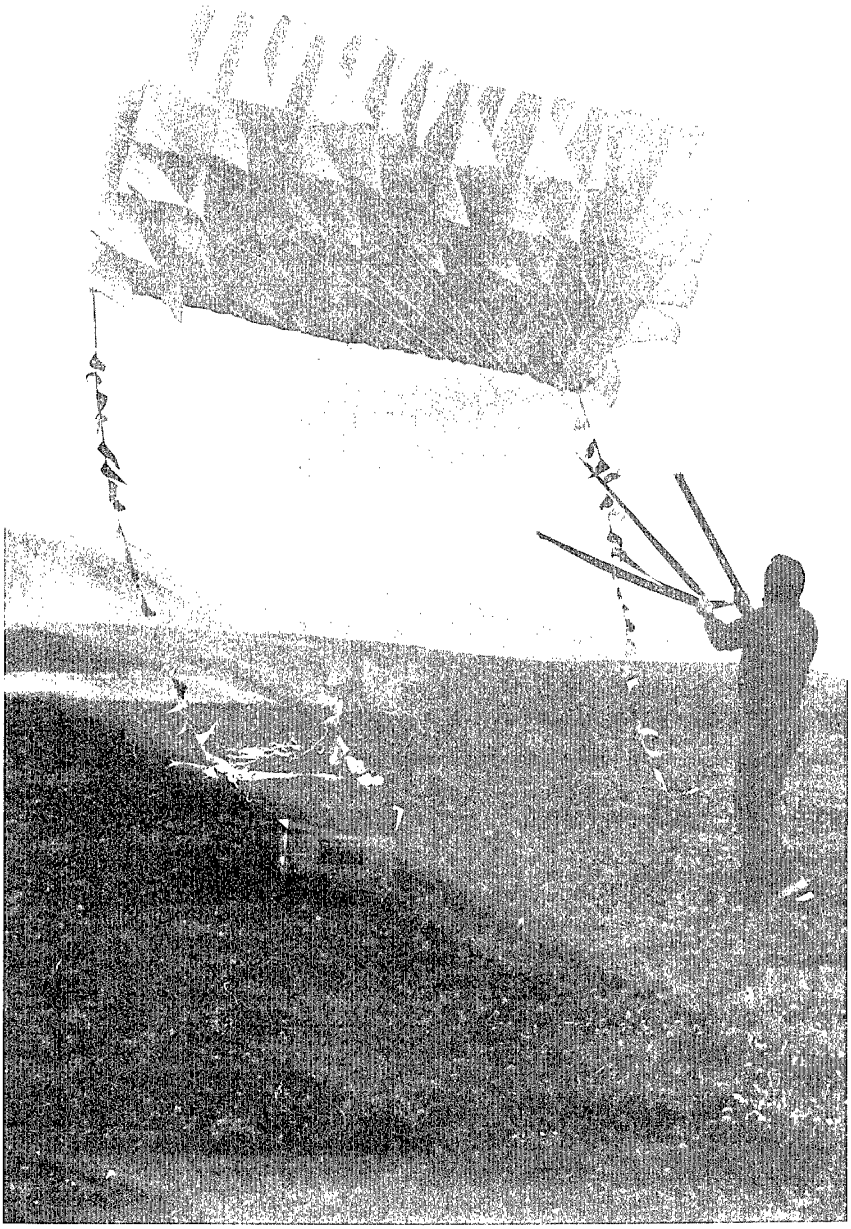
It is believed that the negative radar echo regions are not produced by prior precipitation of available water, but can be attributed to a dynamic interaction between the seeded clouds and their environment. According to this theory, seeding does not squeeze the cloud dry over the increased precipitation area, but rather, generates a gravity wave similar to that in air which passes over a sharp mountain peak. At the peak, precipitation is increased; beyond the peak the pressure and temperature increase, and precipitation is decreased. Positive and negative enhancement occurs periodically downstream until the wave motion is dampened out.

## Ten Years of Cloud Seeding in Kings River Drainage Area

During the summer of 1965, an analysis, jointly sponsored by the Kings River Conservation District in California and the NSF, has been completed of 10 years of commercial cloud-seeding operations carried out by Atmospherics, Inc. The results indicate that a 6-percent increase in the runoff into the Kings River drainage area occurred due to the seeding of winter storms under orographic conditions. While many commercial operators have reported increases in precipitation over short periods of time, this NSF-sponsored study is one of the first to indicate results over a significantly long period of time. There seems to be every indication that under the conditions of operation in the Kings River drainage area, the use of silver iodide has enhanced the rainfall totals. It should be noted that this work was carried out under the supervision of a competent meteorologist, and seeding was performed only when moisture-bearing clouds of the proper structure and meteorological composition were present.

## Field Study of Convective Cumulus Clouds in Arizona

During the summer of 1965, the Pennsylvania State University participated with the University of Nevada; Meteorology Research, Inc.; and the U.S. Army and the Boeing Aircraft Co. in a joint field program at Flagstaff, Ariz., to study convective cumulus clouds over the San Francisco Peak. It is interesting to note some preliminary observations by the Pennsylvania State research team which indicated that atmospheric electricity measurements performed from their aircraft showed that very weak



This airfoil kite used by Colorado State University scientists lifts instruments into clouds over a mountain peak near Climax, Colo. The scientific tasks performed by the instruments include sampling ice crystal forms and recording air temperature, pressure, and humidity.

electric fields exist in clouds which contain only supercooled water droplets. When clouds were seeded with silver iodide, however, an electric field enhancement of several orders of magnitude was immediately noted coincident with the formation of ice particles. While one cannot state that the electric field in convective clouds is always the result of ice formation, these observations tend to indicate a strong correlation of electrical activity with ice formation in clouds of the Flagstaff variety.

Photo by Sigurg Jonasson

**Lightning streaks through a dust cloud during the 1963 volcanic eruption that created the Icelandic island of Surtsey. Dr. B. Vonnegut investigated the phenomena as part of a study of cloud electrification mechanisms. Such mechanisms are believed to be important in thunderstorm charge generation and in the initiation of lightning strokes.**

## Improving Efficiency of Ice-Nucleating Materials

The effectiveness of any cloud-seeding operation depends vitally upon the efficiency of the nucleating material used. Silver iodide was originally investigated as an ice nucleator because its crystal structure most closely resembled that of ice. Its demonstrated efficiency in the laboratory and field as a nucleator seemed to be confirming evidence that its ice-like structure was the key to its performance. Recent studies at the University of Arizona and at Lehigh University have cast doubts on this theory, and seem to prove that the important characteristic is not the crystalline structure of the silver iodide but the nature of the nucleator surface upon which super-

cooled water adheres and freezes. This new work indicates that a good nucleator must be of a hydrophobic material (nonwater absorptive), but must have scattered on its surface small patches of hydrophylic material (attractive to water) upon which tiny clusters of water molecules may cling and freeze into ice. Once these tiny clusters of water have frozen, other water molecules join them, and the ice crystal is then organized and starts to grow.

This theory was partially verified at Lehigh University by the synthesis of good nucleators from materials which were normally poor nucleators by partially "hydrophobing" their surface with inorganic salts. Optimum results were obtained when the water-absorbing centers covered approximately 20–30 percent of the normally water repellent surface of the material. Despite the fact that the crystal structures of the new materials are unlike that of ice, they are quite efficient in producing ice crystals from supercooled water droplets. A seeding flight which was made by Project Whitetop in Missouri during February 1965, using these new materials attested to their efficiency. They were also proven effective at the Fifth Yellowstone Field Research Expedition during January 1965.

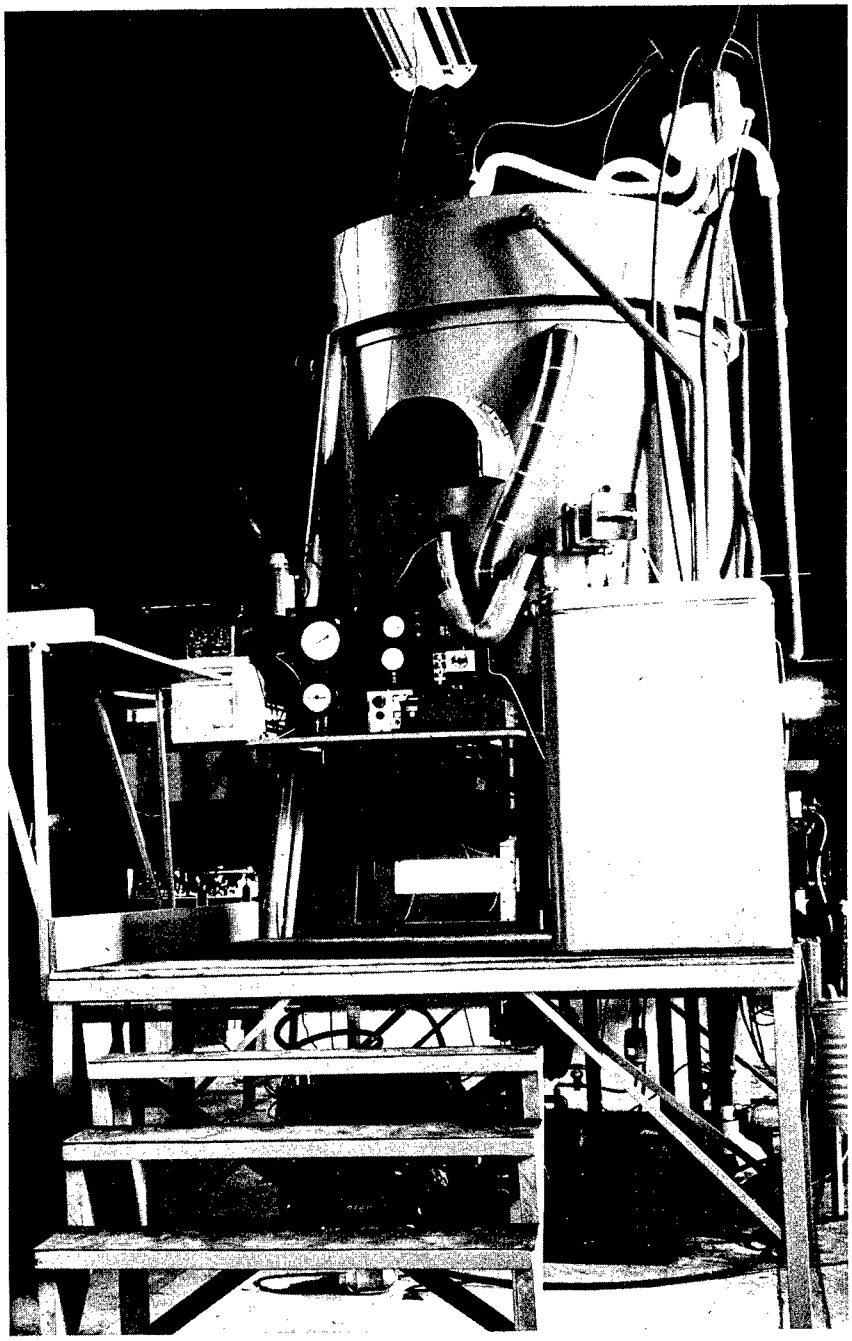
Later in 1965, at the University of Arizona, ultrapure silver iodide was prepared from silver powder and iodine vapor under vacuum. This material was tested in Colorado State University's new isothermal cloud chamber, and it was found to be only 1 percent as effective in producing ice crystals at $-10°$ C. as the more impure commercial grade of silver iodide. It is now suspected that certain trace impurities in the commercial grade of silver iodide are responsible for its efficiency, and that the silver iodide alone is highly ineffective. The University of Arizona is now deliberately contaminating batches of the pure material with traces of other hygroscopic inorganic salts in order to determine which of these might be responsible for the superior nucleating properties of the commercial materials.

Another interesting development has been the discovery of an entirely new class of nucleating materials by a researcher at the University of Chicago. These materials are of types which strongly absorb heat when they go into solution in water. One such substance is common urea, such as used in fertilizer. When ground to particles of between 1 micron and 20 microns in size, urea has been shown to be effective in producing ice crystals from micron-sized cloud droplets at temperatures as high as 6° C. above freezing. It has been injected into $-10°$ C. supercooled stratus clouds from the Project Whitetop aircraft in Missouri, and produced glaciation and clearing of the the clouds as rapidly and efficiently as dry ice. The material is a dry powder and inert when stored in moisture-tight containers. Its cheapness, ease of supply, ease of dispensing, and lack of perishability make it an attractive substitute for dry ice.

A large drop of water breaks up as it falls into the wake of a second drop (lowermost body) during a wind tunnel experiment by Douglas Aircraft Co., Inc. Such raindrop collision processes are closely involved in raindrop formation.

## New Facility for Testing and Standardizing Silver-Iodide Generator Output

The new isothermal cloud chamber completed in fiscal year 1965 at Colorado State University represents a national facility for testing and standardizing the output of silver-iodide generators which has been badly needed since cloud seeding was first attempted. This chamber has a volume of 3,000 liters (about 750 gallons) and operates at any temperature between 0° C. and −20° C. with the wall temperature controllable to ±0.1° C. Facilities are available for testing the efficiency of ice nucleators by counting the number of ice crystals produced under standardized procedures, and electron microscope measurements can be made of the particle size. Already many generators have been tested for field operators, and a routine standardizing procedure has been established. This is a unique facility which the NSF has sponsored to assist in the standardization of reporting procedures in the field of weather modification throughout the United States. Due to the fact that a gram of silver iodide from one type of generator may produce several orders of magnitude more ice forming of nuclei than are produced from another generator using the same amount of basic material, it has been difficult in the past to compare the results of two or more field operations. It should now be possible for operators to report actual nucleus output instead of only grams of material utilized.



This isothermal cloud chamber was developed by Colorado State University scientists to calibrate the output of ice nuclei generators. The National Science Foundation supports the facility to make possible the standardization of generator efficiency.

## New Procedure for Reporting all U.S. Weather Modification Field Operations to the National Science Foundation

In accordance with its national responsibilities for record keeping under Public Law 85–510, during fiscal year 1965 the NSF prepared a new regulation on reporting procedures for maintaining accurate records on all weather modification field operations taking place in the United States. The new regulation has now been drafted and will be published in the Federal Register for a period of 30 days early in fiscal year 1966 for public comment prior to being placed into effect. The new regulation will enable accurate and current records on all weather modification to be maintained by the NSF, and will cover four important points:

1. It will be the responsibility of all field operators to assume the initiative in reporting their activities in weather modification promptly to the NSF under penalty of a fine not exceeding $500.

2. All field operators must provide 30 days advance notice to the NSF of intent to initiate a program of weather modification in the atmosphere. In the event that 30 days advance notice is not possible due to urgency of operational necessity, provisions are made for explanatory notarized statements to this effect.

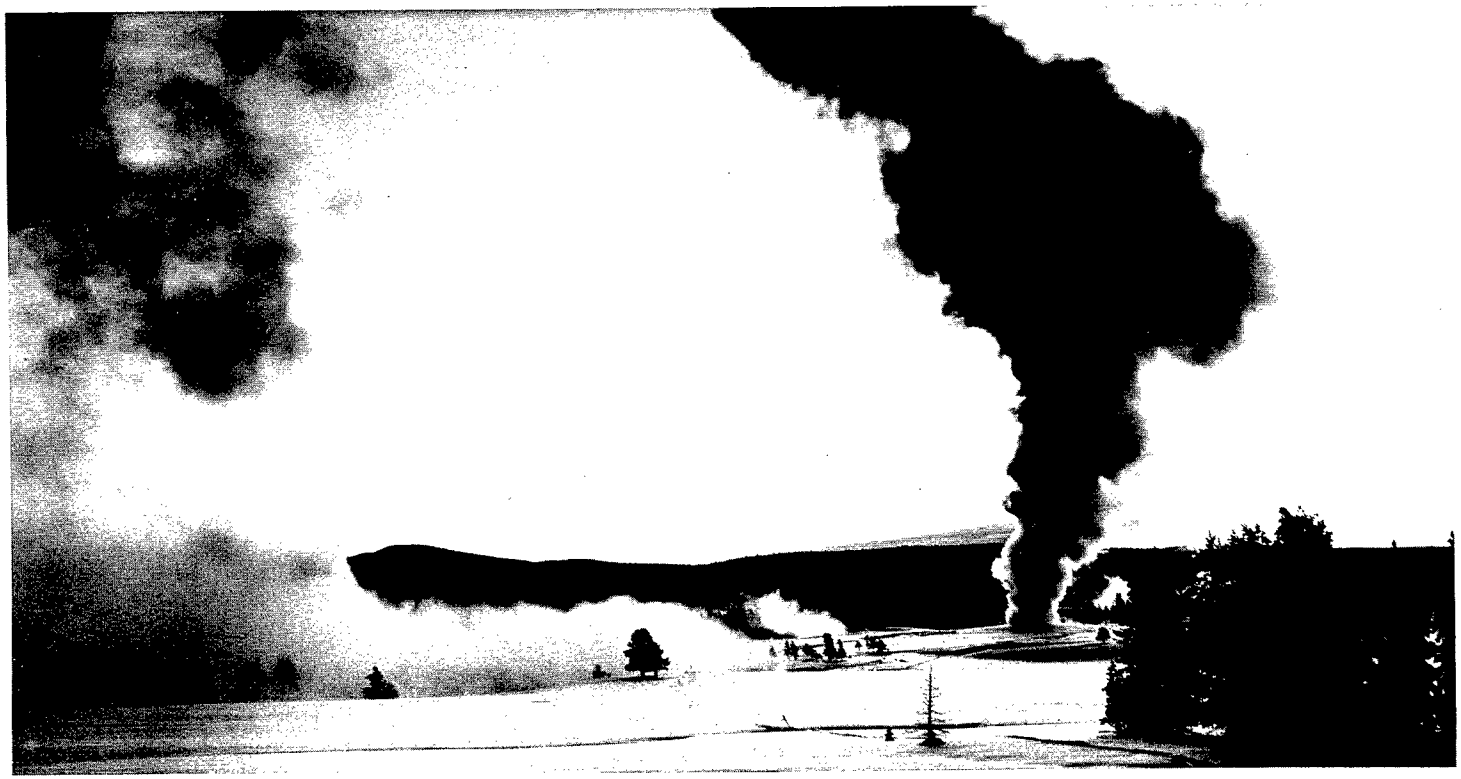
3. Operators of all field weather modifications projects must submit quarterly activity reports to the NSF on the forms provided by the NSF.

4. Operators of all field weather modification projects must maintain log books of their field operations on a day-to-day basis. Logs will be retained by the operators, but will be made available for examination upon request by the NSF for a period up to 5 years after the termination of the project.

The purpose of this reporting procedure is to establish a central file of current and past field operations to provide a record suitable for the evaluation of scientific results and to provide possible warning of potential interference or contamination of existing weather modification experiments. It is not intended to be regulatory in operation but to provide a national record of effort and to provide information for future scientific evaluation.

## Developing an Integrated National Research Effort on the Suppression of Hail and Warm Fog

Hail suppression continues to be one of the major fields of weather modification in which the national research effort is still inadequate. The NSF-sponsored research project at Colorado State University has been continued in the vicinity of Fort Collins, Colo., for the second summer. The results have shown that the ground network established for the observation of hailstorms is not adequate since each hailstorm is in a different segment of its life cycle as it passes over any particular observation point. It is now obvious that such an elusive problem as that of determining the cause and prevention of hail will not be solved by a small group of researchers acting independently. A large-scale national and integrated program is indicated,



"Old Faithful" geyser at Yellowstone National Park creates a heavy vertical cloud in this winter scene. The low cloud extending to the left was produced by seeding nearby moisture-laden air with artificial condensation nuclei and dry ice.

and the NSF has invited the National Center for Atmospheric Research to join forces in preparing a rational plan. This plan will be based on the results of the First National Symposium on Hail Suppression.

The problem of warm fog suppression is an equally difficult and important one, and the NSF has taken much the same approach to this problem by inviting the Air Force to cooperate in the preparation of a plan for an increased research effort in warm fog suppression. A symposium on the causes and means of dissipation of fog will also be held as the basis for preparation of the plan.

It is expected that the plans for expanded research effort in fog and hail suppression will be prepared by spring of 1966, and will be submitted to the Interdepartmental Committee for Atmospheric Sciences for recommendations on implementation and funding.

## Fiscal Year 1965 Funding for Weather Modification

During fiscal year 1965, 28 grants or contracts were initiated by the National Science Foundation under the weather modification program for a total of $2 million. Of this total funding, only 6 percent was available for new efforts due to the rapid expansion of the continuing programs. Approximately 5 percent was utilized in support of activities of the Special Commission on Weather Modification, leaving 89 percent of the remaining funds for renewals. It is evident that funding will have to grow beyond the $2 million level in the future if new and imaginative research efforts in hail and warm fog are to be implemented, and advantage is to be taken of the exciting new developments which are now arising.

Within NSF, the weather modification program is carried on as a part of the research support extended in the broader field of atmospheric sciences. Much of the regular atmospheric research program, including that of the National Center for Atmospheric Research, bears directly on weather modification and is properly considered supplementary to it.

## OTHER FEDERAL GOVERNMENT WEATHER MODIFICATION ACTIVITIES

### Department of Agriculture

Project Skyfire, the U.S. Forest Service program in lightning modification research, is gaining new basic knowledge of the nature of lightning discharges, their modification, and their potential for starting forest fires. With the award, in May 1964, of a 3-year NSF grant, Project Skyfire intensified its research on the effects of silver-iodide seeding on the frequency and character of lightning discharges.

Following a pilot field program in 1964, which yielded some data on lightning from untreated storms, field and laboratory experiments were designed to develop a method of lightning modification and to obtain specific data on lightning discharges from clouds heavily seeded with silver iodide. In support of the field experiments, an area adjacent to the Northern Forest Fire Laboratory at Missoula, Mont., has been instrumented with a network of fast-response electric field-change sensors, photographic and thunder-sound recording stations, and two radar units. Cloud seeding is performed by 12 airborne and 12 ground-based, ram-jet type, silver-iodide generators.

A full-scale program of lightning measurements on treated and untreated storms in the Missoula experimental area began in June 1965 and will continue through two or more summer seasons. With intense lightning storm activity in 1965, the project already has had many opportunities to treat incipient storms with silver-iodide freezing nuclei. Several hundred lightning discharges have been observed, photographed, and recorded by the instrument network. Data analyses, using both statistical and physical evaluation techniques, will continue into the next year.

Closely linked to the lightning modification research is a study to determine the specific properties of lightning discharges that cause ignition in forest fuels. Results to date, from limited data, support the hypothesis that ignition is caused by lightning discharges having long-continuing current portions. Evaluations of treated and untreated thunderstorms will include investigations of whether or not the occurrence of this type of fire-setting lightning discharge is altered by cloud seeding.

Laboratory experiments that may provide a method of modifying the electrical structure of clouds with freezing nuclei were performed in 1965.

These experiments investigated the effect of water drops and ice crystals on the sparking potential of air within a simulated cloud environment. It was found that the sparking potential, $F$, in the presence of water drops in normal cloud concentrations and ranging in size from 0.02 to 0.1 centimeter radius, could be expressed by the equation:

$$F = 3{,}875 \times r^{-\frac{1}{2}}$$

where $r$ is in centimeters and $F$ is in volts per centimeter. Irregular ice crystals 0.1–0.3 centimeter in length lower the sparking potential across a gap by a factor of 0.35–0.40 at a barometric pressure of 675 millimeters Hg. The breakdown field with ice crystals is virtually independent of the size of the crystal. The sparking potential in the presence of ice spheres is changed by both the size of the spheres and the pressure of the surrounding air. Wet ice spheres lower the sparking potential to that found for water drops of the same size.

## Department of Commerce

The research programs of the Department of Commerce related to weather modification are centered in the Weather Bureau, which, on July 13, 1965, became part of the Environmental Science Services Administration. During fiscal year 1965 the Weather Bureau engaged in a number of activities of both immediate and longer range potential in the development of weather modification techniques.

Experiments on tropical cumulus clouds and hurricanes, conducted jointly with the Navy under Project Stormfury, continue. The clouds are being studied in connection with their role in the mature hurricane system, as well as in order to understand their behavior during undisturbed weather conditions. The dynamics of clouds are explored by seeding them with silver-iodide pyrotechnic dispensers called Alectos, and observing their subsequent behavior.

Broader experimental programs are being planned for the future to shed further light on the physical mechanisms occurring within convective clouds over the ocean. Large-scale scientific experiments appear to be necessary in order to determine how storm hazards may be reduced by artificial control of the convective phenomena. In an effort to find answers to basic problems in cloud physics continued research on natural clouds is being supplemented by the development and testing of mathematical cloud and hurricane models.

Project Stormfury conducted seeding experiments on tropical cumulus in the Eastern Caribbean Sea area during July and August of 1965. Massive seeding operations on a hurricane eyewall and rainband were planned for the 1965 hurricane season as part of the program to delve into physics of these and related cloud phenomena, but no suitable storms occurred up to July 1, 1965.

Atmospheric motions on all scales are influenced by the general circulation of the ocean-atmosphere system. Attempts to predict results of modification experiments require an understanding of both the general circulation and the interaction of the general circulation with the phenomena of interest. The Weather Bureau is continuing in the development of theoretical models which are capable of reproducing and accounting for the natural processes which produce the weather, circulation, and climate of the atmosphere.

Some recent advances of particular interest are: (1) A study of the dynamic response of a baroclinic-saline ocean to the heat transfer imposed by the overlying atmosphere; (2) a simulation of the processes responsible for producing and maintaining the troposphere-stratosphere system; (3) consideration of the long-term water balance of the atmosphere, particularly those elements which are responsible for maintaining low relative humidities in the stratosphere and the desert-producing conditions in subtropical latitudes; and (4) the experimental application of general circulation models to weather prediction up to 100,000 feet for the hemisphere, producing 4-day forecasts of temperature, wind, and precipitation. These efforts promise a significant increase in the reliability of medium range predictions.

## Federal Aviation Agency

The Federal Aviation Agency's interest in weather modification is focused on the benefits to be gained for aviation from severe storm modification and fog and low stratus dissipation. The Agency has not sponsored any weather modification contract effort during fiscal year 1965, but actively has been monitoring the research and development programs of other Government agencies, as well as the activities of the airlines and other non-Government groups.

The Agency has begun a program to determine the feasibility of using the fog chamber located at Richmond, Calif., for weather modification experimentation.

The Agency also has begun to develop a technical plan for cold fog dispersal, including an evaluation of operational feasibility and of the supporting research and development. This activity is centered in the Systems Research and Development Service with emphasis on fostering the needed engineering and development of an economically and technically sound technique for aviation application.

## Department of Defense—U.S. Army

Army research in weather modification has been conducted both through contractual support and through "in house" efforts by staff members of the Atmospheric Sciences Laboratory in New Jersey and the Cold Regions Research and Engineering Laboratories in New Hampshire. The principal

efforts of the Atmospheric Sciences Laboratory involved extensive field operations on convective cumulus clouds over San Francisco Peak in Flagstaff, Ariz., during the summers of 1964 and 1965. Personnel from the State University of New York and Meteorology Research, Inc., participated with Army personnel in the operation.

In the Flagstaff operation, a series of airborne aerosol measurements was conducted to determine the vertical distribution and size distribution of larger aerosol particles which may be active as condensation nuclei. From these measurements, which were carried out at altitudes up to 19,000 feet, it can be concluded that there is a considerable dependence of the aerosol concentration on convective processes. At higher altitudes, low concentrations early in the forenoon rapidly increase with the onset of convection during the day.

An infrared temperature-sensing instrument developed for the measurement of free-air temperature from an aircraft was used at Flagstaff to measure the horizontal and vertical temperature profiles of clouds of different types and at different altitudes. The instrument is a radiation thermometer sensitive to the wave length band from 14.5 to 15.25 microns, where the most important source of radiation in the atmosphere is from carbon dioxide. The measurements are not affected by water vapor, but condensed moisture such as cloud droplets is a good emitter of radiation in this band; hence, the instrument is a good detector of cloud temperature. Flights were made through fair weather cumulus and thunderstorm clouds. On all flights, comparisons were made with measurements from a thermistor in a vortex thermometer mounted under the belly of the fuselage. Comparisons were also made with the local radiosonde temperature measurements. Differences between the readings of the two types of aircraft thermometers were as large as 4° at altitudes of 17,000–19,000 feet, but the radiation thermometer measurements agreed generally with the reduced radiosonde temperatures.

Experiments have also been conducted to check the feasibility of discharging a thundercloud by a corona current generated at the sharp points of chaff needles. These were dispersed from a C–47 aircraft in areas below clouds where the electric field exceeded 30,000 volts per meter. The aircraft was equipped with two cylindrical field mills which recorded the three components of the electric field. In the conduct of the experiment, the aircraft would fly below a thunderstorm during the developing stage, and record the electric field. If the field strength surpassed a value of about 30,000 volts per meter, the aircraft would retrace its previous pass and disperse the chaff. During consecutive runs back and forth, the influence of the chaff seeding on the electric field was recorded. In one series of five test runs, three out of five test flights showed that the corona discharge started as soon as the chaff was dropped from the plane, and a field limiting and discharging effect was indicated. One of the important observations made during this program is that the electric field below shower clouds

is of the same magnitude as below thunderclouds; i.e., of the order of 100,000 volts per meter. It was noted, however, that the field of a shower cloud retains its pattern for quite a long period of time.

Measurements of Great Lakes snowstorms were made by the Cornell Aeronautical Laboratories as part of a climatological survey of the lakes' effect on storm occurrence, and in order to develop a mesometeorological description of the storms which would help in the evaluation of proposed methods of artificial modification.

Cloud physics research is being conducted by the University of Illinois employing radar studies of convective precipitation. The relation of weather radar measurements to the intensity of surface precipitation is being investigated at the Massachusetts Institute of Technology.

The Cold Regions Research and Engineering Laboratories have been testing and evaluating the use of rockets and balloon-borne equipment for fog or arctic "whiteout" dispersal. The effects of several ice-nucleating agents such as phloroglucinol, urea, dry ice, and liquid-propane spray on the modification of supercooled and warm fog were observed, and were supplemented by a series of tests using a helicopter to initiate a downward flow of air into shallow warm fogs. The results of the 1965 tests were as follows:

(*a*) *Rockets.*—Rocket performance was good but little result was obtained with any of the chemicals tested. Two holes were observed to form in a stratus deck after seeding with urea, and dry ice caused similar reactions; but neither one displayed any really promising results.

(*b*) *Liquefied gaseous hydrocarbon (propane).*—This liquid was released from ground-based dispensers on six occasions in the Hanover-Lebanon, N.H., area, six times in the Camp Century, Greenland, area and twice at Thule Air Base, Greenland. The following results were obtained:

*Hanover-Lebanon, N.H.*—Of the six tests made here, five were successful. Clearing was complete in the seeded area during three tests, and partial clearing during the two remaining tests. One failure occurred, but it was due to the failure of the propane to reach the base of the low cloud. (To be effective, the liquid propane must be injected directly into the fog.)

*Camp Century, Greenland.*—Six seedings were made; three were complete successes, and three were at least partial successes. These partial successes may have been more nearly complete than the observations indicated since location of the seeded areas may have been partially lost during the tracking procedures.

*Thule Air Base, Greenland.*—

(*a*) Two propane seedings were done here. One cleared the seeded area and one did not. However, the successful one was in supercooled fog, whereas the other one was in fog having a temperature above freezing.

(*b*) It was demonstrated that a helicopter flying slowly above a shallow fog will cause enough warm air to be displaced downward to cause dissipation of that fog.

## Department of Defense—U.S. Navy

The efforts by the Navy in weather modification and control are centered around two phenomena that create special problems for naval surface and air operations. These two phenomena are warm fog, particularly as it exists as marine fog in the northerly reaches of the Atlantic and Pacific Oceans, and the trade-wind cumulus cloud. Virtually every weather situation that confronts the Navy in the tropics and subtropics is tied in one way or another to the cumulus-cloud regime existing over these portions of the oceans.

### NAVAL RESEARCH LABORATORY

The principal laboratory and field work on problems involving cloud dynamics and physics which are related to the Navy's concern in weather modification is done by the Atmosphere and Astrophysics Division of the Naval Research Laboratory. In this program an effort is being made to collect, size, analyze, and determine the source of natural cloud nuclei. The end product of this effort will be an attempt to say something about the character of fog (number of and size of droplets) in terms of the nuclei responsible for the fog formation.

Computer studies of the statistical evolution of raindrops are also underway at NRL. A special effort is being made in this program to determine the influence of the spatial variation of liquid-water-content (LWC) on the rate of precipitation development by coalescence. Data for these computations are being obtained by means of a fast response LWC meter.

Computations are also being made for the purpose of estimating, for the general case, the transfer of radiant energy through a cloud or fog when multiple scattering is taken into account.

One of the principal impediments to progress in cloud physics is the lack of suitable instrumentation required for obtaining certain cloud data. The group at NRL is contributing to this need by their work on—

(*a*) A fast-response airborne meter and recorder for total water-content and liquid-water-content.

(*b*) A portable cloud-nucleus supersaturation distribution meter.

(*c*) A cloud-nucleus concentration counter for use on aircraft.

(*d*) An especially difficult problem is that of designing an instrument to measure the number density of various drop sizes. Three approaches to solving this problem are underway: a replication technique on moving film, scattering and attenuation of light as a function of wavelength (near-ultraviolet to near-infrared), and diffraction and attenuation scattering of ultraviolet.

## OFFICE OF NAVAL RESEARCH

Most of the contract research for work bearing on the problem of modification of marine fog and trade wind cumulus is supported by the Office of Naval Research, with some supplementary contracts being supported by the Naval Weather Research Facility. Contract research on warm fog supported by ONR includes:

(*a*) Efforts by D. O. Zopf of E. Bollay Associates to determine growth rates of fog particles in the 0.1- to 1.5-micron size range by an optical technique.

(*b*) Efforts by Lothar Ruhnke of Litton Systems to verify from field measurements a theoretically derived relationship between the small ion content of fog and the extinction coefficient.

(*c*) In work on trade wind cumulus, Alfred Woodcock of the University of Hawaii is attempting to induce minor perturbations in the lapse rate in the trades sufficient to induce cumulus convection. The attempted perturbations will be generated by means of especially prepared sodium chloride dispersed from an aircraft.

## NAVAL WEATHER RESEARCH FACILITY

The NWRF under contract with Goetz of Meterological Research, Inc., is supporting research to determine the nature of the organic coatings on fog droplets of marine origin that permit the fog to persist under conditions of low relative humidity. The NWRF is also involved in investigations of the trade wind cumulus problem.

NWRF performs planning, analysis, and evaluation of experimental results obtained by Project Stormfury and the other portions of the Navy program in weather modification. As reported in prior years, Project Stormfury is a Joint Weather Bureau-Navy program in weather modification involving attempts to modify hurricanes.

## NAVAL ORDNANCE TEST STATION

Much effort has been devoted to preparation of the Alecto units used for the seeding of hurricanes from a Navy A3B aircraft. In addition, there is some work on the dispensing and testing of seeding agents for supercooled clouds. Work is also continuing on the investigation of seeding agents for warm clouds.

## BUREAU OF NAVAL WEAPONS

The Meteorological Division of the Bureau of Naval Weapons exercises a central coordinating function in the weather modification program of the Navy.

## Department of Defense—U.S. Air Force

The Air Force programs of research in cloud physics and weather modification are conducted by the Air Force Cambridge Research Laboratories at L. G. Hanscom Field, Bedford, Mass. Research in these areas is currently focused on studies of convective cloud structure and dynamics, lightning charge generation in thunderstorms, and supercooled and warm-fog dissipation.

A study of precipitation growth in New England cyclones was conducted during the spring of 1965 as part of AFCRL's Stormy Spring program, utilizing a highly instrumented cloud physics aircraft and radar, in conjunction with special surface and upper-air observations. Flight studies of the initiation and development of cumulus populations into mature thunderstorms were conducted during the summer of 1965 in Florida. Analyses of selected cases of cumulus congestus clouds, using surface mesonetworks, ground-based time lapse and stereo-photography, and aircraft cloud-penetration data, were performed to determine the environmental conditions and cloud parameters necessary for the growth of cumulus clouds to thunderstorm stage. Lightning studies were conducted in Florida with C–130, F–100, and U–2 aircraft to locate the lightning charge centers which produce strikes that may damage an aircraft or missile installation.

The feasibility tests of the various ground-based techniques for dissipating supercooled fog and stratus were completed. After weighing the advantages and disadvantages of the various techniques concerned including seeding rockets, tethered balloons, vertical fans, kites, drone aircraft, and slow-rise seeding balloons, it has been concluded that the slow-rise seeding balloon method is the most effective and is the most practical. By this method, a 100-gram, free-lift ceiling balloon is allowed to rise slowly through the supercooled fog at a rate which is proportional to the sublimation rate of the dry ice, effectively seeding the fog throughout its flight of approximately 1 hour. This system has the definite advantages of being simple, low in cost, continuous, and, most important, within FAA airport safety regulations. This technique has been recommended for operational development by the Air Force.

The second field research program involves a study of the life cycle and variability of warm fog. It was conducted at Otis Air Force Base, Cape Cod, Mass., during the spring and summer of 1965, utilizing a cloud physics observation facility, a mesometeorological network, a micrometeorological tower, and special rawinsonde observations. A thermal-diffusion cloud chamber has been added to the already comprehensive research instrumentation. The numbers of condensation nuclei active at very low supersaturations were monitored as a function of time of day, air trajectory, and synoptic situation. The detailed observations of the naturally occurring phenomena are being analyzed to formulate mathematical and physical models of the evolution, structure, and variability of the fog.

The laser disdrometer has proven capable of measuring the droplet-size distribution of fog. Its capability is being extended to the measurement of the size distribution and shape of other atmospheric hydrometeors. When it is used as a raindrop spectrometer, by demagnifying the sample volume the method is capable of sampling volumes on the order of 1 cubic meter on each film record. Application of the method to nonspherical solid hydrometeors, such as ice crystals and snowflakes, is also feasible. Of significant importance is the capability of the method for determining the relative distribution of hydrometeors in mixed phase clouds. In addition, an automated readout device for rapid processing of the laser disdrometer data is in an advanced stage of development. By reconstructing the sample volume in three dimensions from the two-dimensional diffraction-pattern film record, called a hologram, the size, shape, and relative position of each particle in the original volume are determined.

## Department of the Interior

The Bureau of Reclamation's atmospheric water resources program came into being as a result of an inclusion of $100,000 for this purpose in the Public Works Appropriation Act for fiscal year 1962. An analysis by the Bureau of the then current state of weather modification knowledge and activity led to concepts which can be stated as follows, and which are still believed to be valid:

(*a*) The Bureau of Reclamation's program of weather modification research should be directed toward learning, if it is possible, how to increase inflow into its reservoirs.

Although the physical process or processes of precipitation are not completely understood, there is sufficient evidence that cloud seeding affects the production of precipitation in the mountainous west to justify a program designed to learn how to use cloud seeding to increase inflow to reservoirs. Careful, well-designed field experimentation is essential for this purpose.

(*b*) The hydrometeorological diversity of the regions in which the Bureau reservoirs are located precludes learning all that is required from any single experimental site.

(*c*) Because of the national shortage of creative minds interested in solving weather modification research problems, the Bureau should foster the strengthening of groups competent to perform the required experimentation. Judicious support of ongoing programs is an important means of fostering this development.

(*d*) Since some areas provide greater opportunity for learning than others, the Bureau should foster the development of well-instrumented outdoor laboratories in areas of high learning potential.

(*e*) The Bureau of Reclamation's program should be a compatible part of the Nation's efforts to understand and manage the atmosphere,

seeking, whenever possible, to apply for Bureau purposes the results of work performed or sponsored by other agencies, with full credit given for the contribution.

These concepts guided the initial placement in 1961 of research contracts at the Universities of Nevada and Wyoming and the South Dakota School of Mines and Technology. The intensification of effort occasioned by the elevenfold increase in appropriations for fiscal year 1965 has been carried out in keeping with the above concepts, as will be whatever is continued or undertaken in fiscal year 1966 and in the years to follow.

## PROGRAM REQUIREMENTS

The program requirements were identified to fall into the following categories:

(*a*) Better observational facilities.

(*b*) Improved knowledge of local precipitation and streamflow climatology.

(*c*) Improved seeding equipment.

(*d*) Operational know-how and improved techniques.

(*e*) Improved evaluation procedures.

Each of the contracts which have been let in connection with the program is designed to provide some portion of one or more of the above listed requirements.

*Program Emphasis.*—The task of finding out if it is practicable to apply weather modification techniques to increase inflow into reservoirs is a complex one. There are numerous gaps in knowledge which must be filled before the ultimate solutions will be achieved. Planning the effort to fill these gaps involves decisions about priorities and about the possible need for attacking some problems with more than one approach. The uncertainties attendant fall into two major related categories.

(*a*) Uncertainties related to influencing the precipitation process.

(*b*) Uncertainties related to detection, measurement, and evaluation of the effects produced by seeding.

The attention of a number of investigators around the world has been directed to answering questions about how to affect the precipitation process. A considerably smaller amount of attention has been directed to the detection, measurement, and evaluation of the effect produced.

It is entirely possible for economically important increases in precipitation and streamflow to go undetected or undemonstrated if the observing network is either too sparsely or too crudely instrumented. Much of the present confusion concerning the reality of seeding effectiveness may be the result of insensitive detection, measurement, and evaluation approaches. The smaller the effect on precipitation that man is able to produce, the more critical is the requirement for precise methods of measurements of meteorological parameters and evaluation of precipitation and streamflow.

The Bureau of Reclamation's program is designed to remedy this shortcoming.

*Program Management and Coordination.*—To manage and coordinate the expanded program made possible by the appropriation of $1,100,000 in fiscal year 1965, an Office of Atmospheric Water Resources was created as a part of the Office of Chief Engineer. To staff this new office a small group of engineers, meteorologists, and administrative personnel, numbering seven in all, was assigned. They combine their skills to plan and monitor the various component parts of the program. They are assisted in these efforts by the counsel of a distinguished group of advisors appointed by Secretary of the Interior, Steward L. Udall.

## ACTIVITIES

*The Colorado River Activity.*—An October 1964 report entitled "Design for an Experimental Weather Modification Program" prepared by E. Bollay Associates, Inc., as the result of a 1-year research program sponsored by the National Science Foundation, pointed up the advantages of this area as the site for a major physical experiment. This report, which introduces a new concept of cloud-seeding evaluation, has become the basis for the Bureau of Reclamation's field experimentation in Colorado.

The area east of Steamboat Springs, Colo., rises steeply from a valley floor elevation of 6,800 feet to a ridge of the Park Range with elevations ranging from 10,000 to 12,500 feet. To the west of Steamboat Springs isolated mountains provide vantage points for radar surveillance and high-altitude seeding. Studies of possible field experimentation sites performed by consultants were in agreement that the Steamboat Springs site offered a good combination of learning potential, freedom from social conflict, and difficult but acceptable access for instrumentation and observation.

The principal hypotheses being tested in this experiment are:

(*a*) The auto-correlation and power density spectra of precipitation rate are stable under natural precipitation conditions.

(*b*) Seeding with silver iodide can detectably alter the power spectrum of precipitation rate variations.

The experimental design involves:

(*a*) Installation of a dense network of precipitation rate sensors. This was accomplished in fiscal year 1965.

(*b*) Collection, data processing, and analysis of 1 year's natural storm data. This was partially accomplished in fiscal year 1965 and will be completed in fiscal year 1966.

(*c*) Collection, data processing, and analysis of a series of storm data in which silver iodide seeding has been carried out. This is planned for fiscal year 1966 and fiscal year 1967.

(*d*) Comparison of natural and seeded precipitation rate records.

To help assure adequate seeding procedures, a series of tracer experiments has been conducted during fiscal year 1965 using zinc sulfide and fluorescent

detection equipment. The three-dimensional picture of the plume obtained from a point source located on Quarry Mountain indicates that adequate coverage of the target area in the Park Range can be expected. During fiscal year 1966 seeding with silver iodide will be carried on simultaneously with zinc sulfide dispersal. Detection by neutron activation analysis of the zinc sulfide and silver iodide in snow samples taken from the target area and environs is expected to define the lateral dimension of the seeded area. Monitoring of the vertical extent of the plume of zinc sulfide will be carried out by airborne detection equipment to the extent that flying weather permits.

Although the principal evaluation technique to be applied in the Park Range activity will involve comparisons of power spectra of precipitation rate variation data under seeded and unseeded conditions, there will be other approaches made to evaluation of seeding effectiveness. Comparison of mountain-to-valley precipitation ratios under seeded and unseeded conditions and comparison of streamflow from the seeded target and unseeded areas located both north and south of the target area are contemplated. Supporting contracts with the Soil Conservation Service for snow course readings, the Geological Survey for streamflow measurement, the USDA Forest Service for studies of the effect on runoff production of forest management practices in the area, and with Colorado State University for streamflow evaluation techniques will be continued in 1966 as part of the overall evaluation approach. By the end of the fiscal year there may be a basis for comparing a year of unseeded storm experience with a year of seeded experience and preliminary indication of the usefulness of power spectra as evaluation tools.

In another portion of the Colorado River Basin, a summer activity complements the Park Range program. A program of research into the behavior of orographically induced convective clouds is being conducted near Flagstaff, Ariz., by Dr. Paul MacCready's group, Meteorology Research, Inc., and several interested cooperators. Planning for this program began in 1965. Actual field experimentation will be carried out in 1966.

With a background of 7 years' field experience in the Flagstaff area, the Meteorology Research, Inc., group has the following goals:

(*a*) Observation of the important characteristics of seeded and unseeded convective clouds. Many of the observations are to be made in the surface convergent area downwind of the San Francisco Peaks, called the "Convective Mountain Wake," where frequent major storms have been observed in previous years. Some of the factors to be considered are ice crystal concentration, buoyancy effects, hydrometeors, electrification, and cloud system growth.

(*b*) Quantitative engineering of convective seeding techniques. The techniques used will be ground- and/or airborne-seeding with silver iodide and/or dry ice. Massive volume seeding techniques

(spreading of seeding materials in appropriate quantities over a major percentage of the cloud volume) will be employed.

(*c*) Continued exploration of the effects of the peaks on cloud, precipitation, and wind flow patterns. Emphasis here is to be placed upon balloon trajectory, smoke trail, and surface anemometer observations and their relationship to cloud and precipitation initiation.

(*d*) Establishment of a seedability climatology concept. This is planned as a preliminary step toward developing the plans for both summer and winter seeding.

In the summer of 1965 this work was carried out in cooperation with investigators from the Pennsylvania State University under National Science Foundation sponsorship, the University of Nevada, the State University of New York, the Boeing Aircraft Co., and the National Center for Atmospheric Research. Each organization also pursued related individual goals.

The equipment complement for this experiment included four radars, instrumented aircraft, ground-based weather observing and communication facilities, and silver-iodide generators. It is expected that this program will be conducted in a similar form for at least 2 more years. Eventually it is hoped that a comprehensive report will be produced which should provide a procedure for weather modification operation on orographically induced convective cumulus clouds.

* * *

*The University of Wyoming Activity.*—Among the orographic clouds of Wyoming, the cap cloud offers some unique advantages for experimental purposes. As a persistent stationary cloud that rarely produces precipitation naturally, when seeded there is little doubt that any subsequent precipitation is the result of seeding. Experiments conducted by the Natural Resources Research Institute of the University of Wyoming by John C. Bellamy's group have demonstrated that cap clouds can be manipulated to an extent not evident in other clouds. Cyclic seeding produces similarly cyclic precipitation. Translation of the generator in a direction normal to the windflow produces corresponding translation in the precipitating plume. The amounts produced appear to offer promise of economic significance.

At Elk Mountain, northwest of Laramie, Wyo., a natural laboratory well suited to study of cap clouds had been partially instrumented during fiscal year 1965. Plans for 1966 include further installation of instrumentation and construction of an observatory and shelter near the mountain crest. When completed, the laboratory will provide unique opportunities for experimentation with various seeding techniques.

The planned instrumentation complement includes hygrothermographs, radiometers, recording anemometers, snow pillows, radar, and an instrumented aircraft equipped to permit communication with ground observers.

Equipment for taking soundings and measuring the liquid water content of clouds will be installed when funds permit.

It is planned that the work of the University of Wyoming group will be expanded as funds become available to permit the study of the occurrence and characteristics of cap clouds in other areas of Wyoming. Preliminary study has indicated that the Wind River, Snowy, and Big Horn Ranges have cap clouds which could be seeded from ground-based generators. It would be in these areas that programs of precipitation augmentation are most likely to be economically feasible.

* * *

*The Interior Basin Program.*—The preexisting research interests of two university groups located at opposite sides of the Great Basin are being sponsored to provide necessary answers to questions about the production, detection, and measurement of the effects of cloud seeding.

At the University of Nevada a diversified group under the leadership of Wendell A. Mordy has been building a program ranging widely from theoretical studies of cloud physics and the development of instrumentation and data acquisition systems to actual weather modification operations. Efforts in these areas, including field experimentation, have been carried out under other sponsorship. The Bureau of Reclamation is sponsoring the continuation of those efforts in this broad program which pertain to the practical problems of weather modification. Primary emphasis is being given the development of a data acquisition system which will coordinate calibrated radars, instrumented aircraft, balloon probes, and telemetered ground networks to provide a real-time display of the meteorological and hydrological data necessary to the understanding of what happens during an experiment or operation on clouds. By the end of fiscal year 1965 the final design of the system was not complete but some portions, such as the telemetering system, had been specified. During fiscal year 1966 it is planned to construct an operational system that will permit the taking of cloud data by airborne sensors, the combining or multiplexing of the data for transmission to the ground, storing on magnetic tape, demultiplexing, and real-time displaying. The magnetic tape will be subsequently processed for digital storage. Operation of this system in the Mount Rose area will provide a well-instrumented outdoor laboratory in which to carry out future studies of seeding effectiveness.

At Utah State University under Dr. Vaughn Hansen, a prior interest in telemetry as applied to automatic precipitation measuring and reporting networks is being supported. This equipment is being developed by Dr. Joel Fletcher. Once adequately developed, a dense network will be employed in a statistically designed seeding experiment along the Wasatch Front between Salt Lake City and Ogden. In this experiment, which is in its initial planning stages, a network of 10 automatic silver iodide generators located at valley and mountain top sites will be operated selectively under radar surveillance to affect individual convective cells in orographic systems as they pass across the reporting precipitation network. Operation of the genera-

tors will be such as to permit division of the precipitation network into treated and untreated areas. This experiment is an outgrowth of a project conducted for the past 10 years by R. D. Elliott of North American Weather Consultants. This firm will cooperate in the present experiment.

Principal emphasis during fiscal year 1966 will be on adapting existing Utah State University 30-megacycle telemetry designs to permit operation on 170 megacycles at higher power and antenna gains and on solution of the problems of network operations. Concurrently, assembly of past hydrologic data for the experimental area will be accomplished.

* * *

*Southern Sierra Program.*—The southern portion of the Central Valley of California has been a focal point of intense interest in cloud seeding. Several commercial operators have been active in the area and each has his own group of enthusiastic backers. In addition, a group at the Naval Ordnance Test Station (NOTS), under the leadership of Dr. Pierre St. Amand, has been active in the development of silver iodide pyrotechnics and studies of condensation nuclei. The Bureau of Reclamation is attempting to contribute to the coordination of efforts of the interested groups in order to increase the probability of obtaining reliable information about the effectiveness of cloud seeding in the area. A contract with NOTS, which provides for performance of engineering research, including cloud-seeding experiments, has as its primary purpose the furthering of efforts to develop improved airborne nucleating devices. This work, which began in fiscal year 1965, will be continued in 1966.

Under a separate contract with Precipitation Control Co. of California, Taft, Calif., a seeding aircraft and flying personnel are made available to NOTS for purposes of testing nucleating devices. The airplane is operating under the control of the Navy scientists.

Professor Lawrence Peahl, a mathematical statistician at Taft College, is developing an experimental design for the evaluation of seeding efforts associated with the aforementioned seeding tests.

Dean T. H. Evans of Fresno State College Foundation has been retained to perform a study of the feasibility of activating a coordinated effort in the Southern Sierra area. The desired result of this effort would be a joint experiment in which cooperating private seeding groups would conduct discrete portions. This would minimize the conflict resulting from one group's control area becoming another group's target area. This entire program is in the very first stages of planning. It is expected that more specific details will be available in 1966.

* * *

*The Pacific-Northwest Program.*—Under a contract with the Weather Modification Board of the State of Washington, which began in fiscal year 1965, planning has begun for a program of experimentation which hopefully will lead to the development of techniques for shifting precipitation from areas of surplus to areas of deficit.

In Washington and Oregon the windward slopes of coastal mountains receive large amounts of precipitation (on the order of 100 inches a year) the runoff from which flows back to the ocean unused. Further inland, there are areas where precipitation is on the order of 10 inches per year. If it were possible to achieve transmountain diversion of the coastal excess by cloud-seeding techniques, considerable economic benefit would result.

At the present time an effort is being made under the leadership of the Weather Modification Board to put together a group of interested meteorologists who would design the necessary experiments to test whether the desired transmountain diversion of precipitation is possible. We expect the experimental design to be accomplished during fiscal year 1966.

* * *

*The Northern Great Plains Program.*—At the South Dakota School of Mines and Technology, a group under the leadership of Dr. R. A. Schleusener, Director, Institute of Atmospheric Sciences, has come together for the purpose of defining the goals of weather modification for the northern Great Plains. The interests of the group are broad. Those interests which pertain to putting more water in reservoirs are being sponsored by the Bureau of Reclamation. Working under a concept that the Institute will eventually operate as a regional center for the northern Great Plains, a program has started which includes climatological studies concerned mainly with precipitation anomalies, numerical model studies which attempt to simulate a natural growth of cumulus cloud and a randomized seeding experiment.

In preparation for the cloud physics studies, a Piper Apache aircraft was instrumented during fiscal year 1965 under the supervision of D. R. Booker, president of Weather Science and Engineering Co.

Displayed and recorded on an 18-channel light beam oscillograph are measurements of pressure altitude, rate of climb, true airspeed, turbulence, cloud liquid water content, temperature, wet bulb depression, infrared temperature of the underlying surface, longitudinal velocity, vertical velocity, magnetic heading, manifold pressure, and distance from a VORTAC (very high frequency omnidirectional range tactical air navigation) station. An event condition marker is also included. Time-lapse cameras looking forward and downward, a balloon launcher and a tape-recorder intercommunication system, the operations of which are all keyed to the recording oscillograph, complete the instrumentation package.

Using the instrumented aircraft in coordination with a Nike-Ajax radar system, a program of cloud penetrations was begun in fiscal year 1965 and is continuing in 1966 with several specific objectives:

(*a*) To determine the presence or absence of ice particles at $-5°$ C. in cumulus clouds in the Great Plains.

(*b*) To determine by a cloud census, the characteristics of cloud systems which yield precipitation naturally.

(*c*) To determine the causes of "hot spots" which favor the forma-

tion of cumulus clouds. Preliminary results indicate that the frequency of occurrence of ice crystals at the −5° C. level in the northern Great Plains is about 20–25 percent. Approximately 4 out of 5 cumulus clouds sampled have shown no ice crystals at the time of the first pass of the aircraft.

The randomized seeding experiment begun in 1965 and to be continued in fiscal year 1966 consists of operations over two experimental areas. One is designated as the Rapid City project and the other as the Shadehill project. Operations on the Rapid City project are conducted by personnel of the Institute of Atmospheric Sciences of the South Dakota School of Mines and Technology, while the Shadehill project is operated by Atmospherics, Inc., of Fresno, Calif., under the personal supervision of Thomas J. Henderson, president. Operational procedures for the two projects have been jointly arrived at so as to increase comparability of the results from the two areas. The concept involved is the trading of space for time in order to shorten the required period of learning.

In both areas individual convective storms will be seeded with silver iodide dispensed from seeding aircraft. Selection of the storm will be made from the ground by a radar meteorologist with the decision to seed or not seed being made on random basis when the seeding aircraft is airborne and in a position to begin an actual seeding run. The raingage networks which have been installed over each of the target areas will be read as soon as possible after the selected storm has moved out of the area. It is intended that the seeding procedures for the season of 1966 be revised as lessons are learned from the cloud physics studies.

The projects described above are viewed as the beginning of a concerted drive to find practical answers to the many questions which confront the Bureau of Reclamation in discharging its congressionally assigned obligation to find out if the water supply to Reclamation projects can be increased by weather modification techniques. The Bureau's program is an evolving one with flexibility deliberately built in so as to permit improvements in the light of new experience and understanding. The Bureau is building its engineering research effort on the foundations laid by university and private meteorologists with the support of the National Science Foundation and the other agencies whose programs have contributed to the present state of knowledge.

It is the aim of the Bureau of Reclamation program to proceed aggressively toward the goal of practical application of weather modification knowledge as rapidly as is consistent with sound engineering practices.

## National Aeronautics and Space Administration

During fiscal year 1965 the efforts of NASA in weather modification have been directed toward a better understanding of warm fog properties and possible fog modification concepts.

A study entitled "Project Fog Drops" is being sponsored with the Cornell Aeronautical Laboratories. This study includes detailed analytical and experimental investigations of a proposed electrical method of fog modification and a proposed method for preventing dense radiational fog. It will also involve investigation of the effects of atmospheric nuclei and the acquisition of data using a fog tube and a conventional cloud chamber.

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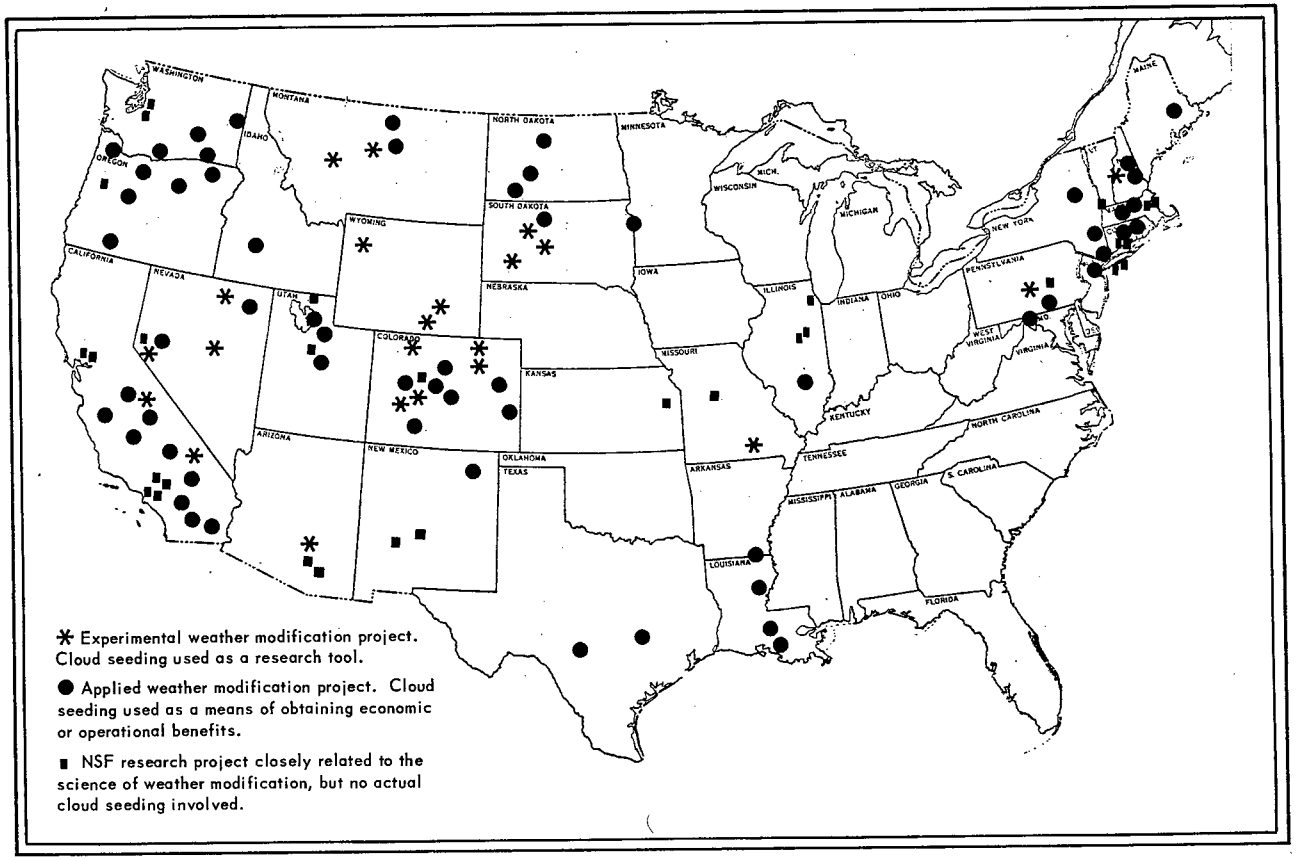


**Weather Modification Projects in the United States—Fiscal Year 1965**

## Appendix A

# NATIONAL SCIENCE FOUNDATION GRANTS AND CONTRACTS FOR WEATHER MODIFICATION RESEARCH, 1965

The following summary is divided into field investigations, laboratory research, and theoretical and statistical studies. Included where available, in each entry is a citation of publication(s) produced in connection with the project. These publications represent evidence that the results of the research sponsored have been made available to the scientific community where they can be both stringently judged and effectively used in future research. Grants awarded in previous years which are still active are also listed.

## Field Investigations

1. *University of Arizona.*—"Field and Laboratory Studies of Lightning Processes"

Studies are being carried on by W. H. Evans and R. C. Jones to determine the electrical field and charge distribution in clouds through the observation of lightning strokes by means of high-speed photography. For this purpose a 195–foot lightning research tower has been erected on nearby Mount Lemmon at 9,200 feet. Electric fields in thunderclouds are also being explored by a new dropsonde instrument which is dropped into thunderclouds at altitudes from 25,000 to 30,000 feet. This equipment measures the field strength within the cloud during its fall through the cloud column, and the results are recorded by using radiosonde telemetry and U.S. Weather Bureau recording equipment.

Measurements of charge transfer in lightning have been made using stereo photographs which are taken and correlated with records of the rapid-run magnetographs at the Tucson Magnetic Observatory of the U.S. Coast and Geodetic Survey. Considerable effort has been made to calibrate the instruments for lightning-like discharges.

Predischarge radio radiation (at 108 and 38 megacycles) from thunderstorms has been studied in building cumulus clouds as a means of detecting electrical activity. Such activity has been detected as early as 15 minutes before the first lightning stroke.

Work is being initiated on a study of lightning streamer formation using two collimated photomultiplier cells for the detection of random streamer formation below active thunderstorm cells. Theoretical calculations indicate that these weak streamers should be barely detectable and their velocity

discernible. Computations are being made on the attachment and diffusion of ions in the atmosphere.

M. A. Uman, "The Conductivity of Lightning," *Journal of Atmospheric and Terrestrial Physics,* September 1964.

M. A. Uman, L. E. Salanave, and R. E. Orville, "The Mass Density, Pressure, and Electron Density in Three Lightning Strokes Near Peak Temperature," *Journal of Geophysical Research,* December 1964.

M. A. Uman and R. E. Orville, "Electron Density Measurement in Lightning From Stark Broadening of H," *Journal of Geophysical Research,* December 1964.

M. A. Uman and R. E. Orville, "The Optical Continuum of Lightning," *Journal of Geophysical Research,* January 1965.

J. Smith, "Negative Ion Effect on Whistler Mode Propagation," *Journal of Geophysical Research,* January 1965.

W. H. Evans, "A New Device For the Measurement of Static Electric Field," *Journal of Geophysical Research,* (In press).

2. *Atmospherics, Inc.*—"Physical Studies of Winter Storms in the Sierra Nevada Range of California"

The Kings River Drainage Area of the western slope of the Sierra Nevada Range in California provides an excellent natural study area for the investigation of winter storms under orographic influence. During the past 10 years, the Kings River Conservation District has given support to a full-scale cloud-seeding program conducted by Thomas J. Henderson of Atmospherics, Inc. This grant supports a study of the physics of clouds and precipitation in the on-going cloud-seeding program. The object is to obtain a better understanding of the winter-storm mechanism and to provide a means of evaluating the results of the operation. Necessary aircraft support is provided by the Conservation District contract. An analysis has now been performed by Henderson on the 10-year results of the Kings River seeding operation and indicates clearly an increase of 6.1 percent in the runoff over an average 10-year period in which seeding was performed.

Thomas J. Henderson, "Tracking Silver Iodide Under Orographic Influence," *Proceedings of the Severe Storm Conference,* Reno, Nev., October 1965.

Thomas J. Henderson, "The Kings River Project—A Non-Randomized 10-Year Cloud Seeding Program," *Proceedings of American Meteorological Society,* Denver, Colo., January 1966.

3. *E. Bollay Associates, Inc.*—"Study of the Fundamental Characteristics of Natural and Simulated Rainfall"

A trial network of five tipping-bucket rain gages has been installed by Eugene Bollay in Valsetz, Oreg., for the purpose of studying the possible rainfall patterns caused by cloud formations passing over the area. Valsetz is normally known for its record of heavy precipitation over most of the winter and spring months. The tipping-bucket gages provide a means for measuring the rate of fainfall during the period of an entire storm and make it possible to measure the fluctuations of rainfall intensity as a cloud system moves over the network. The network was established in order to test the theory that rainfall patterns over any particular region are characteristic

of that region and are repeated over and over again providing the winds are in the same direction and approximately of the same speed.

During the last spring operation, the rainfall in Valsetz has been below normal and insufficient data have been obtained to test the hypothesis. It is now planned to extend the observations over an additional year and to observe the protracted winter storms which are characteristic of the region. These data will be analyzed by digital computer program in order to obtain both storm and seasonal power spectra, coherent and phase, and interstation precipitation ratios. The results will demonstrate the natural patterns of precipitation along a Pacific coast for comparison with similar data gathered by others in the Rocky Mountains.

4. *University of Chicago.*—"The Role of Ice in Summer Rain"

Project Whitetop was established by Roscoe Braham for the purpose of studying the precipitation processes in summer convective clouds and possible means of modifying these processes. Basic cloud studies and randomized seeding experiments were conducted for a number of years in the vicinity of a field station at West Plains, Mo. The results of these field trials indicated the importance of the warm rain process in the formation of precipitation in convective type clouds, and raised a number of questions as to the importance of the Bergeron-Findeisen Process in the formation of rain in supercooled convective cloud systems. In the summer of 1965 Project Whitetop's operating base was moved from West Plains, Mo., to Bemidji, Minn., to provide access to a larger variety of cloud systems in which to conduct the studies. In the new operation at Bemidji studies of natural precipitation processes are being continued, but at the present time no seeding operations are being carried out.

The objective of the Whitetop operation in Bemidji is to determine the relative importance of the coalescence mechanism and the ice crystal mechanism in the formation of rain in clouds of this region. The TPS 10 radar is operated routinely from about 0830 until 2030 central daylight time on all days when precipitating clouds are in the area. An instrumented cloud-physics aircraft is flown into clouds that are precipitating or which may precipitate to measure the concentration of coalescence drops or ice particles.

Preliminary analysis of the summer operation appears to indicate that the coalescence mechanism operates much more slowly in clouds in this area than was found in the Missouri clouds. Characteristically the first ice found in Missouri cumuli was in the form of compact pellets and graupel, but in Bemidji it is usually in the form of crystals and snow. Pellets occur much less frequently and seem to have lower bulk densities than those taken from the cumuli in Missouri. Techniques have been perfected for making thin sections of these small pellets and viewing them under a microscope in polarized light.

The observations will continue at Bemidji for another year after which

it is expected that an assessment of the role of ice in summer clouds can be made with somewhat more assurance than was possible in the past.

5. *Colorado State University.*—"Physical and Statistical Study of Rocky Mountain Orographic Clouds"

Studies are being carried on by Lewis O. Grant in the mountain area of Climax, Colo., of orographic clouds being lifted over the mountain chain during the winter months. Silver-iodide generators located on the windward side of the mountain introduce silver iodide into the air as it is lifted and produce nucleation of the cloud that forms on top of the mountain. On the leeward side, a network of snow gages determines the catch that results from the seeding. Ice nuclei counts are made at the top of the mountain, and ice crystals are sampled and counted.

Development of a kite system and associated instrument package for systematic sampling of the physical conditions in orograph clouds over the Rocky Mountains has proceeded as scheduled. The ability of the transport vehicle, the parafoil, to support the instrument package into clouds above the mountain has been demonstrated. Measurements are made of the size, concentration, and shape of cloud droplets and ice crystals, as well as of the concentration of ice nuclei and the associated pressure temperature, and airflow. Initial in-cloud observations were started during the latter part of the winter. It is expected that it will be possible to prepare water budgets for these clouds which will show the amount of atmospheric water being transported in vapor, liquid and ice forms, and the growth characteristics of cloud ice particles. Since most modification activities intended to increase precipitation are affected by the ratio of liquid water to ice existing in the clouds, this will provide basic information on the natural precipitation efficiencies to be expected and the potential for increasing precipitation.

Equipment for nucleating test clouds locally for the purpose of changing the ratio of ice to liquid water immediately upwind of the instrumented kite has also been developed. This consists of silver-iodide generating rockets and dry ice and liquid nitrogen packages.

Random seeding of the orographic clouds has been continued. Observations were made of associated snowfall characteristics and ice nuclei concentrations as well as precipitation amounts. A 5-year summary analysis of the effect of this seeding on snowfall characteristics, ice nuclei, and amount of precipitation is now in progress.

Lewis O. Grant, "The Use of Radar in Observing Mountain Snowfall," *Proceedings of 33d Annual Western Snow Conference,* 1965.

E. E. Hindman, "The Phase Change in an Artificial Supercooled Cloud Upon Heterogeneous and Homogeneous Nucleation" (paper submitted to the Father James B. Macelwane annual awards competition for original student papers on meteorological topics).

R. A. Schleusener and Lewis O. Grant, "Weather Variation and Modificiation," American Society of Agronomy Monograph on Irrigation in Agriculture, ch. V., 1965.

6. *Arthur D. Little, Inc.*—The "Origin and Role of Electricity in Clouds"

This project is designed to study the mechanism of cloud electrication and to make measurements of clouds in their natural environments. The principal investigators, Bernard Vonnegut and Charles Moore, have hypothesized that the negative charges attracted to the positive top of the thundercloud are carried by downdrafts to lower parts of the cloud and that the positive charges released by point discharge by the earth beneath the cloud are carried by updrafts into the upper parts of the cloud. This idea suggests that convection may build up strong electric fields that will accelerate precipitation formation by coalescence.

During the summer of 1965, field operations were started in the vicinity of Socorro, N. Mex. X-band and S-band radars were established at the Langmuir Laboratory in the Magdalena Mountains, on Mount Withington, and in the valley between these peaks. The radars are being used to examine the liquid water development in the clouds at the same time that observations of the electrical field strength are made on the mountaintops and on instrumented aircraft. Balloon-borne rain catchers have been utilized to measure the charge on droplets. This information is telemetered to the ground.

At the present time, the readings obtained in the field are in the process of analysis.


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B. Vonnegut, C. B. Moore, R. Anderson, S. Bjornsson, D. Blanchard, S. Gatham, J. Hughes, S. Jonasson, and H. J. Survilas, "Electricity in Volcanic Clouds," *Science,* vol. 148, No. 3674, pp. 1179–1189, May 28, 1965.

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C. B. Moore, "Charge Generation in Thunderstorms," *Problems of Atmospheric and Space Electricity,* Ed. S. C. Coroniti, Elsevier Publishing Co., Amsterdam, 1965.

B. Vonnegut, "Thunderstorm Theory," *Problems of Atmospheric and Space Electricity,* Ed. S. C. Coroniti, Elsevier Publishing Co., Amsterdam, 1965.

B. Vonnegut, "Thundercloud Electricity," *Discovery,* March 1965.

B. Vonnegut and J. Latham, "Electrification of Frost Deposits," *Quarterly of the Journal of the Royal Meteorological Society,* vol. 91, No. 389.


7. *University of Nevada.*—"Nevada Atmospheric Research Project"

The Desert Research Institute of the University of Nevada, directed by Wendell Mordy, has continued its cloud-seeding experiments in north-

eastern Nevada near Elko. Ground generators were operated on 9 days during the 1964–65 winter season. A rawinsonde unit was operated for a few trial ascents in May in preparation for its employment for soundings during seeding periods in the 1965–66 season. It was found that the FAA radar station at Battle Mountain, Nev., provided excellent views of precipitation patterns over the Elko area; the proven feasibility of collecting time-lapse photographic records of the Battle Mountain radar scope at the Salt Lake City FAA Air Traffic Control Center during storm periods obviated further maintenance and use of an M–33 radar set at Elko.

At Reno the DRI C–45 research aircraft was further equipped for cloud and precipitation studies by the installation of the following instruments: pressure-altitude transducer, Rosemount temperature probe, Barnes infrared radiometer, Johnson-Williams liquid water content meter, and a 16-millimeter time-lapse camera for cloud photography. Most recently added was an MRI cloud particle sampler which can be monitored in flight by means of a specially designed television system. A tape deck was installed in June 1965 to complement and eventually supplant the oscillograph recorder. In April the twin engines of the Beechcraft were overhauled and equipped with blowers for greater altitude capability. Approximately 15 missions were flown in the period February through June 1965.

In mid-January 1965 some experiments were conducted on airborne-seeding with "dry ice" of supercooled stratus clouds over the Truckee Meadows. A large hole was opened in the thick cloud layer while large snowflakes were observed to fall and whiten the ground at the Reno Airport. An insufficient amount of seeding material was dispensed to effect a permanent clearing but the practicability of the operation was indicated. Also, a high cloud cover prevented a large part of the sun's radiation from heating the ground in the clearing. Thus, fog quickly reformed.

At the temporary DRI field station at the Truckee-Tahoe Airport experiments were carried out to develop various measurement techniques, including M–33 radar tracking of the instrumented aircraft over the Reno-Lake Tahoe area. Radar tracking of horizontally floating balloons (tetroons) for the study of airflow patterns over the Carson Range was also carried out and rawinsonde ascents were made in which the M–33 radar was used to obtain the fine-structure of the wind velocity profile. A program was developed for machine computation and tabulation of the rawinsonde data at the University of Nevada. Photographs of cloud formations were made from the ground and from the air during most of the storms over the central Sierra-western Nevada region in the period February through June 1965.

Final plans for an automatic weather station were completed, the instrument shelter and tower were constructed by the contractor, and the decision was made to install it at 9,650 feet on the top of Slide Mountain overlooking Lake Tahoe and Carson Valley. The data on wind velocity, temperature, pressure, humidity, sunshine, rainfall, etc., will be received by teletype at the Atmospherium.

Work has started at DRI on the development of activation analysis methods for detecting cloud-seeding materials in precipitation. Snow samples were collected from the remaining snowpacks in the Sierra ranges in May 1965, so that measurements could be made of the concentrations of naturally occurring elements in the precipitation in this geographical region.

Theoretical studies of cloud droplet growth by collection have suggested regions of drop sizes that should be measured in a cloud study and have offered a basis for interpreting these measurements. Numerical computations using various authors' collection efficiencies have demonstrated a common pattern of droplet growth, with wide and important variations resulting from the different collection efficiencies. New analytic solutions of the collection equation have helped guide the numerical work and have revealed the effects of some properties of the collection kernel. A general formulation has been given to the cloud droplet growth problem, including condensation, convection, sedimentation, as well as collection. This formulation has provided the background for the numerical computations so far performed.

*Technical Reports*

E. X. Berry and W. A. Mordy, "Cloud Particle Growth by the Combined Effects of Condensation and Collection," Tech. Report. No. 8, March 1964.

W. T. Scott, "Analytical Studies of Cloud Droplet Coalescence I," Tech. Report No. 9, February 1965.

E. X. Berry, "The Effect of Collection Efficiencies on Droplet Growth," Tech. Report No. 10, September 1965.

*Theses*

E. X. Berry, "Cloud Droplet Growth by Collection: A Theoretical Formulation and Numerical Calculation," Ph. D. dissertation, April 1965.

*Conference Papers*

(Presented at AMS Conference on Cloud Physics and Severe Storms, Reno, Nev., Oct. 18–22, 1965.)

W. T. Scott, "Analytic Studies of the Kinetic Equation for Cloud Droplet Growth by Coalescence."

E. X. Berry, "The Effect of Collection Efficiencies on Cloud Droplet Growth."

F. Went, "Organic Volatiles From Plants: A Major Source of Condensation Nuclei."

R. Sill, "Phase Transitions and Phase Equilibrium."

W. A. Mordy, "Scales of Turbulence in Relation to the Development of Cloud Droplet Spectra."

J. A. Warburton, "The Detection of Silver in Rainwater."

8. *State University of New York.*—"Cloud Physics Field Research Seminar at Yellowstone National Park"

The fifth winter expedition to the Old Faithful region of the Yellowstone Park took place from January 5 to February 2, 1965. As a part of the program, seminars and associated programs of research were organized and supervised by Vincent Schaefer. This is the fourth such expedition sponsored by the National Science Foundation and some 41 participants were active in the research seminars and in the field experiments.

The major objective of the program this year was to explore the possibility of utilizing areas other than Old Faithful for cloud seeding sites. Three new locations were utilized. The Blue Star Spring proved to be an excellent location. A second location found is the area near the newly active White Geyser (south of Old Faithful Inn). The third is near Scallop Spring and Sawmill Geyser. Preliminary studies of the ice replicas made when several sites were used simultaneously indicate that the multiple site approach will have immense value for making comparative studies. Crystals produced using the same type of seeding appeared to be identical except for size. Since the seeding sites are at different distances from the observation site, comparisons can be made of crystalline structure, relative size, and volume of concentration as a function of distance from the seeding site.

Two seeding runs produced a very impressive growth and fallout of snow crystals. The first was carried out January 18, 1965, when 20 grams of silver iodate were burned in a pyrotechnic flare in the vicinity of Old Faithful. A spectacular snowfall of clustered hexagonal platelets fell with a velocity of about 1 meter/second at the Castle Geyser observation site. A 180-gram sample of snow was obtained on a 10-square-meter sheet of polyethylene for subsequent studies using neutron activation analysis. A similar fall of clustered plates followed a light seeding with dry ice. The most impressive feature of these two seeding runs was the quite noticeable accumulation of snow that formed within a layer of supersaturated and cloudy air not more than 100 meters in vertical thickness. Further analysis is being prepared for formal publication.

Another study made during the expedition was of the mechanical effects of simulated lightning discharges on the hydrometeors. Twenty-nine observations of this type were made during eruptions of Old Faithful over a period of 2 weeks. Thunder effects were simulated by the detonation of varying lengths of 56-grain primacord suspended from captive balloons anchored at various distances from the cone of the geyser. It was observed that short waves of hail pellets immediately followed the detonation of the primacord. Samples of the micro-hail pellets were replicated and observed under the miscroscope. The replicas indicate that the samples were rimed ice droplets slightly larger than 0.5 millimeter in diameter. Studies were also made to detect the shattering of large droplets in the Old Faithful plume through impact of the shock wave. It was found that the effect of detonation was to increase the number of droplets collected in the lee side of the plume by a factor of fivefold to sixtyfold. This effect was attributed to the shattering of the larger droplets by the shock wave. It is believed that these observations constitute conclusive evidence that lightning discharges produce important mechanical effects upon precipitating supercooled clouds.

Tests were made of several newly developed pyrotechnic devices for generating icing and condensation nuclei in the supercooled fogs above the Old Faithful basin. These units range in size from two large flares containing 1,000 grams of silver iodide each with a burning time of 3 minutes down

to a Very pistol yielding approximately 6 grams of silver iodide. Design information was obtained as a result of these firings and some changes will be made in the composition of the pyrotechnic devices as a result of these tests.

Charge transfer between ice-coated spheres in a cloud of steadily falling ice crystals was also studied. A smooth ice-coated sphere was suspended from an insulating fiber string and whirled through a cloud of the falling crystals. The sphere was then quickly lowered into the induction can connected to an electrometer, thus providing a measurement of the charge accumulated by the sphere. The results were in agreement with laboratory experiments showing that there is a marked enhancement in charge transfer with increasing surface roughness and impact velocity.

L. Randall Koenig, "Stabilization Process Paper as a Rain-Drop Sensor," *Journal of Applied Meteorology,* vol. 3, No. 1, p. 112, February 1964..

Paul B. MacCready, Jr., and Clement J. Todd, "Continuous Particle Sampler," *Journal of Applied Meteorology,* vol. 3, No. 4, pp. 450–460, August 1964.

F. W. Went, "The Nature of Aitken Condensation Nuclei in the Atmosphere," *Proceedings of National Academy of Sciences,* vol. 51, No. 6, pp. 1259–1267, June 1964.

V. J. Schaefer, "Studies of Cirrus Type Clouds at Ground Level," *Proceedings of the International Conference on Cloud Physics,* pp. 414–418, Tokyo/Sapporo, Japan, May 24–June 1, 1965.

J. Hallett, "Field and Laboratory Observations of Ice Crystal Growth from the Vapor," *Journal of Atmospheric Sciences,* vol. 22, pp. 64–69, (1965).

9. *Pennsylvania State University.*—"Investigation of the Dynamics and Microphysics of Clouds"

These studies are concentrated primarily in the region of the Nittany Valley in Pennsylvania, a 40-mile long section surrounding Pennsylvania State University. For the past 6 years, a research group under the direction of Dr. Charles L. Hosler has continued to explore the role of motions of clouds caused by local topography in modifying cumulus cloud dynamics and the degree to which the release of additional heat by the conversion of a cloud into ice can modify the buoyancy of the cloud. In the region of central Pennsylvania where precipitation is significantly modified by the air motion induced by the mountainous topography, measurements continue to sustain the hypothesis based on earlier observations that timely glaciation of the cumulus clouds can increase cloud growth and extend cloud lifetime. Seeding experiments have been carried on in central Pennsylvania and the expected growth in the cloud has been observed to result in an increase in the lifetime and intensity of the cloud as observed by radar.

During the fall of 1964 and winter of 1965, a twin Commanche aircraft was instrumented and tested. The aircraft was equipped with turbo chargers, oxygen system, and navigational instruments suitable for cloud penetration and operations to altitudes near 30,000 feet. During some of the test flights, supercooled stratus were seeded and the development within the seeded

volume of snow flurries was monitored by successive passes through the clouds. Positive radar control was maintained in order to orient the aircraft with respect to the test clouds.

In the spring of 1965, 14 flights were made with the twin Commanche in coordination with the radar and balloon studies. These flights were arranged so as to obtain comprehensive observations on internal cloud parameters in relation to airflow patterns and radar characteristics of the clouds. One cloud-seeding operation was carried on in which a cloud was seeded to release latent heat for buoyancy. Environmental soundings had indicated that the situation was suitable for influencing the natural growth of the cloud. The expected growth and increased lifetime of the seeded cloud was obtained. The seeding was accomplished with six pyrotechnic flares fired from a flare gun in the aircraft.

During the summer of 1965, four members of the Pennsylvania State University staff participated in a joint field program at Flagstaff, Ariz., with the University of Nevada, Meteorology Research, Inc., the U.S. Army, and the Boeing Aircraft Co. In this operation, penetrating aircraft were vectored into seeded and nonseeded clouds to monitor the internal structure while 3-centimeter and 10-centimeter radars were also monitoring the development of the precipitation. Various types of balloons were used to measure winds and to obtain temperature readings. The twin Commanche made nearly 200 cloud penetrations; 18 physical parameters were measured; cloud particle samples were collected; and still and moving pictures of the test clouds were taken. The results of these operations are now under analysis.

D. R. Booker, C. L. Hosler, and L. G. Davis, "Air Flow Over the Allegheny Mountains," *Bulletin of American Meteorological Society* (Abstract), vol. 45, p. 695 (1964).

D. R. Booker and L. Cooper, "Superpressure Balloons for Weather Research," *Journal of Applied Meteorology,* vol. 4, No. 11, pp. 122–129 (1965).

L. G. Davis, D. R. Booker, and C. L. Hosler, "Observations of Natural and Artificial Alterations of Cumulus Buoyancy," *Proceedings of 1965 International Conference on Cloud Physics,* pp. 20–24, Tokyo, Japan, May 24–June 1965.

C. L. Hosler, L. G. Davis, et al., "Modifications of Convective Cloud Systems in Central Pennsylvania," *Mineral Industries,* vol. 34, pp. 1–5 (1965).

J. E. Jiusto, "Cloud Particle Sampler," Report No. 6, NSG–24850, The Pennsylvania State University, University Park, June 1965.

## FIELD INSTALLATIONS CONTINUING FROM PREVIOUS GRANTS

10. *Colorado State University.*—"Modification of Hailstorms in the High Plains"

The equipment and techniques developed by Richard A. Schleusener for measuring physical characteristics, duration, and frequency of rain and hail at the ground have been carried on by John D. Marwitz during the summer of 1965. Over the 2-year period 1964–65, a total of 16 test cases have been observed, of which 6 were seeded and 10 were not seeded. It is noted that 1964 was a severe drought period, while 1965 produced a large number of very efficient rain-producing thunderstorms.

On June 7, 1965, an excellent record was obtained of the moisture, pressure, temperature, number of Aitken nuclei, and number of ice nuclei in the sub-cloud layers of a thunderstorm that produced hail (and a hook-type echo on the radar). The documentation was made using the U.S. Weather Bureau's RFF DC–6 aircraft with support from the project T–6 aircraft and a ground radar network. As a result of the two-season operation, it was concluded that it was unreasonable to use a fixed, ground-based network for the evaluation of hailstorm modification experiments, since each hailstorm is in a different segment of its life cycle as it passed over a particular observation point. A mobile network involving aircraft radar and mobile observers was considered to be necessary for future operation. Results from a limited number of observations to date, suggest that the continental air masses over Fort Collins may be somewhat deficient in Aitken nuclei as compared to other continental areas. All ice particles observed at the $-5°$ C. to $-10°$ C. level can be accounted for as having been caused by seeding from cirrus clouds above the thunderstorm or by artificial nucleation by project personnel. The artificial seeding appears to give a higher concentration of ice particles in the form of rimed ice pellets, which are different from any naturally occurring particles which have been encountered. It has been found that when the height of the visual tops of the thunderstorms in the Fort Collins area exceeds the height of the radar tops by more than 10,000 feet, dissipation will usually occur within 30 minutes.

During the 1965 season in northeastern Colorado, a large number of tornadoes and funnel clouds were found to occur. This is unusual for the area since it normally receives only two to three funnel clouds per year. A study of the summertime lee waves in the atmosphere indicates that those in the vicinity of Fort Collins have wavelengths on the order of 8–10 nautical miles and amplitudes of 200–6,000 feet with a median of about 1,000 feet.

Analysis on randomized test cases as well as nonrandomized test cases will continue, and several analyses of cloud physics data will be made using data from 1964 and 1965 seasons. Studies will also be made of the tornadoes and flooding situations which have occurred in northeastern Colorado during the 1965 season.

J. D. Marwitz, "Autocorrelation and Regional Correlation of Summer Rainfall," Thesis, Department of Civil Engineering, Colorado State University, Fort Collins, Colo., December 1964.

R. A. Schleusener, J. D. Marwitz, and W. L. Cox, "Hailfall Data From a Fixed Network for the Evaluation of a Hail Modification Experiment," *Journal of Applied Meteorology,* vol. 4, No. 1, pp. 61–68, February 1965, CER64RAS–JDM–WLC13.

J. D. Marwitz, T. J. Henderson, and R. A. Schleusener, "Radar Climatology of Hailstorms In and Near Northeastern Colorado," May 15 through July 31, 1964, Prepared for the Crop-Hail Insurance Actuarial Association, March 1965, CER65JDM19.

A. H. Auer, Jr. "The Vertical Distribution of Aitken Nuclei in the Vicinity of Fort Collins, Colorado," Thesis, Department of Atmospheric Science, Colorado State University, Fort Collins, Colo., June 1965.

J. D. Marwitz and R. A. Schleusener, "Persistence of Thunderstorms," Paper to be presented to Conference on Cloud Physics and Severe Local Storms, Reno, Nev., October 1965.

A. H. Auer, Jr., and W. Sand, "Vertical Velocity Measurement in the Vicinity of Cumulus and Cumulonimbus Clouds" (paper to be presented to Conference on Cloud Physics and Severe Local Storms, Reno, Nev., October 1965).

R. A. Schleusener, P. St. Amand, and Wayne Sand, "Case Study of Apparent Stimulation of Convection by Seeding a Thunderstorm with Alecto Pyrotechnic Devices" (paper to be presented to Conference on Cloud Physics and Severe Local Storms, Reno, Nev., October 1965).

11. *New Mexico Institute of Mining and Technology.*—"Atmospheric Research in Weather Modification Activities"

Continuing studies are being made by the staff of the New Mexico Institute of Mining and Technology on cloud forms and natural processes which occur in clouds and thunderstorms in the vicinity of Socorro, N. Mex., and at the mountain laboratory in the Magdalena Range. Marvin H. Wilkening reports that measurements of winds, dew point, solar radiation, electric field, polar conductivity, corona current, earth currents, magnetic field, and natural radioactivity are essentially complete at the Langmuir Mountain Observatory from August 1963. A cloud census within a 50-kilometer radius of the laboratory for July and August 1964 has now been completed. Eight separate research organizations have conducted experiments from the Langmuir Mountain Observatory during the 1965 season. Included in these are Arthur D. Little, Inc.; Southwest Research Institute; Edgerton, Germeshaven, and Greir; and the University of Pennsylvania. The Observatory has been playing host to as many as 35 researchers a day during the active thunderstorm season.

An analytical study on convection in incipient thunderstorms has been started at Socorro. Pressure decreases at the ground are observed near beginning thunderstorms. The pressure drop from the ambient and the rate of pressure decrease are measures of the amount of convective buoyancy which has been developed and its rate of development. Studies of feasibility of estimating convective buoyancy in a single cell from surface pressure measurements are underway.

The electrical properties of a moving ice-water interface have been investigated theoretically. In particular the Workman-Reynolds effect has been quantitatively explained using a postulated inequality in the ionic distribution coefficients. Calculations made on the mathematical model resulting from this postulate give the correct shape and magnitude of the freezing potential and freezing current curves. In addition, the model gives the correct dependence of the magnitude of the freezing potential on such variables as the pH of the liquid phase, interface velocity, and the resistance of the ice to electric charge flow.

A program for estimating thunderstorm-induced atmospheric interchange between the stratosphere and the troposphere by analyses of the tritium content of rainwaters from various types of storms as well as from samples collected at different times during the development of a single storm was begun during the summer of 1964. It appears that additional useful information can be obtained from tritium analyses of water condensed from the atmosphere early in the days on which storms are likely to occur. The measurements are to be continued during the summer of 1965.

"Research Facilities—Atmospheric Physics," *Physics, Today,* vol. 17, pp. 62–63, 1964.

Ralph M. Mc Gehee, "The Influence of Thunderstorm Space Charges on Pressure," *Journal of Geophysical Research,* vol. 66, pp. 1033–1035, 1964.

Don J. Latham, "A Study of Thunder from Close Lightning Discharges," Master's Thesis, New Mexico Institute of Mining and Technology, 1964.

Don J. Latham and Marx Brook, "A Study of Thunder from Close Lightning Discharges" (paper presented at the Southwest Regional meeting of the American Geophysical Union, Socorro, N. Mex., Jan. 28, 1965).

Marvin H. Wilkening, "Atmospheric Elements at the Langmuir Laboratory" (paper presented at Southwest Regional Meeting of the American Geophysical Union, Socorro, N. Mex., Jan. 28, 1965).

Niels Jonassen, and M. H. Wilkening, "Conductivity and Concentration of Small Ions in the Lower Atmosphere," *Journal of Geophysical Research,* vol. 70, Feb. 15, 1965.

12. *New Mexico Institute of Mining and Technology.*—"Thunderstorm Electrification"

Observations of thunderstorms in the New Mexico mountains have been carried on for a number of years by Marx Brook in an attempt to understand the electrical phenomena associated with them and to relate these phenomena to meteorology of the environment. The primary research efforts in fiscal year 1965 have been divided among three areas of thunderstorm phenomena involving lightning studies, acoustical measurements of thunder and high-pressure shock waves from lightning discharges, and cross-polarization measurements of reflected radar energy from the clouds.

In the area of lightning studies, many new instrumental techniques for the study of the fine structure of lightning discharges have been developed in this project. Among these are the photoelectric, lightning-stroke counter utilizing an H-alpha filter in front of a red-sensitive photomultiplier to permit the counting of lightning strokes during the daylight hours. A daytime lapse time camera using an H-alpha filter was also developed for taking lightning photographs in the daytime.

A preliminary study has been completed on measurements of thunder from nearby lightning. (This is the subject of a master's thesis by one of the graduate students.) This work is being examined closely in light of the possibility that shock waves produced by lightning discharges may trigger the freezing of supercooled water droplets or may have an influence on the shattering of water droplets within the cloud. Energies associated with these

discharges are being examined and further work is contemplated in this area of research.

Cross polarization radar measurements provide a powerful tool for examining hydrometeors in a cloud to determine whether they may be identified as water droplets or as ice crystals. Since ice crystals may reflect radar energy polarized in one direction differently from that polarized in another direction while spherical water drops are not expected to show this effect, it is possible to distinguish between the two types of target in many cases. Measurements will be continued throughout the remainder of the summer in 1965 and it is expected that data will result of interest to weather modification techniques.

M. Brook and N. Kitagawa, "Radiation from Lightning Discharges in the Frequency Range 400 to 1000 Mc/s," *Journal of Geophysical Research,* vol. 69, No. 12, June 15, 1964.

Toshio Ogawa and M. Brook, "The Mechanism of the Intracloud Lightning Discharge," *Journal of Geophysical Research,* vol. 69, No. 24, Dec. 15, 1964.

Leon E. Salanave and M. Brook, "Lightning Photography and Counting in Daylight, Using H-alpha Emission," *Journal of Geophysical Research,* vol. 70, No. 6, Mar. 15, 1965.

D. J. Latham, "Thunder from Close Lightning Discharges," Master's Degree Thesis, New Mexico Institute of Mining and Technology, June 1, 1965.

E. L. Ausman and M. Brook, "Water Drops in Strong Electric Fields" (paper presented at Western Regional A.G.U. meeting, Socorro, N. Mex., February 1965.

M. Brook and E. L. Ausman, "The Measurement of Strong Electric Fields in Clouds Using Cross-Polarized Radar" (paper presented at the International Conference on Cloud Physics, Tokyo and Sapporo, May 27, 1965).

## Theoretical and Statistical Studies

1. *University of Arizona.*—"Physics of Convective Clouds and Cloud Modification"

Studies performed by Louis J. Battan have indicated that silver-iodide seeding of convective clouds during the period of 1957–60 failed to show that rainfall had been increased. During the summers of 1961, 1962, and 1964, another set of cloud-seeding tests were made. The procedures were somewhat different than in the first set of experiments.

Silver iodide was dispersed by means of U.S. Forest Service generators mounted on a Cessna 172. The airplane was flown at an altitude just below the cloud bases along a track perpendicular to the wind at flight altitude about 5–10 miles upwind of the edge of the target area. Seeding was carried on for periods of 2–4 hours on each seeded day.

Over the 3-year total period, thirty-seven 2-day test periods were selected. A procedure was used wherein the first day of the pair was either seeded or not seeded according to a randomization procedure. For the 3 years, the average rainfall on seeded days was about 33 percent less than on the nonseeded days. Quite obviously, these results fail to show that the seed-

ing increased precipitation. The question arises as to whether the data in fact show that rainfall was decreased. The Wilcoxon sign-rank test yields a significance level of 0.17. Thus, it is concluded that the observed difference in rainfall was probably a result of chance. An extensive report on the rainfall analyses is being prepared for publication. The rainfall data as well as the observations collected by means of radar and cloud cameras are still being analyzed.

Pulsed doppler radar is being used to perform an analysis of a "steady" winter rain in which raindrop size distributions are being calculated directly from the radar data. To date, comparison of calculated spectra with those observed at the ground are very encouraging.

Observations have been made of the field of vertical motion, and the presence of hail in moderately large thunderstorms. These observations give a detailed cross-section through an intense updraft core. By means of the radar data, calculations have been made of the size distribution of hailstones at 8 kilometers.

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2. *University of California.*—"Weather Modification Section of the Fifth Berkeley Symposium on Mathematical Statistics and Probability"

The Berkeley Symposia on Mathematical Statistics and Probability are held every 5 years and are attended by statisticians and physical scientists from many countries. While the symposium covers all aspects of statistics and probability, one section will be devoted to the application of these scientific disciplines to weather modification. The purpose of this grant is to support the travel and preparation of papers by eminent foreign scientists who will participate in the activities of the Weather Modification Section. The proceedings of the Weather Modification Section will be published as a separate volume. The following topics will be discussed:

1. The extent of current cloud seeding.
2. The type of experimentation that has been conducted to date.
3. Current ideas on the physical mechanism of precipitation and of means for producing it artificially.
4. Statistical evidence of the effectiveness of cloud seeding.
5. Methodology of experimentation and of statistical evaluation.

* * *

3. *University of California.*—"Simulation of Global Climate and Climate-Control Experiments with a High-Speed Computer"

Yale Mintz is utilizing high-speed electronic computers to study the dynamics of global climate and to simulate climate control experiments by the integration of the primitive equations of atmospheric motion. A limited computer model of the atmosphere has already been constructed by this investigator under a previous grant from the National Science Foundation and he is now proceeding with the improvement of the present

two-level general circulation model. These improvements will take the form of a reduction of the grid size in order to obtain better horizontal resolution and the incorporation of water vapor as an explicit dependent variable with a revised parameterization which takes account of the release of latent heat.

Studies are being made by various scientists on the feasibility of modifying ocean temperatures or diverting ocean currents as a means of weather modification. One of these studies by Joseph Fletcher of The Rand Corp. has indicated that rather significant changes in the atmospheric circulation might result from the removal of arctic sea ice. Several numerical general-circulation experiments have been suggested by Fletcher, and the principal investigator is making the preliminary two-level model available to him for use in some preliminary computations. The results will be a useful guide in the design and execution of later calculations which will use the improved numerical model when it has been completed.

Under the chairmanship of Jacob Bjerknes, the University of California at Los Angeles is organizing an internal workshop on the heat balance in the arctic. This workshop is international in character and brings together recognized experts in the field of arctic meteorology for the purpose of making available the best information currently obtainable on the present thermal regime of the high-latitude regions of the earth's surface and atmosphere. In addition, this workshop has the purpose of assessing the status of present knowledge of the arctic heat balance and reaching a consensus concerning the most fruitful approach for obtaining and collecting additional items.

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4. *Douglas Aircraft Company, Inc.*—"Study of Natural and Artificial Precipitation Formation"

For the past 3 years, a numerical experiment in precipitation physics has been carried on by L. Randal Koenig. The original goal of this study was to test the hypothesis that the splintering of freezing drops is responsible for the high concentrations of ice particles found in relatively small, cumulonimbus clouds with bases about 10,000 feet below the freezing level, for example, the common Midwestern, summertime, small, cumulonimbus clouds.

The basic objective of this program has been expanded to explore the consequences of modifying the natural behavior of clouds. The approach has been to develop a mathematical model that simulates natural cloud behavior with sufficient accuracy so that confidence may be placed on the computed evolution of clouds whose characteristics such as the distribution of ice-forming nuclei and the droplet size distribution are artificially modified. In this way, one should be able to determine how clouds might respond to artificial control applied by one means or another.

The numerical model simulates—

1. The addition and removal of water substance by diffusion.
2. The coalescence of water drops.
3. The coalescence of water and ice particles.
4. The break-up of unstable droplets.
5. The production of ice splinters during drop freezing.
6. The separation of electric charge during splintering.

Results of the experiment support the hypothesis that the splintering of drops can account for the behavior of certain clouds observed to glaciate at relatively warm temperatures. The field observations used to check the numerical experiment are primarily those gathered by the University of Chicago's Project Whitetop.

L. R. Koenig, "A Numerical Experiment in Precipitation Physics," Douglas Aircraft Co. Report No. SM–48696 (dated May 1965) final report to the National Science Foundation on Contract NSF C–357.

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5. *University of Illinois.*—"Time Altitude Variations of Atmospheric Electricity Variables"

During the summer of 1963, 48 aircraft soundings to measure atmospheric electricity parameters within clouds were made within a period of 27 days at West Plains, Mo., by Glenn E. Stout. These soundings were made in connection with the weather modification program being carried on by the University of Chicago under Project Whitetop. Flights were made twice a day to an altitude of 10,000 feet and recordings were taken of the vertical and horizontal potential gradient, conductivity, temperature, and humidity. This project will permit an analysis of the airborne data to be made in order to compute the electrical conduction and convection currents inside and in the vicinity of the cloud systems. The vertical distribution of space charge in stratified air will be calculated by differentiating the potential grandient curve. The analysis is expected to yield a quasi-climatological description of the space-charge potential gradient, conduction current, and convection current over southcentral Missouri. From this information, it is expected that knowledge will be gained concerning the mechanisms that support the convection current. It is expected that these data will later be correlated with measurements made by Roscoe Braham of the University of Chicago on cloud variables and on the first echo-radar data collected simultaneously. The data will further our understanding of the mechanisms involved in convection currents and their relationships to space charge.

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6. *University of Illinois.*—"The Effect of Artificially Produced Space Charge on the Electrification of Clouds"

During the summer of 1960, the Illinois State Water Survey cooperated with a joint program between the University of Illinois and A. D. Little, Inc., under the direction of Dr. Bernard Vonnegut and C. B. Moore of Arthur D.

Little, Inc. The electrification of clouds was studied with an instrumented light aircraft by Richard Semonin over an 8-mile line source of artificially produced space charge. The study showed that the space charge produced by the high voltage wire was convected in to the cloud base and that fair weather cumulus was weakly electrified.

This project is designed to review and analyze the data obtained during the field operation of the high voltage wire and to determine how much information can be learned concerning cloud dynamics through a study of the charge transport. This information will be used to supplement the more conventional observational data obtained by other observers on cloud dynamics and to determine whether some identifiable modification of cloud life can be detected through the injection of space charge. While charging of clouds was observed in a meteorological situation where some major effects might have been anticipated, the expected explosive buildup of the seeded cloud did not occur. The ion trajectories did, however, provide a valuable tracer technique for tagging parcels of air convecting from ground level into the cloud.

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7. *New York University.*—"Satistical Design and Evaluation of Extraterrestrial Correlations with Meteorological Parameters"

Max A. Woodbury and Glenn Brier continue to amass and analyze lengthy weather records in the light of an earlier finding that interactions between extraterrestrial forces and atmospheric events are of greater importance to both theoretical and practical meteorology than had previously been thought. During the past year the detailed proofs of the reality of the lunar effect on precipitation first reported on in 1962 have been published, and much headway has already been made in the direction of establishing the nature of the physical mechanisms by which such effects are produced. Considerable evidence indicates that atmospheric tides are a key factor, although departures of the observational data from certain theoretical expectations point to the probable efficacy of other forces as well. Although these tidal forces are small, a mathematical and statistical analysis indicates that under certain circumstances it is not the size of a triggering impulse that is of greatest importance but rather the state of a system and its rate of change at the time a perturbation is applied. In examining the evidence for manmade effects on the atmosphere, it is suggested that one consider not only mean effects but possible changes in the timing of events as well.

G. W. Brier and D. A. Bradley, "The Lunar Synodical Period and Precipitation in the United States," *Journal of the Atmospheric Sciences,* vol. 21, No. 4, pp. 386–395, July 1964.

D. A. Bradley, "Tidal Components in Hurricane Development," *Nature,* vol. 204, No. 4954, pp. 136–138, Oct. 10, 1964.

G. W. Brier, "Diurnal and Semidiurnal Atmospheric Tides in Relation to Precipitation Variations," *Monthly Weather Review,* vol. 93, No. 2, pp. 93–100, February 1965.

D. A. Bradley, "Tidal Components of Hurricane Development, *Nature*, vol. 206, No. 4989, pp. 1143–1144, June 12, 1965.

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8. *The Rand Corp.*—"Weather Control Program"

As part of the general program of research on weather modification within the Rand Corp., Stanley Greenfield is investigating the basic problems and concepts underlying the techniques for weather modification. At the present time, emphasis is being placed on studies of the heat balance of the Arctic region. Studies are being made by Joseph Fletcher on the relationship of the solar heat balance of the Arctic to general circulation phenomena. It is believed that the general atmospheric circulation patterns are very strongly influenced by the thermal regime in the Arctic and Antarctic regions, and the effects of theoretically removing the polar ice caps or of sprinkling reflective or absorptive material on the surface of the ice is being studied by high-speed computer techniques.

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## THEORETICAL AND STATISTICAL STUDIES CONTINUED FROM PREVIOUS GRANTS

9. *University of California.*—"California Rainfall Processes"

Jacob Bjerknes is studying the basic rainfall processes to obtain a better understanding of the possible effects of the weather modification activities conducted throughout California. The three-dimensional field of vertical motion accompanying the various types of rainstorm situations in California are being derived by electronic computation from the observed sequence of pressure-height fields. A representative variety of western rainstorms was investigated in order to determine the distribution of precipitation as a function of the joint vertical motion inherent in the storm structure and the forced vertical motion at mountain barriers. New and presumably better estimates of the field of vertical motion of any given synoptic situation over the ocean or flat parts of the continent were made.

T. N. Krishnamurti, "The Finite Amplitude Mountain Wave Problem With Entropy as a Vertical Coordinate," *Monthly Weather Review*, vol. 92, No. 4, April 1964.

Roger A. Helvy, "Meso-scale Behavior of Rainfall in Los Angeles County During the Rainstorms of Jan. 25–26, 1956," M.S. Thesis, UCLA, 1964.

Jurcec Vesna, "Nongeostrophic Vertical Motions and Energy Transformations," Ph. D. Thesis, UCLA, 1964.

10. *University of Missouri.*—"An Evaluation of a Cloud Seeding Experiment"

The fifth and final year of the cloud seeding experiment associated with Project Whitetop has been completed by Wayne L. Decker. It is possible to present the complete summaries.

In accordance with the design of the experiment, those days which were favorable for cumulus cloud development in southern Missouri were con-

sidered in pairs and one of the pair was designated as a seeded day and the other as a nonseeded day. On the days which were designated as seeded days, a smoke plume of silver iodide drifted with the prevailing winds across the research area. On days designated as nonseeded days, no seeding was performed but the direction of the prevailing winds was monitored to determine the trajectory over which a seeded plume might have passed if seeding had been actually performed. For each type of day, a comparison was made of the rainfall which fell along the trajectory of the actual seeded plume or the trajectory of the hypothetical nonseeded plume with the adjacent areas not touched by the trajectory. These average rainfall rates are listed in inches per hour in the following table for each of the 5 years of operation.

*Average Precipitation for the 5-Year Cloud-Seeding Experiment*

(Inches per hour)

| | Seeded days | | | | Nonseeded days | | |
|---|---|---|---|---|---|---|---|
| Year | Number of days | Under the trajectory | Outside the trajectory | Year | Number of days | Under the trajectory | Outside the trajectory |
| 1960..... | 26 | .0056 | .0084 | 1960..... | 17 | .0074 | .0104 |
| 1961..... | 17 | .0093 | .0072 | 1961..... | 20 | .0137 | .0125 |
| 1962..... | 16 | .0022 | .0040 | 1962..... | 23 | .0142 | .0089 |
| 1963..... | 23 | .0066 | .0056 | 1963..... | 17 | .0064 | .0057 |
| 1964..... | 20 | .0066 | .0070 | 1964..... | 19 | .0074 | .0044 |
| Period.. | 102 | .0061 | .0066 | ..... | 96 | .0102 | .0085 |

Tests of the statistical significance indicate that no evidence exists that the differences reported in the table could not have occurred by chance. Further, a comparison of outside the trajectory average rainfall for the seeded and nonseeded days indicates that on the nonseeded days more natural rainfall occurred than on the seeded days. This chance grouping of days may have caused the under plume trajectory area on seeded days to experience less overall rainfall than on nonseeded days.

A more detailed analysis of the close-in radar echo pattern on seeded days has indicated a possible increase in radar echo intensity of almost 10 percent for a distance of approximately 40 miles downwind of the seeding point. Beyond this distance, echo pattern appears to be below normal. Evaluation of the close-in effects is still under way to see whether a regrouping of the raingage data will substantiate the radar data.

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11. *New York University.*—"Feasibility of Artificial Modification of Tropical Storms"

The primary objective of the project is to develop a dynamic model of a hurricane with which to study through numerical experiments on an electronic computer the feasibility of artificial modification of tropical storms. Toward this end, efforts have been continued by D. Ooyama to improve his three-layer balanced symmetric hurricane model. The model now takes into account the rate of evaporation from the sea surface to the boundary inflow layer. It has been found that the finite rate of evaporation moderates the growth of a model hurricane considerably and that it also reduces the radius of the eye to a reasonable size of 60 to 80 kilometers. These results are a significant improvement over those of the earlier model, in which the instantaneous adjustment of the boundary layer humidity to an equilibrium state with the sea surface was assumed. Currently under way is a further modification of the model to incorporate a nonlinear lateral friction in order to test effects of the nonlinear friction on the wind fields.

Staff members of the project have conducted studies on several related topics. A synoptic analysis of the tropical Atlantic oceans for the period August 12–22, 1963, has been virtually completed by V. J. Cardone. Toward the end of the analyzed period, Hurricane Beulah developed. The infrared radiation measurements from Tiros VII and television cloud photography from Tiros VI and VII were analyzed and combined with the conventional synoptic analysis of all the available meteorological data to show the changes in cloud structure associated with a developing tropical cyclone. Based on the same synoptic data, R. Bermowitz has been testing an objective method of computing the divergence field in the planetary boundary layer.

A theoretical study on rigorous criteria for instability of a baro-clinic circular vortex was completed by K. Ooyama, and numerical computations of unstable solutions are being carried out by S. H. Chiu in order to examine details of unstable motion.

In cooperation with the National Weather Satellite Center, C. Barrientos has extended his study on the transverse circulation in steady-state hurricanes. He has also started analyzing the aircraft observation data of hurricanes (supplied by National Hurricane Research Laboratory) to assess quantitatively effects of the asymmetry in wind fields on the momentum and energy budgets.

C. S. Barrientos, "Computations of Transverse Circulation in a Steady-State, Symmetric Hurricane," *Journal of Applied Meteorology,* vol. 3, No. 6, pp. 685–692, 1964.

K. Ooyama, "A Dynamical Model for the Study of Tropical Cyclone Development," *Geofysica Internacional,* vol. 4, No. 4, 1964.

K. Ooyama, "On the Stability of a Baroclinic Circular Vortex: A Sufficient Criterion for Instability" (submitted for publication in *Journal of Atmospheric Science*), 1965.

J. Spar, "A Survey of Hurricane Development," *Geofysica Internacional,* vol. 4, No. 4, pp. 169–178, 1964.

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12. *Oregon State University.*—"Observation and Analysis of Showers of Small Hail and Related Atmospheric Phenomenon in the Oregon Coast Range, West of Corvallis, Oreg."

Research has been carried on by Fred W. Decker and Lyle B. Calvin to observe and analyze hail storms in the Oregon Coast Range during the winter season. This region has more hail falls than any other part of the country. The hailstones have small diameters, and the region presents an excellent opportunity for the study of storms with the purpose of obtaining a detailed description of the conditions under which small hail will form. During this year, a number of simultaneous observations were made of surface phenomena and radar echos from precipitating clouds on both hail and nonhail days.

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13. *University of Utah.*—"Evaluation of Weather Modification"

Research has continued under J. Vern Hales to investigate the effects of weather modification upon the water budget and heat budget of the Southwest United States; specifically, the effects of 1, 5, 10, 20, and 50 percent increases in the main annual precipitation. One aspect of this research is the investigation of the effect of increasing the natural precipitation of the Southwest, particularly, upon the heat budget.

Investigation of Gambel's quail population hypothesis related to precipitation patterns has been investigated. Preliminary study indicates that the population of these small game birds is limited by water supply over much of the Western United States. There is believed to be a definite relationship between precipitation amounts and bird population. Work on this interesting relationship is proceeding under the Department of Biology.

Investigations were also continued on the relationship between precipitable water, terrain parameters, and precipitation amounts. One of the students on this project, Edward Hindman II, has won an American Meteorological Society student research prize for his work on this subject.

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14. *University of Washington.*—"Continuation of Blue Glacier Studies: Mass and Energy Budgets and Some Winter Cloud Characteristics"

The micrometeorology program on the Blue Glacier is being carried out by Phil E. Church as a continuation of an IGY glaciology project which examined the mass and energy exchange between a temperate alpine glacier and its maritime environment. The work has been extended to studies of the cloud characteristics of the region, and is directed towards future planned experimentation work in weather modification in the State of Washington.

Three years of records have provided information, unique in this country, on glacier climatology and mass budgets. Micrometeorological observations of melting snow and ice surfaces were continued. Data on glacier-flow dynamics, such as velocity measurements connected with icefalls and the strain rate measurements, were collected. The mapping of glacier ice and firn depths by hot-point drilling was also undertaken.

It has been observed that rime ice is frequently formed during snowstorms. Even vertical slopes of mountains become white with rime deposits, indicating a considerable amount of supercooling in the clouds passing over the area. These observations suggest that it may be possible to modify clouds associated with storms coming in from the ocean. Detailed studies of the amount of supercooled water present in the clouds during periods in the winter were made with this object in view.

B. Kamb and E. LaChapelle, "Director Observation of the Mechanism of Glacier Sliding Over Bedrock," *Journal of Glaciology,* vol. 5, No. 38, June 1964.

E. LaChapelle, "Instruments and Methods, A Simple Thermal Ice Drill," *Journal of Glaciology,* vol. 4, No. 35, June 1963.

E. LaChapelle, "Assessing Glacier Mass Budgets by Reconnaissance Aerial Photograph," *Journal of Glaciology,* vol. 4, No. 33, October 1962.

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## Laboratory Research

1. *University of California.*—"Growth of Ice Crystal and Cloud Drops"

Morris Neilburger and Hans R. Pruppacher are continuing their research to gain a better understanding of the mechanism of the growth of solid and liquid cloud particles into precipitation elements. The work has been primarily concentrated on the determination of the growth velocity of ice crystals in solutions at various temperatures and the testing of the methods of computing collision efficiency of cloud droplets. In addition, some approaches to the growth of cloud and precipitation particles by coalescence have begun.

(1) *Crystallization velocity.*—Using a setup in which aqueous solutions were contained in polyethylene tubes the linear crystallization velocity of ice in solutions of 21 salts was determined for temperatures in the range of 0° to −15° C and solute concentrations of $10^{-5}$ to 1 mole per liter. The growth modes were studied using colored motion pictures.

It was found that the growth velocity varies systematically with temperature, concentration, and type of solute. For a given temperature no effect on the crystallization velocity was observed as the concentration of some solutes was increased up to $10^{-3}$ and reduced velocities were observed for larger concentrations; with other solutes increased crystallization velocities occurred at low concentrations and decreased velocities occurred at higher concentrations, with the maximum velocity being observed at concentrations between $10^{-3}$ and $10^{-5}$ mole per liter, depending on the particular solute.

The relation of these results to such factors as self-diffusivity and water structure was studied.

The free crystallization velocity is being measured in drops of solution situated at the interface of two organic liquids, using motion pictures. These velocities will be compared with the linear velocities in tubes.

(2) *Collision efficiency.*—To test the method used by Shafrir and Neilburger for computing the collision efficiencies of cloud drops having radius in the range from 30 to 130 microns, experiments using solid spheres falling in oil were carried out and the results were compared with computations of the collision efficiencies for the conditions of the experiment. Transfer of electric charge was used as a criterion for collision. The experimental values corroborated the computed values for large Reynolds numbers within the range considered, but charge transfer occurred in experiments for smaller Reynolds numbers for which the computations gave zero collision efficiency. The question whether charge transfer could have occurred without actual collision in these cases is being investigated, and new attempts are being made to design a test using water drops in air.

M. Neilburger and H. R. Pruppacher, "Experimental Tests of a Method of Computing Collision Efficiencies of Spheres Falling in a Viscous Medium," *Proceedings of International Conference on Cloud Physics,* IUGG, Tokyo, May 24–June 1, 1965.

H. R. Pruppacher, "The Crystallization Velocity of Ice in Pure Water and Aqueous Solutions," *Proceedings of International Conference on Cloud Physics,* IUGG, Tokyo, May 24–June 1, 1965.

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2. *University of Chicago.*—"Research in Cloud Physics"

The Cloud Physics Laboratory at the University of Chicago, under the direction of Horace Byers, is an established facility which has for many years been studying the problems of nucleation of cloud particles and their role in precipitation. The work of the laboratory also includes the study of circulation patterns within clouds and their effect on the microphysical processes which occur within the circulating mediums.

Staff members have carried out analyses of the liquid-water content, temperature, and air-speed measurements made in hurricane cloud systems. The data used were obtained from five hurricane flights performed by the National Hurricane Research Project. A total of 57 traverses were analyzed, 35 of which passed through convective areas, 13 through cellular rain areas, and 9 through stratified clouds. Altitudes ranged from 9,000 to 17,500 feet. The results showed that although the spectra of the measurements for individual traverses varied considerably, all have much the same general characteristics.

In order to obtain a better understanding of ice crystal formation in clouds, an automatic cloud chamber has been constructed by members of the staff for observing the behavior of artificial nucleating particles. Apart from providing a fairly good simulation of a natural cloud, the chamber produces finely dispersed water droplets which serve as a quasi-uniformly

distributed moisture source to keep the vapor pressure within the chamber at saturation level during nucleation and growth of the ice crystals. A special feature of the chamber makes possible the extractions of samples of the injected nucleant (on a membrance filter) for further analysis by microchemical methods or with one electron microscope. The ice crystals falling out of the artificial cloud are not merely counted in a solution, but are replicated so that they can be examined later. In this manner not only their number, but also their size and shape, can be determined.

Studies are also being made on the evaporation and trajectory of raindrops. It is well known that evaporation of raindrops plays an important role in the production of cold air in thunderstorms and squall lines, and it is this cold air that provides the negative buoyancy for the downdraft.

The problem of the role of evaporation in a downdraft is a complicated one even if questions of trajectories and sorting are taken care of. It is being approached by calculating the equilibrium relative humidity corresponding to assumed constant values of the downdraft velocity, drop size, liquid-water content, vertical temperature and humidity gradient.

Work is also being done on tracing the flux of giant sea-salt nuclei from the oceans and their distributions in the atmosphere. A theory has been produced which is in agreement with studies of wind-plume and measurements made in the atmosphere.

Work is continuing on the developing means for identifying ice nuclei in the atmosphere by means of electron microscopy. The work to date indicates that a majority of the identifiable particles in ice-crystal nuclei are clay minerals. From a study of the distribution of sizes of 130 different nuclei, approximately 38 percent were found to be in the range of 0.4 to 0.7 micron, 29 percent in the range of 0.1 to 0.4 micron, 18 percent from 0.4 to 1.0 micron, and the remaining 15 percent larger than 1 micron. The size spectrum does not differ greatly from that found by Kumai for snow crystals.

Theoretical work on the vapor pressure over solution droplets has been carried on. A derivation of a simplified expression for this quantity has been published in the *Journal of Chemical Education.*

Theoretical studies have also been carried on concerning the entrainment in cumulus clouds of air masses which mix into the cloud during its growth process. Two equations have been developed to describe the thermodynamic processes associated with entrainment.

H. R. Byers, "Identification of Ice Nuclei in the Atmosphere," *Proceedings of the International Conference on Cloud Physics,* Tokyo and Sapporo, Japan, May–June 1965.

H. R. Byers, "The Relation of Lightning and Thunderstorms to Meteorological Conditions," *Problems of Atmospheric and Space Electricity,* S. C. Coroniti, Ed., pp. 491–497, Amsterdam, 1965, Elsevier Publishing Co.

H. R. Byers, "Vapor Pressure Over Solution Droplets," *Journal of Chemical Education,* vol. 42, pp. 338–339, 1965.

J. Rucklidge, "The Examination by Electron Microscope of Ice Crystal Nuclei from Cloud Chamber Experiments," *Journal of Atmospheric Sciences,* vol. 22, pp. 301–308, 1965.

Y. Toba, "On the Giant Sea-Salt Particles in the Atmosphere, I. General Features of the Distribution," *Tellus,* vol. 17, pp. 131–145, 1965.

Y. Toba, "Global Aspects of the Production and Distribution of Giant Sea-Salt Particles," *Proceedings of the International Conference on Cloud Physics,* Tokyo and Sapporo, Japan, May–June 1965.

H. R. Byers, "Nucleation in the Atmosphere," *Industrial and Engineering Chemistry,* vol. 57, 1965.

Y. Toba, "On the Giant Sea-Salt Particles in the Atmosphere, II. Theory of the Vertical Distribution in the 10–m Layer Over the Ocean, III. An Estimate of the Production and Distribution Over the World Ocean," *Tellus,* vol. 17–18, 1965–66.

H. R. Byers, "Elements of Cloud Physics," University of Chicago Press, 191 pp., 1965.

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3. *University of Washington.*—"Laboratory Research in Cloud Physics"

In the past 2 years a laboratory research program in cloud physics has been developed in the Atmospheric Sciences Department of the University of Washington under the direction of Peter V. Hobbs. A well-equipped laboratory, including a walk-in coldroom, is now fully operational. Five graduate students are doing research in cloud physics for higher degrees.

A fairly wide range of experimental and theoretical problems related to the microphysics of clouds is being investigated, including work on ice-crystal habits, the surface properties of ice, nucleation of supercooled water, and thunderstorm electrification. Particular attention has been paid to the adhesive properties of ice crystals, and a comparison of the laboratory and theoretical work with observations on natural ice-crystal aggregates has shown that aggregation of ice crystals can probably take place in clouds at temperatures as low as $-40°$ C. Measurements are being made on the infrared reflection spectra of ice and water; this work is yielding interesting results related to the surface structure of ice, and is also of importance in the interpretation of infrared reflection measurements from planetary atmospheres. Studies on the crystalline structure of frozen droplets are continuing and the results are being related to droplet shattering and to charge separation in clouds. Finally, a quantitative explanation for the variation of ice-crystal habits with temperature has been given by Hobbs and Scott.

P. V. Hobbs, "The Effect of Air Bubbles in Ice on Charge Transfer Produced by Asymmetrical Rubbing," *Journal of the Atmospheric Sciences,* vol. 21, p. 706, 1964.

P. V. Hobbs and W. D. Scott, "Step-growth on Signel Crystals of Ice," *Phil. Mag.,* vol. 11, p. 1083, 1965.

P. V. Hobbs, "The Aggregation of Ice Crystals in Clouds and Fogs at Low Temperatures," *Journal of the Atmospheric Sciences,* vol. 22, p. 296, 1965.

P. V. Hobbs, "The Effect of Time on the Physical Properties of Deposited Snow," *Journal of Geophysical Research,* August 1965.

P. V. Hobbs and L. F. Radke, "The Densification of Artificial Firn," Fourth Western National Meeting of AGU University of Washington, December 1964.

P. V. Hobbs and W. D. Scott, "A Theoretical Study of the Variation of Ice-Crystal Habits with Temperature," International Conference on Cloud Physics, Tokyo, May 24–June 1, 1965.

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4. *University of Wisconsin.*—"Effect of Heat of Solution on Freezing and Condensation Nuclei"

Experimental research performed by Robert Knollenberg at the University of Chicago has indicated that finely divided urea in 1 to 20 micron sizes is effective as a nucleating material for supercooled clouds. Urea is an endothermic material which absorbs heat when it is dissolved in water solution. When sprinkled into a supercooled cloud, it reduces the temperature of the droplets into which it is introduced to the point where immediate freezing takes place. In many ways the results produced are similar to those caused by dry ice. It has the advantage, however, that it is a nonperishable material, and can be dispensed as a powder. The work at the University of Wisconsin is further extension of Robert Knollenberg's work under Verner Soumi in the department of meteorology.

The purpose of this program is to continue investigations of urea as a nucleating material and to search for other endothermic materials which may be even more effective. Basic studies are being made of the nucleation processes initiated by endothermic reactions, and a study of the use of such compounds in mixtures with other types of ice nucletors will be made in an effort to raise the threshold temperature of the mixtures. The possibility exists that such techniques may permit the dissipation of fogs with temperatures of 6 to 10 degrees above freezing. To date such fogs have not yielded to treatment with conventional materials.

Robert G. Knollenberg, "Urea as an Ice Nucleant for Supercooled Clouds," Technical Note No. 29, Cloud Physics Laboratory, University of Chicago, April 1, 1965.

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## LABORATORY RESEARCH CONTINUING FROM PREVIOUS GRANTS

5. *University of Arizona.*—"Surface Properties of Heterogeneous Condensation Nuclei"

A study of the nucleating surfaces and the relationships of their characteristics to the efficiency of nucleation is being carried on by Myron L. Corrin. In particular, attention is being given to silver iodide as an active nucleating material, and studies are being made of the surface properties which affect its nucleating efficiency.

Pure silver iodide has been prepared in a vacuum by the reduction of iodine with silver powder, and an ultrahigh purity silver iodide has been obtained. The properties of this ultrapure silver iodid has been found to be considerably different from those of silver iodide obtained through the usual precipitation chemistry. It has been found that silver iodide pre-

pared under vacuum is no longer photosensitive and can be exposed to light for long periods of time and still retain its bright yellow color. In addition, it was found that the ultrapure silver iodide has a hydrophylic surface, in contrast to the hydrophobic properties of the surface of silver iodide produced by the wet chemical method.

Tests performed in the isothermal cloud chamber at Colorado State University have indicated that the pure material is about only 1 percent as effective as impure silver iodide in initiating the formation of ice nuclei at −10° C. The nucleating mechanism of silver iodide, therefore, cannot be based upon the properties of silver iodide alone.

Work is in progress on characterizing the silver-iodide surface in terms of the thermodynamics of its interaction with water vapor and with methanol vapor. A program has been initiated in which pure silver iodide is quantitatively doped with a hygroscopic inorganic salt, and the product will be investigated in terms of water vapor adsorption and efficiency as a condensation nucleant. An investigation of the lead-iodide system has also been initiated, and this substance has been prepared by direct reaction in vacuum between lead and iodine.

M. L. Corrin, Harry W. Edwards, and John A. Nelson, "The Surface Chemistry of Condensation Nuclei: II. The Preparation of Silver Iodide Free of Hydroscopic Impurities and Its Interaction with Water Vapor," *Journal of Atmospheric Sciences,* vol. 21, p. 565, 1964.

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6. *Colorado State University.*—"Anhydrous Ammonia, Silver Iodide Nucleation"

During the last fiscal year Roger L. Steele has investigated two basic methods of dispensing silver iodide using anhydrous ammonia as the carrier. One of these methods employs thermal processing and the other does not. The silver-iodide particles generated by both techniques have been studied by electron microscope, and the development of various support equipment, including an isothermal cloud chamber, has been completed.

The principle of the silver iodide-ammonia system is based on the fact that silver iodide will dissolve readily in liquid ammonia. Concentrations as high as 60 percent of silver iodide by mass may be obtained. Solution preparation is simple and direct with no corrosion or deposition problems as in ordinary ferrous materials. The thermodynamic properties of the complex up to 40 percent concentration follow those of pure ammonia. Simple expansion of the solution from a high pressure vessel into atmospheric pressure and temperature through a simple hydraulic nozzle has not yielded satisfactory results to date. At the present time, a nucleation effectiveness of only $10^{12}$ nuclei per gram at −20° C. has been obtained. If, however, the solution is expanded at high pressure and into a high ambient temperature, it shows considerably more promise. The high-temperature expansion indicates an effectiveness of $3 \times 10^{14}$ nuclei per gram at −13° C.

An isothermal cloud chamber, with a volume of approximately 3,000 liters, was completed in March 1964, and is being used in this research program. The wall temperature of the chamber is controllable to ±0.1° C. over the range 0°−−20° C. A vertical temperature gradient of about 2° C/meter develops when a cloud is introduced into the chamber continuously. However, temperatures at a given level remain constant within ±0.1° C. The chamber permits a detailed study of the ice-nucleating characteristics of various substances over the range of interest. With minor modification, the chamber can be used to study condesation processes in warm clouds.

Roger L. Steele, "Characteristics of Silver-Iodide Ice Nuclei Originating from Anhydrous Ammonia-Silver Iodide Complexes" (to be presented at the National Meeting of the American Meteorological Society on Cloud Physics and Severe Local Storms), October 1965.

7. *Lehigh University.*—"Surface Chemistry of Ice Nucleation"

Research by A. C. Zettlemoyer is being conducted to determine the surface characteristics of good ice nucleators and to develop a theory of nucleation. In addition, new inexpensive substrates are being prepared for initiating ice formation in clouds.

During the past year, considerable emphasis has been placed on the preparation and testing of new ice nucleators. The hypothesis used in preparing these materials is that a surface suitable for the nucleation and growth of ice from the vapor phase should be neither completely hydrophylic nor hydrophobic, but somewhere in between, i.e., nominally hydrophobic with some hydrophylic sites in analogy to the known characteristics of silver-iodide particles which are suitable for seeding.

The nucleating agents prepared were, for the most part, silicas treated by several procedures to make them only partially water receptive. Several samples prepared by heating silicas in contact with certain inorganic salts have produced excellent results.

The new materials have been tested in a small mixing-type cloud chamber constructed in the laboratory. In addition to the laboratory cloud-chamber experiments, flight tests of several materials were also carried out by R. R. Braham at the University of Chicago with encouraging results. The materials were also tried during the Fifth Yellowstone Field Research Expedition in January 1965. To date, the artificial materials look extremely encouraging.

A. C. Zettlemoyer, K. S. Narayan, and R. Bassett, "Hydrophobic Silicas as Ice Nucleators," International Symposium on Nucleation Phenomena, Case Institute of Technology, April 1965.

A. C. Zettlemoyer, Ice Nucleation was included in Lecture in "Frontiers in Chemistry," Series, April 1965.

A. C. Zettlemoyer, K. S. Narayan, and D. R. Bassett, "Hydrophobed Silicas as Ice Nucleators" (to be presented at the American Chemical Society meeting), September 1965.

Patent: First office action taken on patent, "Nucleating Process and Composition," with royalty-free license for the Federal Government.

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8. *University of Nevada.*—"Crystalline Studies Applied to the Freezing and Melting of Ice"

A study of the phase transition and phase equilibria of certain families of crystals is being conducted by Wendell Mordy and Richard Sill. It is known that cloud droplets will not freeze until they have reached a temperature considerably below 0° C. Progress in the study of water has been impeded by the difficulties in getting it in pure form and keeping it from becoming contaminated.

In this work, an investigation will be made of the melting and solidification of a variety of different substances which are easier to work with than pure water. The experimental procedure will be to investigate the variation of the melting temperature of certain pure materials as a function of crystal size, using experimental procedures in which the variation of melting temperatures with crystal thickness can be demonstrated by direct observation. These experiments will be carried out under various conditions of contamination.

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9. *State University of New York.*—"Dynamic Behavior of Nuclei in Ice Formation"

Narayan R. Gokhale of the Department of Earth and Atmospheric Sciences is continuing his research on the dynamic behavior of nuclei in ice formation, a project begun in 1963.

A study is being conducted of the freezing process of supercooled water drops, with respect to number, size, type of nuclei, and the nature of their surfaces. Artificial as well as naturally occurring nuclei will be used for the study, such as AgI, CuS, volcanic ash, and different silicate minerals. In addition, being investigated is the effect on the efficiency of nuclei as freezing nucleants after treating their surfaces with ultraviolet radiation and traces of ammonia.

N. R. Gokhale, "Comparison of Ice-nucleating Efficiencies of Chemical Aerosols in a Supercooled Cloud and in Bulk Water," *Proceedings of the International Conference on Cloud Physics,* Tokyo, Japan, June 1965, pp. 176–180.

N. R. Gokhale, "Time-Dependence of Heterogeneous Nucleation," Presented at the 150th National American Chemical Society Meeting (Symposium on Nucleation and Nucleating Agents), Atlantic City, N.J., September 1965.

## Appendix B

## WEATHER MODIFICATION PROGRAMS FUNDED BY THE FEDERAL GOVERNMENT IN FISCAL YEAR 1965

| Reporting agency | Performing agency or institution | Principal investigator | Title | Amount |
|---|---|---|---|---|
| Department of Agriculture. | Forest Service | Fuquay | Project Skyfire lightning research (joint with NSF). | $140,000 |
| Total | | | | 140,000 |
| Department of Commerce. | Weather Bureau | Simpson | Project Stormfury (joint with Navy and NSF). | 98,000 |
| | | Gilman | Weather modification planning study | 17,000 |
| Total | | | | 115,000 |
| Department of Defense: | | | | |
| Army | Internal Programs | | Aerosol and infrared temperature measurements and chaff seeding. | 150,000 |
| | Army Cold Regions Research and Engineering Laboratories. | | Fog dispersal | 24,000 |
| | External Programs: | | | |
| | Cornell Aeronautical Laboratories, Inc. | | Interactions between the Great Lakes and the atmosphere. | 25,000 |

| | | | | |
|---|---|---|---|---|
| | State University of New York | | Atmospheric Science Research Center field project at Flagstaff, Ariz., on measurements of wind distribution and evaluation of flight data and lightning records. | 7,000 |
| | Meteorology Research, Inc. | | Analysis of Flagstaff data | 48,500 |
| Subtotal (Army) | | | | 254,500 |
| Navy | Bureau of Naval Weapons | St. Amand | Project Cyclops and support for Project Stormfury at NOTS, China Lake, Calif. | 250,000 |
| | Naval Research Laboratory | Twomey | Cloud processes | 200,000 |
| | | Dinger. | | |
| | | Ruskin | Cloud physics instrumentation | 200,000 |
| | | Twomey. | | |
| | Navy Weather Research Facility. | Stinson | Planning studies for future field experiment | 100,000 |
| | | Todd. | | |
| | Forest Service, Macon, Ga. (supporting funds). | Taylor | Warm cloud and warm fog studies | 150,000 |
| | Office of Naval Research: | | | |
| | E. Bollay Associates, Inc. | Zoph | Fog droplet growth | 24,417 |
| | University of Hawaii | Woodcock | Convective studies in the tradewind area of the Pacific. | 50,000 |
| | Litton Systems Corp | Ruhnke | Fog parameters | 24,991 |
| Subtotal (Navy) | | | | 999,408 |
| Air Force | AFCRL: | | | |
| | Technical Operations, Inc. | Thompson | Droplet size instrumentation | 55,000 |
| | Singco, Inc. | Sing | Fog field measurements | 95,000 |



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| Reporting agency | Performing agency or institution | Principal investigator | Title | Amount |
|---|---|---|---|---|
| Department of Defense—Continued | | | | |
| Air Force—Continued | In-house | Silverman | Warm fog research and modification | $22,000 |
| | | Kunkle | Fog electricity | 15,000 |
| | | Church | Cold fog and stratus modification | 6,000 |
| Subtotal (Air Force) | | | | 193,000 |
| Total | | | | 1,446,908 |
| Department of the Interior. | Internal Programs: | | | |
| | Geological Survey | Odell | Stream-gaging requirement studies | 5,000 |
| | Bureau of Reclamation | Bellport | General program support | 169,792 |
| | External Programs: | | | |
| | Department of Commerce—Weather Bureau. | Smagorinsky | Numerical dynamical circulation studies | 18,000 |
| | | Klein | Synoptic-climatology of orographic precipitation. | 22,000 |
| | | Miller | Case studies of storm types | 23,500 |
| | | Mason | Aircraft measurements | 28,000 |
| | Naval Ordnance Test Station. | St. Amand | Study of nucleating agents | 75,000 |
| | Department of Agriculture: | | | |
| | Forest Service | Fletcher | Interpretation of behavior of forested drainage basins. | 4,500 |
| | Soil Conservation Service | Washichek | Snowfall measurement operations | 25,000 |
| | Colorado State University | Yevdjevich | Development of methods of evaluation using streamflow records. | 10,000 |

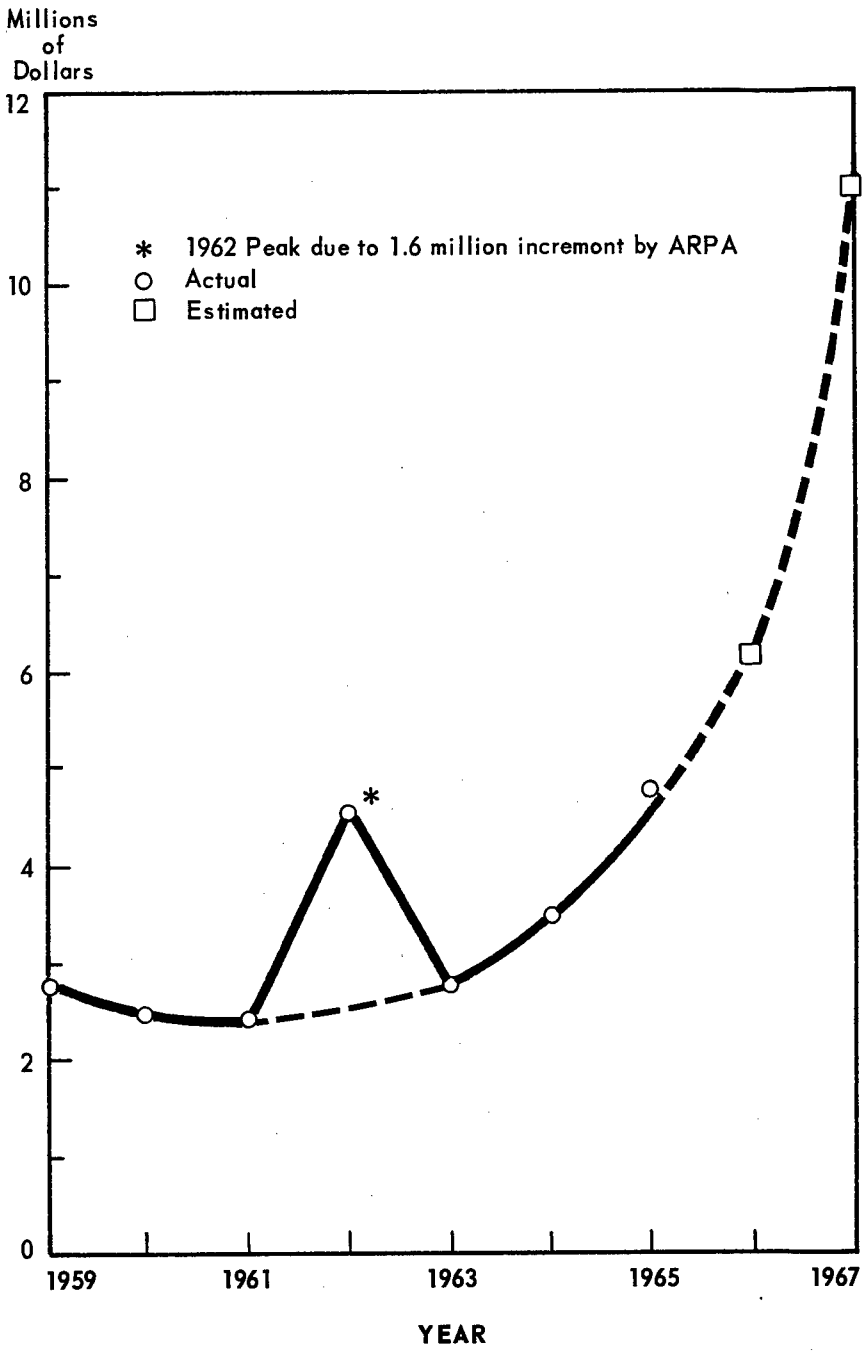
| | | | | |
|---|---|---|---|---|
| | Fresno State College | Evans | Feasibility study for Southern Sierra Program. | 2,000 |
| | University of Nevada | Mordy | Laboratory and field studies of weather modification requirements in Nevada. | 109,652 |
| | South Dakota School of Mines and Technology. | Schleusener | Convective studies on Northern Great Plains. | 267,346 |
| | Taft College | Peahl | Statistical evaluation | 1,000 |
| | Utah State University | Hansen | Study of snowpack augmentation procedures for Utah. | 20,000 |
| | University of Wyoming | Bellamy | Cap cloud studies | 194,000 |
| | E. Bollay Associates, Inc | Bollay | Park Range winter orographic effects | 237,728 |
| | Meteorology Research, Inc. | MacCready | Arizona summer convective cloud studies | 20,000 |
| | Precipitation Control Co | Merrill | Research seeding flights | 26,250 |
| | Washington State Weather Modification Board. | Shumway | Feasibility study of shifting precipitation across mountain barriers. | 3,500 |
| Total | | | | 1,262,268 |
| National Science Foundation. | Department of Agriculture—Forest Service | Fuquay<br>Baughman. | Lightning research | 132,000 |
| | University of Arizona | Battan | Physics of convective clouds and of cloud modification. | 26,700 |
| | | Evans | Field and laboratory studies of lightning processes. | 99,750 |
| | Atmospherics, Inc | Henderson | Physical studies of winter storm mechanisms as related to cloud seeding efforts in the Sierra Nevada range of California. | 28,270 |
| | E. Bollay Associates, Inc | Bollay | Determination of natural precipitation signature. | 32,500 |

| Reporting agency | Performing agency or institution | Principal investigator | Title | Amount |
|---|---|---|---|---|
| National Science Foundation—Continued | | | | |
| | University of California, Berkeley. | LeCam<br>Neyman. | Weather modification section of the Fifth Berkeley Symposium on Mathematical Statistics and Probability. | $12, 450 |
| | Los Angeles | Mintz | Simulation of global climate and climate control experiments with a high-speed computer. | 43, 600 |
| | | Neiburger<br>Pruppacher. | Growth of ice crystals and cloud drops | 7, 000 |
| | University of Chicago | Braham | Role of ice in summer rain | 239, 200 |
| | | Byers | Research in cloud physics | 261, 000 |
| | | Sewell | Symposium on the Economic and Social Aspects of Weather Modification. | 36, 400 |
| | Colorado State University | Grant | Physical and statistical study of Rocky Mountain orographic clouds and precipitation and their modification. | 256, 800 |
| | Douglas Aircraft Co., Inc | Koenig | Study of natural and artificial precipitation formation. | 8, 356 |
| | Duke University | Livingstone | Biological aspects of weather modification | 34, 800 |
| | University of Illinois | Semonin | The effect of artificially produced space charge on the electrification of clouds. | 17, 400 |
| | | Stout | Time-altitude variations of atmospheric electricity variables. | 12, 600 |

| | | | | |
|---|---|---|---|---|
| | Johns Hopkins University | Wolfers | Preparation of a paper on the international aspects of a national program of weather modification. | 490 |
| | Arthur D. Little, Inc | Moore<br>Vonnegut. | The origin and role of electricity in clouds | 214, 800 |
| | University of Minnesota | Brown | Series of scientific conferences on the statistical aspects of weather modification. | 14, 800 |
| | National Academy of Sciences | Sievers | Panel on Weather and Climate Modification | 17, 500 |
| | University of Nevada | Mordy | Nevada atmospheric research project | 66, 600 |
| | State University of New York, Albany. | Schaefer | Cloud physics field research | 51, 500 |
| | New York University | Woodbury | Statistical design and evaluation of extra-terrestrial correlations with meteorological parameters. | 21, 750 |
| | Operations and Policy Research Inc. | Schwartz | International program in weather | 3, 960 |
| | Pennsylvania State University | Hosler | An investigation of the dynamics and microphysics of clouds. | 221, 200 |
| | Rand Corporation | Greenfield<br>Rapp. | Weather control program | 43, 000 |
| | Southern Methodist University | Taubenfeld | Legal study and analysis of weather modification data. | 3, 960 |
| | University of Washington, Seattle. | Hobbs | Cloud physics research | 77, 000 |
| | University of Wisconsin | Suomi | Study of the effect of the heat of solution on freezing and condensation nuclei. | 22, 000 |
| Total | | | | 2, 007, 386 |

| Reporting agency | Performing agency or institution | Principal investigator | Title | Amount |
|---|---|---|---|---|
| National Aeronautics and Space Administration. | | | | |
| Federal Aviation Agency | No fiscal year 1965 funds expended. | | | |
| Atomic Energy Commission. | | | | |
| Department of Health, Education, and Welfare. | | | | |
| Grand total | | | | $4,971,652 |

## Federal Funding of Weather Modification Programs



# Appendix C

# ADVISORY PANELS, COMMITTEES, AND COMMISSIONS

## Special Commission on Weather Modification

The Special Commission on Weather Modification was established by the National Science Board in 1964 to study the present status and potential of the United States in weather modification, covering all aspects of the problem such as scientific, economic, legal, social, ecological, and international. The first meeting of the Special Commission was held at the National Science Foundation on July 9, 1964. Up to July 1, 1965, the Commission has held five meetings. The Commission plans to complete its studies and prepare a final report on its findings and recommendations by January 1, 1966.

A. R. Chamberlain (Chairman)
Vice President for Administration
Colorado State University
Fort Collins, Colo.

William C. Colman
Executive Director
Advisory Commission on
Intergovernmental Relations
Washington, D.C., 20575

John C. Dreier
Visiting Professor of Latin American
Affairs
School of Advanced International
Studies
Johns Hopkins University
1740 Massachusetts Avenue NW.
Washington, D.C., 20036

Leonid Hurwicz
Department of Economics
University of Minnesota
Minneapolis, Minn., 55455

Thomas F. Malone
Second Vice President
Research Department
Travelers Insurance Co.
Hartford, Conn., 06115

John Bardeen (Vice Chairman)
Department of Physics
University of Illinois
Urbana, Ill.

Arthur W. Murphy
Professor of Law
Columbia University Law School
New York, N.Y., 10027

Sumner T. Pike
Vice President
The Trident Packing Co., Inc.
Lubec, Maine

William S. von Arx
Woods Hole Oceanographic Institution
Woods Hole, Mass.

Gilbert F. White
Department of Geography
University of Chicago
Chicago, Ill., 60637

Karl M. Wilbur
Department of Zoology
Duke University
Durham, N.C., 27706

## Interdepartmental Committee on Atmospheric Sciences of the Federal Council on Science and Technology

The Interdepartmental Committee on Atmospheric Sciences (ICAS) is the high-level interagency committee established in 1959 to make recommendations to the Federal Council of Science and Technology on the development of a balanced and integrated Federal agency research effort in the atmospheric sciences.

FEDERAL COUNCIL FOR SCIENCE AND TECHNOLOGY

J. Herbert Hollomon (Chairman), Assistant Secretary for Science and Technology, Department of Commerce.

NATIONAL SCIENCE FOUNDATION

Leland J. Haworth (Vice Chairman), Director.
Staff Assistant: Earl G. Droessler, Head, Atmospheric Sciences.

DEPARTMENT OF AGRICULTURE

Theodore C. Byerly, Administrator, Cooperative State Experiment Station Service.
Staff Assistant: Keith Arnold, Director, Forest Protection Research Division, U.S. Forest Service.

DEPARTMENT OF COMMERCE

Robert M. White, Chief, U.S. Weather Bureau.
Staff Assistants: Jerome Spar, Director, Office of Meteorological Research, U.S. Weather Bureau.
C. Gordon Little, Chief, Central Radio Propagation Laboratory, National Bureau of Standards.

DEPARTMENT OF DEFENSE

Chalmers W. Sherwin, Deputy Director (Research and Technology), Office of the Director of Defense Research and Engineering.

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Robert J. Anderson, Chief, Bureau of State Services.
Staff Assistant: Vernon G. MacKenzie, U.S. Public Health Service.

DEPARTMENT OF THE INTERIOR

Harry Perry, Bureau of Mines.

ATOMIC ENERGY COMMISSION

George M. Kavanagh, Deputy Assistant General Manager for Research and Development.
Staff Assistant: Eugene W. Bierly, Division of Biology and Medicine.

FEDERAL AVIATION AGENCY

Robert J. Shank, Associate Administrator for Development.
Staff Assistant: William E. Eggert, System Design Team–RD 15, Systems Research and Development Service.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Hugh L. Dryden, Deputy Administrator.
Staff Assistant: Robert F. Fellows, Office of Space Sciences.

DEPARTMENT OF STATE

Herman Pollack, Acting Director, Office of International Scientific Affairs.
Staff Assistant: J. Wallace Joyce, Office of International Scientific Affairs.

FEDERAL COMMUNICATIONS COMMISSION

Lee Loevinger, Commissioner.
Staff Assistant: Edward Allen, Chief Engineer.

OBSERVERS:

Bureau of the Budget, Samuel A. Lawrence.
Office of Science and Technology, David Z. Robinson.
National Academy of Sciences, Committee on Atmospheric Sciences, John R. Sievers, Executive Secretary, Committee on Atmospheric Sciences.

COMMITTEE STAFF:

Richard E. Hallgren, Scientific Assistant, Office of Assistant Secretary for Science and Technology, Department of Commerce.
Sherman W. Betts, Executive Secretary, Interdepartmental Committee for Atmospheric Sciences.

* * *

## ICAS Select Panel on Weather Modification

The Select Panel on Weather Modification was established in January 1965 to delineate and make recommendations on major policy issues regarding weather modification and to recommend immediate steps ICAS should take in this area. The select panel was constituted as follows:

Earl G. Droessler (Chairman)
Jerome Spar
Howard H. Eckles
Bernard A. Silverman
Sherman W. Betts

## Advisory Panel for Weather Modification of the National Science Foundation

This panel provides continuing expert advice to the Foundation on all weather modification program activities. Special emphasis is placed on examining the national program for balance and program deficiencies. Through this panel, the Foundation maintains a close rapport with scientists and engineers working on university research and on industrial research in weather modification.

Dean F. Peterson (Chairman)
Utah State University
Logan, Utah

Louis J. Battan
Institute of Atmospheric Physics
University of Arizona
Tucson, Ariz.

Archie M. Kahan
Bureau of Reclamation
Department of the Interior
Denver, Colo.

Gordon J. F. MacDonald
Institute of Geophysics and Planetary Physics
University of California
Los Angeles, Calif.

Yale Mintz
Department of Meteorology
University of California
Los Angeles, Calif.

Bernard Vonnegut
Arthur D. Little, Inc.
Acorn Park
Cambridge, Mass.

## Panel on Weather and Climate Modification, Committee on Atmospheric Sciences, National Academy of Sciences

In November 1963, the Committee on Atmospheric Sciences of the National Academy of Sciences appointed a Panel on Weather and Climate Modification to undertake a deliberate and thoughtful review of the present status of activities in this field, and of its potential and limitations for the future. It was anticipated that at least 2 years would be required for this study. During 1965, the scientific status of weather modification was reviewed at a series of meetings in which many interested scientists participated.


Gordon J. F. MacDonald (Chairman)
Institute of Geophysics and Planetary Physics
University of California
Los Angeles, Calif.

Julien H. Bigelow
School of Mathematics
Institute for Advanced Study
Princeton, N.J.

Jule G. Charney
Department of Meteorology
Massachusetts Institute of Technology
Cambridge, Mass.

Francis S. Johnson
Southwest Center for Advanced Study
Dallas, Tex.

Heinz Lettau
University of Wisconsin
Madison, Wis.

Edward N. Lorenz
Department of Meteorology
Massachusetts Institute of Technology
Cambridge, Mass.

James E. McDonald
University of Arizona
Tucson, Ariz.

Joseph Smagorinsky
Geophysical Fluid Dynamics Laboratory
U.S. Weather Bureau
Washington, D.C.

Verner E. Suomi
Chief Scientist
U.S. Weather Bureau
Washington, D.C.

Edward Teller
Lawrence Radiation Laboratory
University of California
Livermore, Calif.

Helmut K. Weickmann
Chief, Atmospheric Physics Branch
U.S. Army Electronics Laboratory
Fort Monmouth, N. J.

E. J. Workman, President
New Mexico Institute of Mining and Technology
Campus Station
Socorro, N. Mex.

## Advisory Committee on Atmospheric Water Resources, Bureau of Reclamation, Department of Interior

The Secretary of the Interior has appointed an advisory committee of outstanding atmospheric scientists from within and outside of the U.S. Government structure to meet periodically with the top-level administrators of the Bureau of Reclamation's Atmospheric Water Resources Program in order to provide technical advice and guidance on the formulation and implementation of a program for increasing runoff into the Bureau of Reclamation's system of dams and reservoirs through the use of weather modification techniques. Two meetings of the advisory committee were held in fiscal year 1965 after its formation in February 1965.

B. P. Bellport, Chairman
Chief Engineer
Bureau of Reclamation
Denver, Colo.

John C. Calhoun, Jr.
Science Adviser to the Secretary
U.S. Department of the Interior
Washington, D.C.
(Dr. Calhoun was succeeded as Science Adviser by Dr. Thomas F. Bates, who became an additional member of the Advisory Committee)

Verner E. Suomi, Chief Scientist
U.S. Weather Bureau
Department of Commerce
Washington, D.C.

Jack S. Barrows, Director
Forest Fire Research
Forest Service
Department of Agriculture
Washington, D.C.

Vincent J. Schaefer, Vice Chairman
Director of Research
Atmospheric Sciences Research Center
State University of New York
Schenectady, N.Y.

Walter Orr Roberts, Director
National Center for Atmospheric Research
Boulder, Colo.

Earl G. Droessler, Head
Atmospheric Sciences Section
National Science Foundation
Washington, D.C.

Max Kohler, Chief Hydrologist
Weather Bureau
Department of Commerce
Washington, D.C.

William G. Shannon, Head
Snow Survey and Water Supply Forecasting
Soil Conservation Service
Department of Agriculture
Washington, D.C.

## Interagency Conference on Weather Modification

The conference membership consists of all the working scientists in the Government agencies and laboratories responsible for research and development activities in weather modification. Annually, the National Science Foundation calls the scientists together for a 2-day full discussion and debate on the state, the progress, and the plans of the Federal programs in weather modification. The material contained in the report in appendix A, "Weather Modification Programs Funded by the Federal Government" was collected and published under the auspices of the Seventh Interagency Conference on Weather Modification, which was held at Big Meadows Lodge, Shenandoah National Park, Va., on September 30 and October 1, 1965.

CHAIRMAN

Earl G. Droessler, Atmospheric Sciences Section, National Science Foundation

DEPARTMENT OF AGRICULTURE

Jack S. Barrows, Forest Service
Donald M. Fuquay, Forest Service
Dee Taylor, Forest Service

DEPARTMENT OF COMMERCE

Glenn W. Brier, U.S. Weather Bureau
William E. Hardy, U.S. Weather Bureau
Dwight Kline, U.S. Weather Bureau
Helmut Weickmann, U.S. Weather Bureau

DEPARTMENT OF DEFENSE

Jesse B. Havard, Office of the Director of Defense Research and Engineering

DEPARTMENT OF DEFENSE (AIR FORCE)

Herbert S. Appleman, Air Weather Service
Nicholas Chavasse, Assistant for Weather, Headquarters
James F. Church, Air Force Cambridge Research Laboratories
Robert W. Cunningham, Air Force Cambridge Research Laboratories
William P. Elliott, Air Force Cambridge Research Laboratories
Walter Gallie, Office of Aerospace Research

### Department of Defense (Army)

James R. Hicks, Army Cold Regions, Research and Engineering Laboratory
Heinz Kasemir, Army Research and Development Laboratories
Frances Whedon, Office of the Chief of Research and Development

### Department of Defense (Navy)

J. E. Dinger, Naval Research Laboratory
M. W. Edelstein, Naval Weather Service
James H. Hughes, Office of Naval Research
Paul Joregensen, Naval Ordnance Test Station
Thomas O'Neill, Naval Weather Service
Albin F. Pyle, Bureau of Naval Weapons
Robert E. Ruskin, Naval Research Laboratory
Pierre St. Amand, Naval Ordnance Test Station
J. R. Stinson, Weather Research Facility
Clement J. Todd, Weather Research Facility

### Federal Aviation Agency

Arthur Hilsenrod

### Health, Education, and Welfare

Larry Neymeyer

### Department of the Interior

Thomas Bates, Office of Science Adviser
Archie Goodman, Bureau of Reclamation
Archie Kahan, Bureau of Reclamation
Wendell C. Munson, Bureau of Reclamation

### National Science Foundation

Sherman W. Betts, Interdepartmental Committee on Atmospheric Sciences
Jack C. Oppenheimer, Atmospheric Sciences Section
P. H. Wyckoff, Atmospheric Sciences Section

# Appendix D

## TEXT OF PROPOSED NSF REGULATION ON REPORTING WEATHER MODIFICATION ACTIVITIES

(Reproduced From Federal Register, September 8, 1965.)

### NATIONAL SCIENCE FOUNDATION

[45 CFR Part 635]

WEATHER MODIFICATION ACTIVITIES

Keeping of Records and Furnishing of Reports

The National Science Foundation is considering the issuance of a regulation which would require that persons engaging in, or intending to engage in, activities aimed at modifying the atmosphere, through atmospheric seeding or other means, provide advance notice to the Foundation of intention to conduct such an activity, submit monthly reports as the activity progresses and keep records as specified in the proposed regulation. Interested persons may submit written comments, suggestions or objections with respect to the proposed regulation to the Director, National Science Foundation, Washington, D.C., 20550, within thirty days of the date of publication of this notice in the FEDERAL REGISTER. As presently contemplated the regulation will provide as follows:

### PART 635—KEEPING OF RECORDS AND FURNISHING OF REPORTS IN CONNECTION WITH WEATHER MODIFICATION ACTIVITIES

Sec.



AUTHORITY: The provisions of this Part 635 issued under 72 Stat. 353 and sec. 11(a), 64 Stat. 153.

### § 635.1 Purpose.

The purpose of this part is to develop information for use in carrying out the responsibility of the National Science Foundation to support a program

of study, research and evaluation in the field of weather modification as authorized by the National Science Foundation Act of 1950, as amended. Section 14(f) of the Act authorizes the Director of the Foundation to obtain, by regulation, subpoena, or otherwise, such information in the form of testimony, books, records or other writings, to require the keeping of or furnishing such reports and records, and to make such inspections of the books, records and other writings and premises or property of any person or persons as may be deemed necessary or appropriate by him to carry out this responsibility, where adequate and authoritative data is not available from any Federal agency. The information required under this regulation is not so available and therefore must be obtained from individuals and organizations engaged in weather modification activities.

### § 635.2 Application of part.

This part applies to any person, and to any organization whether commercial or nonprofit, engaged in or intending to engage in any weather modification activity (including research) intended to modify the atmosphere through artificial means. Such activities include, but are not limited to, any of the following:

(a) Intentional seeding of clouds to alter drop size distribution, produce ice crystals, produce coagulation of droplets, or in any way to influence the natural development cycle of the cloud or its environment by dispersing into it any material or gas such as silver iodide, lead iodide, carbon black, dry ice, ammonia, etc.

(b) Intentional initiation of large heat sources or fires to influence convective circulation or evaporate fog.

(c) Intentional modification of solar radiation exchange of the earth or clouds through the release of gases, dusts, liquids, or aerosols into the atmosphere.

(d) Intentional modification of the energy transfer characteristics of the earth's land or water surface by dusting with powders, liquid sprays, or dyes.

(e) Intentional release of electrically charged particles, radioactive particles or ions into the atmosphere to alter its electrical field pattern or produce localized electrical field anomalies.

(f) Intentional application of shock waves, sonic energy sources, or other explosive or acoustic sources to the atmosphere to influence cloud growth, dissipation, or precipitation patterns.

### § 635.3 Reporting requirements.

(a) *Prior notice.* Each individual or organization intending to engage in any weather modification activity shall give not less than thirty days advance notice to the Foundation of intention to engage in such activity. Such notice will be submitted on a Foundation report form, copies of which will be made available upon request from the National Science Foundation, Washington, D.C., 20550. Where intention to engage in a

weather modification activity develops less than thirty days prior to the planned activity, the required report shall immediately be forwarded to the Foundation by airmail and shall be accompanied by a notarized statement explaining why the thirty day requirement could not be met.

(b) *Status reports.* After the weather modification activity reported pursuant to § 635.3(a) of this section has commenced, each person or organization engaged in such activity shall submit to the Foundation a progress report of such activity on a monthly basis. This report will be submitted on the form referred to in § 635.3(a) of this section.

### § 635.4 Maintenance of logs.

Each individual or organization engaging in a weather modification activity shall maintain a daily log of such activity. The log shall contain all relevants facts, including the following:

(a) Daily Log of Ground Weather Modification Activities (including Seeding Releases):

(1) Average direction and speed of surface winds at each generator site.

(2) Location of nearest available radiosonde station providing a sounding in or near target area.

(3) Description of meteorological situation in target area and control area such as types of clouds, percent cloud cover, temperature, humidity, appearance of lightning, hail, funnel clouds, severe rain, snow and unusual radar patterns, during observational period.

(4) Quantitative measurements of precipitation obtained from such sources as rain gauges, snow pillows, radar, optical transmissometers and streamflow gauges, in target and control areas.

(5) Remarks by project director covering any pertinent observations not listed above, such as estimate of success of operation and location of files where raw data are maintained.

(6) In the case of the operation of a ground silver iodide generator or other dispenser of particles, aerosols or gases, the daily log shall include:

(i) Location of each generator in use.

(ii) Name of individual responsible for turning each generator on or off.

(iii) Time each generator was turned on and turned off.

(iv) Basis or criteria for turning on or off each generator.

(v) Type of material dispersed by each generator.

(vi) Rate of material release of each generator during operation.

(vii) Total material released by each generator during each operational period.

(b) Daily Log of Airborne or Mobile Weather Modification Activities (including Seeding Releases):

(1) Complete log of each aircraft flight or mobile generator run including, but not necessarily limited to, ground track, altitude, air speed, times over check points, release points of seeding or other charges, temperature,

average wind direction and speed at release altitude, and for aircraft specify type of aircraft, airport or airports used and names of crew members.

(2) All other pertinent information as listed above for ground weather modification activities.

### § 635.5 Retention of records.

Records required to be maintained by this part, including logs, shall be available for inspection upon request of the National Science Foundation for a period of not less than five years after the date of completion of the project. Such records shall not be required to be produced at any place other than the place where normally kept, provided a true copy of such record is made available to the Foundation, as may be requested, or there is agreement as to the information contained therein.

### § 635.6 Disclosure of information.

Information developed as a result of the reporting procedures set forth herein shall be made publicly available on a periodic basis by the Foundation. This information will not include trade secrets or other data required to be kept confidential under section 1905 of Title 18 of the United States Code, except where the Director of the Foundation determines that the withholding of such information would be contrary to the purposes of sections 3(a)(9) and 14 of the National Science Foundation Act of 1950, as amended. Individuals and organizations reporting weather modification activities may request that information which they consider to be included within the scope of 18 U.S.C. 1905 be withheld from public disclosure and the Foundation will give due consideration to granting such requests.

### § 635.7 Penalty.

Any person willfully failing to meet the requirements imposed by this regulation shall, upon conviction, be fined not more than $500.

This regulation is issued pursuant to the authority of the National Science Foundation contained in sections 11(a) and 14(f) of the National Science Foundation Act of 1950, as amended.

Dated: September 2, 1965.

LELAND J. HAWORTH,
*Director.*

[F.R. Doc. 65-9454; Filed, Sept. 7, 1965; 8:53 a.m.]



U.S. GOVERNMENT PRINTING OFFICE : 1966 O—796-055