NSF 66-3

WEATHER AND CLIMATE MODIFICATION

Report of the

SPECIAL COMMISSION ON WEATHER MODIFICATION

NATIONAL SCIENCE FOUNDATION

WEATHER AND CLIMATE MODIFICATION

Report of the

SPECIAL COMMISSION ON WEATHER MODIFICATION

NATIONAL SCIENCE FOUNDATION

LETTER OF RANSMITTAL

The Honorable Leland J. Haworth
Director
National Science Foundation
Washington, D. C.

Dear Dr. Haworth:

It is an honor to transmit herewith to the National Science Foundation the report of the Special Commission on Weather Modification, authorized by the National Science Board at its meeting on October 17-18, 1963, in accordance with Sections 3(a)(7) and 9 of the National Science Foundation Act of 1950, as amended, and appointed by you on June 16, 1964. The Commission was requested to examine the physical, biological, legal, social, and political aspects of the field and make recommendations concerning future policies and programs.

The physical science aspects have been studied primarily through cooperative liaison with the National Academy of Sciences' Panel on Weather and Climate Modification.

Much of the background work for the treatment of the other aspects of the problem was carried out under National Science Foundation grants or contracts, reports of which research and study are to be published as stated in the Appendix.

The Commission held eleven meetings supplemented by many days of study, research, writing and conferences. The Commission report has been prepared by and its content is concurred in by all the members of the Commission.

The Commission was assisted throughout its deliberations by an Executive Secretary. Dr. Edward P. Todd served in this capacity during the early months. Mr. Jack C. Oppenheimer succeeded Dr. Todd and has done an outstanding job of assisting the Commission.

Respectfully submitted,
A. R. Chamberlain, Chairman
Vice President
Colorado State University

December 20, 1965

SPECIAL COMMISSION ON WEATHER MODIFICATION

The Commission was established pursuant to Section 3(a)(7) and 9 of the National Science Foundation Act of 1950, as amended.

The names and affiliations of the Commission members are:

CONTENTS

HISTORICAL BACKGROUND

Twenty years ago General Electric Company scientists Irving Langmuir and Vincent Schaefer modified clouds by "seeding" them with dry ice pellets. Not long afterward Bernard Vonnegut, a co-worker, demonstrated that a smoke of silver iodide crystals would accomplish the same result. This was the beginning of the modern American history of weather and climate modification through cloud seeding.

These American scientists on November 13, 1946, had verified experimentally the theory advanced in 1933 by the Swedish meteorologist, Tor Bergeron, and the German physicist, Walter Findeisen, that clouds would precipitate if they contained the right mixture of ice crystals and supercooled water drops. The Bergeron-Findeisen theory was antedated by the work of the Dutch scientist, August Veraart. The enthusiastic reports by Veraart of his 1930 experiments with dry ice and supercooled water-ice in Holland were not well received by the Dutch scientific community, and thus were given no serious consideration elsewhere.

Weather and climate modification, or "rainmaking" (the more popular and also more restricted concept), is not new to our era or to our country. Many traditional societies, including the American Indians, have practiced some type of religious or ritualistic rainmaking. The ceremonials and rituals have varied from dousing holy men with water to burying children up to their necks in the ground in the hope that the gods would be sympathetic and drop tears from the heavens. These ceremonies are not only to induce some form of desirable weather but also to reinforce the tribal religious beliefs and opinions which maintain social unity.

Through ancient and modern times many methods have been proposed and attempted to induce or to aid rainfall. Two U. S. Government patents on methods of rainmaking were issued before the turn of the 20th century based, respectively, upon the production of carbon dioxide by expending "liquified carbonic acid gas" and upon concussion by the detonation of explosives. Interestingly enough the long since expired patent, based on the production of carbon dioxide in the form of dry ice, anticipated the cloud seeders of today. The pioneering field and laboratory work of meteorologists in the War and Navy Departments on the popular notion that rainfall could be caused by the detonation of explosives was supported by Federal Government funds.

Even social, political and legal conflicts over weather and climate modification are not new. In 1916 San Diego's employment of a rainmaker, resulting in claims of loss of life and property damage of a million dollars, anticipated by half a century the litigation and State and local legislative action of today.

The 1946 demonstration that clouds might be modified and rain produced by scientific methods arose out of the World War II investigations of fog particles by Langmuir and Schaefer. The military possibilities of this discovery led the armed services to support a broad theoretical, laboratory and field program in cloud modification from 1947 to 1952, known as Project Cirrus. Civilian and military implications were investigated by the Cloud Physics Project of the U. S. Weather Bureau, Air Force and National Advisory Committee for Aeronautics from 1948 to 1951. The military services followed the termination of Project Cirrus in 1952 with a Department of Defense 5 year Artificial Cloud Nucleation Project.

Whether or not the multi-million dollar commercial rainmaking activities of the late 1940's and early 1950's grew out of the obvious interest of the Federal Government in weather and climate modification research or the coincidental severe drought conditions in some parts of the nation, relatively vast operations became a fact of life. It was disclosed between 1951 and 1953 in the Congressional Hearings leading up to the establishment of the Advisory Committee on Weather Control that during the height of cloud seeding activities $3 to $5 million a year was being spent by water users, particularly in the West, for commercial cloud seeding, and that about 10% of the land area of the United States had become the target of cloud seeding attempts.

The weather modification events of the late 40's and early 50's in the United States encouraged cloud seeding programs in Australia, France and South Africa to increase precipitation and renewed the scientific interest in hail suppression that had been practiced in Alpine Europe since the mid 30's. The dozen nations experimenting with cloud seeding during the late 1940's more than doubled by 1951 to about 30 countries representing every continent.

Meanwhile, the drought that held sway in many parts of the country, the claims of some of the rainmakers and the criticism from portions of the scientific community led the Congress to create an Advisory Committee on Weather Control to study and evaluate public and private experiments in weather modification. In its final report in 1957 the Advisory Committee on Weather Control found, among other things, on the basis of statistical evaluations, that cloud seeding in the mountainous areas of western United States of storms occurring during the cooler and moist winter and spring months produced an average increase in precipitation of 10 to 15 percent from seeded storms with a satisfactory degree of probability that the increase was not the result of natural variations in the amount of precipitation. On the basis of its physical evaluations, the Committee found, among other things, that seeding from the ground with silver iodide generators is a valid technique for seeding clouds. As a consequence of these findings and their related scientific and technical studies the Advisory Committee on Weather Control recommended:

The development of weather modification must rest on a foundation of fundamental knowledge that can be obtained only through scientific research into all the physical and chemical processes in the atmosphere. The Committee recommends the following:

(1) That encouragement be given for the widest possible competent research in meteorology and related fields. Such research should be undertaken by Government agencies, universities, industries, and other organizations.

(2) That the Government sponsor meteorological research more vigorously than at present. Adequate support is particularly needed to maintain continuity and reasonable stability for long-term projects.

(3) That the administration of Government-sponsored research provide freedom and latitude for choosing methods and goals. Emphasis should be put on sponsoring talented men as well as their specific projects.

(4) That an agency be designated to promote and support re-

search in the needed fields, and to coordinate research projects. It should also constitute a central point for the assembly, evaluation, and dissemination of information. This agency should be the National Science Foundation.

(5) That whenever a research project has the endorsement of the National Science Foundation and requires facilities to achieve its purpose, the agency having jurisdiction over such facilities should provide them.

The above recommendations of the Advisory Committee on Weather Control together with the 1957 report of the American Meteorological Society and the 1958 third report of the Committee on Meteorology of the National Academy of Sciences emphasized the need for: fundamental knowledge; research; experimentation; education and training in meteorology and related fields; promotion, support, coordination, evaluation and information assembly and dissemination by the National Science Foundation; and increased Federal support to universities for basic research in the atmospheric sciences.

On July 11, 1958, the President approved PL 85-510 which, in pertinent part, authorized and directed the National Science Foundation to:

. . . initiate and support a program of study, research, and evaluation in the field of weather modification, giving particular attention to areas that have experienced floods, drought, hail, lightning, fog, tornadoes, hurricanes, or other weather phenomena, and to report annually to the President and the Congress thereon.

. . . consult with meteorologists and scientists in private life and with agencies of Government interested in, or affected by experimental research in the field of weather control.

. . . carry out the purposes . . . whether conducted by the Foundation or by other Government agencies or departments, . . . through contracts with, or grants to, private or public institutions or agencies, including but not limited to cooperative programs with any State through such instrumentalities as may be designated by the governor of such State.

Thus, for the last $7^1/_2$ years the Foundation has been providing major support for the Federal Government's weather modification program and also has been a focus for Government-wide program planning and coordination through various mechanisms, including its annual Interagency Conference on Weather Modification. During this same period, the Departments of Agriculture, Commerce, Defense, and Interior have either initiated or continued mission-oriented programs of research and development in weather and climate modification. These programs have been devoted to such matters as research on the suppression of lightning-induced forest fires by the U. S. Forest service; observation, analysis and experimental seeding of severe storms and hurricanes by the U. S. Weather Bureau; cloud physics research, experimental seeding of clouds and dispersal of clouds and fog by the military departments; and research on reduction of water evaporation through use of chemical films and increase of water supplies through research and experimental seeding by the U. S. Department of the Interior.

The FY 1966 total annual spending for all the various Federal agency programs of weather modification research and development is about 7.2 million dollars. During the year ending June 30, 1965, there were 59 cloud seeding projects by 15 commercial operators concerning operations in 26 different states. At present there are research activities reported from 15 foreign nations.

In November 1963, in response to increased concern over the potentialities for man-made changes of weather and climate and the interest in undertaking large scale weather modification activities, the Committee on Atmospheric Sciences of the National Academy of Sciences (NAS) appointed a Panel on Weather and Climate Modification "to undertake a deliberate and thoughtful review of the present status and activities in this field, and of its potential and limitations for the future." On June 16, 1964, the Director of the National Science Foundation announced the appointment of the Special Commission on Weather Modification, as previously authorized by the National Science Board at its 89th Meeting on October 17-18, 1963. The Commission was assigned to: (1) fulfill the need of the National Science Foundation for a review of the state of knowledge on weather and climate modification, make recommendations concerning future policies and programs and examine the adequacy of the Foundation's program; and (2) respond to the request of the Interdepartmental Committee for Atmospheric Sciences of the Federal Council for Science and Technology of August 19, 1963 to prepare an analysis of the modification and control of the weather for useful purposes other than military. The Commission's assignment included consideration of not only the scientific aspects but also the legal, social and political problems in the field.

In view of the broad categories of questions directed to the Commission by the National Science Foundation, the Commission activated seven subgroups, each of which was headed by one or more members of the Commission. The physical, biological, statistical, social, international, legal and legislative, and administration and funding aspects have been studied by these sub-groups. The physical science aspects have been studied primarily through cooperative and continuing consultation and liaison with the National Academy of Sciences' Panel on Weather and Climate Modification. Much of the background work for the treatment of the various aspects of the problem was carried out under National Science Foundation grants or contracts. Reports of these research and study activities are to be published as stated in the Appendix. The National Academy of Sciences has just completed its final report, entitled *Weather and Climate Modification—Problems and Prospects,* Vols. I and II.

SUMMARY

INTRODUCTION

Man is becoming so numerous and his influences on his environment so profound that he cannot consider himself free to heedlessly or improvidently exploit the air, water, land, and growing things of this earth. He no longer lives under the constant threat of a wilderness but, instead, is changing his environment and, therefore, must plan for its conservation and development.

With advances in his civilization man has learned how to increase the fruit of the natural environment to insure a livelihood. The main problems which now threaten his future are:

1) large-scale, catastrophic warfare;
2) providing sustenance for a rapidly increasing population;
3) waste disposal and environmental change accompanying the discharge of matter into the atmosphere, open waters, and subterranean spaces.

Recognizing these circumstances of human activity, it is fortunate that growing knowledge of the natural world has given him an increasing awareness of the changes that are occurring in his environment and also hopefully some means for deliberate modification of these trends. An appraisal of the prospects for deliberate weather and climate modification[1] can be directed toward the ultimate goal of bringing use of the environment into closer harmony with its capacities and with the purposes of man—whether this be for food production, relief from floods, assuring the continuance of biologic species, stopping pollution, or for purely aesthetic reasons.

The National Science Foundation Special Commission on Weather Modification was asked to consider one aspect of the problem of environmental conservation and utilization. With the physical possibility of modifying the weather and climate already partly demonstrated, it is important to inquire: How by artificially inducing deliberate changes in the environment may man act to control or develop

[1] Throughout this report the term "weather and climate modification" is taken to mean artificially produced changes in the composition, motion, or dynamics of the atmosphere, whether or not such changes may be predictable, their production deliberate or in advertent, or their duration transient or permanent.

changes in the atmosphere considered to be desirable by society? With this question in mind, the Commission has concerned itself with the physical, biological, social, engineering and legal aspects of weather and climate modification.

Weather and climate modification is becoming a reality. The daily activities of man influence the atmosphere in a number of ways and his ability to induce deliberate changes in measurable magnitude by artificial means is progressing. The scale of known operational ability for deliberate routine weather modification is presently the dissipation of supercooled fog and stratus over an area approximately the size of an airport, for a short period of time. On a larger scale, the inadvertent modification of the weather and climate by such influences as the products of urban development, surface modification for agriculture and silviculture, compositional changes through the combustion of fossil fuels and other exhausts are becoming of sufficient consequence to affect the weather and climates of large areas and ultimately the entire planet.

Deliberate modification of weather and climate may be accomplished by not only artificially influencing the atmosphere but by controlling inadvertent changes. For example, smog is the result of *deliberate* pollution which causes *inadvertent* modification of urban weather and climate. A number of questions are involved:

1. If deliberate modification of the atmospheric environment is already a growing physical possibility, what are the scientific prospects for the future?

2. What may be the biological consequences of weather and climate modification activities?

3. What might be the social, human and economic benefits to man?

4. Are there legal, political and legislative issues to be resolved?

5. How should the plans of the United States in weather and climate modification be communicated to and coordinated with other nations?

6. What are the organizational and funding needs for a national program in weather and climate modification?

These questions are explored in some detail in the body of the report. Summarized here are some of the Commission's findings and conclusions relevant to these questions.

Scientific Prospects

1. Several cubic miles of supercooled cloud droplets can be transformed into ice crystals by seeding with dry ice or silver iodide. Supercooled fog on the ground can be dissipated. No practical approach to the dissipation of warm fog is at hand.

2. While the evidence is still somewhat ambiguous, there is support for the view that precipitation from some types of clouds can be increased by the order of ten percent by seeding. If the results are confirmed by further studies they would have great significance. The question of corresponding decreases of precipitation outside the target area is unresolved.

3. Results from attempts to suppress hail in the United States are as yet inconclusive but more promising results in other countries are leading to the establishment in this country of a program that should provide a more definitive answer.

4. Experiments in lightning suppression are beginning to show some promise.

5. Modification of hurricanes has reached the stage of preliminary field experimentation but the results, so far, are inconclusive.

6. Changing the course or intensity of extratropical cyclones and altering climate over large areas remain as problems for the future. No serious attempt has yet been made to control tornadoes.

7. Inadvertent changes in climate as a consequence of human activity (e.g., urbanization, air pollution, increase of atmospheric carbon dioxide by burning fossil fuels) are amenable to analysis and deserve early attention.

With respect to the scientific prospects for the future, the Commission finds that attractive opportunities exist. Advanced experimental techniques and application of sophisticated concepts in statistical design promise to reduce the present uncertainty in the interpretation of field experiments. The scientific exploration of weather and climate modification is passing from the speculative phase to the rational phase. Within reach are mathematical and laboratory modeling techniques that permit the simulation of atmospheric processes. By these means it should become possible to assess in advance the probable consequences of deliberate intervention.

An expanded program of basic and applied research is needed to take advantage of these scientific opportunities.

Biological Consequences

Great uncertainty has been encountered regarding the biological consequences of weather and climate modification. Augmentation of rainfall over cultivated areas could partially alleviate the increasing problem of food production. However, there is an accompanying possibility that instabilities might result in the balances of biological communities. Such imbalances can be expected in the diseases and pests of man's domesticated plants and animals. In small areas of natural communities it is possible that some wild species may be severely stressed. The timing of the atmospheric intervention relative to the reproductive cycle of the various species in the community may be of more importance than the magnitude of the intervention. Both field and simulation studies of these biological relationships are needed before, during and after sustained operational programs. These studies should help avoid undesirable, unanticipated and irreversible ecological changes.

Special Implications

Weather and climate are among the major determinants of economic and social activity. Any change in precipitation, temperature, and wind—whether deliberate or inadvertent—is likely to have a significant effect upon society. Although a number of techniques are available for the study of the economic and social impact of weather modification, relatively little has been done. Much remains to be learned of the manner in which man responds to the normal variability in weather conditions. Relatively little is known of the processes of decision-making in human activities in relation to present day weather prediction. Economic and social analysis of these relationships is urgently required as an aid in developing and applying techniques of weather and climate modificiation. If the developing techniques of weather and climate modification are to be used intelligently, the human consequences of deliberate or inadvertent intervention need to be anticipated before they are upon us.

Legal Aspects

Weather and climate modification poses legal questions as to the existence of "property" interests in weather and the responsibilities of weather modifiers for damage to others, as well as problems of regulation. It is too early to make specific suggestions as to the law which should govern "property" in weather, or the liabilities of weather modifiers. However, recommendations are made as to needed regulation and indemnification of those working on government supported programs.

International Relations

The Commission finds far-ranging international implications in weather and climate modification. By its very nature weather transcends national boundaries. An attractive opportunity exists to anticipate the effect of technological development in weather and climate modification upon international relations. Specific steps are recommended to foster international cooperation in research and in the peaceful use of any physical capability that may evolve.

Organization and Funds

The national program should involve basic research, technology, operations and regulation. There needs to be assigned to a single existing government agency, or to a completely new agency, the responsibility for developing the technology of weather and climate modification. The National Science Foundation should continue and expand its support of research in the atmospheric sciences, including its program directed at providing a satisfactory scientific basis for weather and climate modification. Other governmental agencies should undertake such research and operational activities in weather and climate modification as their missions may require.

Federal financial support for research and development activity in weather and climate modification should be increased several fold over present levels.

SCIENTIFIC POSSIBILITIES

In pursuing means to modify weather and climate man assumes the character of a force of nature. That state is not at all novel in that man by inadvertent acts has already modified some aspects of weather and climate through urban development, surface changes for agriculture, forest culture and flood control, and altered the composition and thus the radiation balance of the atmosphere through the combustion of fossil fuels. Deliberate alteration of the atmospheric regimen is, however, a new concept. Thus far the brightest hope for deliberate intervention lies in the possibility of altering precipitation rates and dissipating supercooled fog by silver iodide or dry ice seeding. This has caused the prospect of weather and climate modification to be viewed mainly in the light of these techniques and their attendant geographic scales.

If it is granted that the possibility of successful use of seeding procedures is a real one, it must also be recognized that it is in the character of modern man that he will press on to develop larger scale measures; some of which are already in the conceptual stages of evolution. For this reason, planning for research in weather and climate modification must be broad enough at its very outset to accommodate future progress toward large scale or manifold activities. Moreover, judgment of sound action must be based on a suitably broad foundation of informed scientific, economic, legal and other opinion, with a clear appraisal especially of the biological and ecological risks involved.

There are four needs to be met in weather and climate modification:

1. To assess and understand natural climatic change.

2. To assess and understand the inadvertent changes in weather and climate that the technological evolution of man has produced;

3. To improve man's ability to predict the behavior of the atmosphere so that he may arrange his affairs with a minimum of danger or surprise; and

4. To devise a variety of techniques for deliberate intervention in the course of atmospheric (or other) processes which will alter weather and climate in the interest of mankind.

Why attention to the field is timely is well explained in the Introduction to Vol. I of the Report of the Panel on Weather and Climate Modification of the National Academy of Sciences.[1]

---

[1] Weather and Climate Modification—Problems and Prospects, Vols. I and II, National Academy of Sciences-National Research Council, 1966 (NAS-NRC 1350). Volume II contains an extensive bibliography.

One might ask why so detailed a survey of the status and outlook of atmospheric modification as we have made should be undertaken at this time. During approximately the past decade, subtle but significant shifts have occurred in long-term prospects for weather and climate modification; in many fundamental respects, an earlier era of speculation had gradually been superseded by the present period in which rational and systematic exploration of modification potentialities has become possible. Several changes stand out as factors causing this shift:

(1) Formulation of increasingly complete and elaborate theories of atmospheric processes has advanced to a state in which moderately realistic mathematical models can be constructed for a variety of atmospheric systems ranging in scale from micrometeorological to global. Admittedly crude and rudimentary in many instances, such models constitute a necessary first step in reducing the degree of empiricism that has characterized most past speculations concerning atmospheric modification.

(2) Prior to about 1950, such mathematical models were for the most part unproductive because of the sheer mathematical complexity of the systems of equations constituting the models. The advent of high-speed automatic computers has, within the past decade or so, radically altered this picture. Computing speeds and storage capacity have risen by many orders of magnitude, and a growing body of investigators in the atmospheric sciences has seized this powerful new tool to use it in analyzing critical aspects of the physics of our atmosphere. The important practical goal of improved numerical weather prediction became a stimulus that has recently led many workers to conduct increasingly elaborate computer studies in the broad area of numerical experimentation. Today, numerical simulation, albeit impressively complex and varied in scope, is almost certainly only a primitive first step toward future levels of understanding of the subtle and highly interdependent workings of our atmosphere; but it is a beginning with foreseeably profound implications for weather modification. This development alone is significant enough to justify a new and deeper examination of modification prospects.

(3) Man's ability to measure and to observe the atmosphere with its myriad parameters has been growing steadily. Two decades of improvement in use of aircraft as measurement platforms, two decades of elaboration of radar-meteorological techniques, and soon a full decade of experience with the incomparable synoptic observing capabilities of the meteorological satellite, combine with many other advances in instrumentation and observation systems to permit almost entirely new dimensions in man's ability to keep track of the rapid changes that are so characteristic of weather. Clearly, still further improvements may be expected in the future, but one senses that already we have available the measurement skills requisite to monitoring adequately many of these atmospheric systems we seek to modify.

The three considerations discussed above are of sufficient basic importance to prospects for present and future weather modification that, even without the particular stimulus of current advances in cloud modification per se, it would be most timely to undertake a survey of the field of atmospheric modification.

Much of the present effort in weather modification stems from the suggestion in 1946 of Langmuir and Schaefer that precipitation could be enhanced by introduction of ice, or ice-like nuclei, into clouds. The basis for the suggestion is that condensation of water droplets into particles large enough to fall may occur by growth of ice crystals in supercooled parts of the cloud. Water droplets may be supercooled well below the freezing point unless freezing nuclei are present. If clouds lack a sufficient number of natural nuclei, precipitation could, according to the theory, be enhanced by introduction of artificial nuclei into the appropriate parts of the cloud. In subsequent years the many experiments done in this country and abroad to test the theory have led to inclusive and controversial results. It has only been during the past year, largely as a result of a thorough analysis of available data by the NAS Panel on Weather and Climate Modification, that statistical evidence, although still somewhat ambiguous, appears to show that precipitation can be modestly enhanced locally by seeding.

Most of the experiments on which this conclusion is based are of an empirical nature. Typically nuclei are introduced by ground-based silver iodide generators. Rainfall is measured in a target area extending perhaps 30 to 50 miles downwind and also in a control area upwind from the generators. By comparing the observed rainfall during the seeding operations in the two areas with averages over past years, one can estimate the increase, if any, caused by seeding. In some cases the seeding is done on a randomized basis and a comparison is made between seeded and unseeded days and areas. Because of the wide variability of cloud systems, a great deal of data is required to obtain statistically significant results and also to ascertain under what conditions and what geographical locations seeding may be effective. The possibility of some sort of systematic error or bias must be eliminated by statistical design.

There is need for more empirical studies carefully designed to determine how effective seeding is in increasing rainfall or in suppressing hail and lightning in various situations. These experiments should be designed to give reliable and statistically significant data.

Toward this end a program of planned field experiments should be undertaken which provide continuity over a period of 5 to 10 years on a sufficient scale to permit geographic comparisons and differentiation, as well as stratification according to the type of seeding agent, mode of injection, cloud type, etc. Provision should be made for the inclusion of relevant precipitation data in addition to other relevant physical variables. This program should be designed and evaluated in close association with statisticians with extensive experience in experimental design.

Another approach is through basic research on cloud physics. These studies have shown that cloud systems are extremely complex and that precipitation can probably occur in a number of ways. There is only a rudimentary knowledge of how the artificially induced nuclei enter the clouds and how precipitation is actually affected. Thus, there is a wide gap between the basic research studies and cloud physics and an understanding of the empirical results of seeding.

In order to optimize seeding procedures and to better assess their inherent limitations, much more must be learned about the actual physical mechanisms involved. This requires more elaborate and expensive field experiments in which a number of variables are measured in addition to over-all precipitation, or, in the case of hail studies, the amount and nature of the hail.

A number of suggestions have been made of possible methods to produce changes in the climate extending over large areas. It is known that rather abrupt changes in climate have occurred in the historical past, but there is as yet little understanding of the factors which brought them about. It is possible that changes in climate may also be produced inadvertently by activities of man. To assess the probable consequences of both deliberate and inadvertent changes requires much better knowledge than is now available of the general circulation of the atmosphere and oceans, sources and sinks of heat, and energy interchanges at the surface of the earth. To acquire such knowledge will require many years of basic research. Man is now learning how to simulate the atmosphere numerically with use of large digital computers and by use of laboratory models. It has been estimated that computers two orders of magnitude faster than those now in use will be required for adequate simulation of the atmosphere on a global scale for general circulation and on a limited scale for local storms. A broad research program of this sort is required and can be justified for aid in long-range forecasting. Its importance for making possible predictions of consequences of deliberate and inadvertent modifications of climate gives it added justification.

Computer simulation and other studies should include a search for triggering mechanisms and means for suppressing violent but marginally sustained extremes in weather. Further development of laboratory and computer simulation should also yield insights crucial to the design of field experiments, to systematic efforts to modify weather and to long-range international planning of non-atmospheric methods of weather and climate modification.

It is assumed that the mission-oriented programs already underway, such as that of the Department of Interior to attempt to increase precipitation over its Reclamation project watershed areas and those of the Departments of Agriculture, Commerce and Defense will be continued in both their scientific engineering and operational phases. These present experiments should be continued. But, it is essential that there be an increase of effort, either by agencies of government or by academic and other groups to insure that the biological, legal, social and statistical aspects of the experiments are given sufficient attention. Present mission-oriented field experiments are examples of work undertaken despite the fact that there has been insufficient fundamental research. If large-scale field seeding activities are properly designed and controlled and can be supported by adequate ecological investigations, with monitoring and associated fundamental research, there is no question that such experiments will yield knowledge benefiting weather modification research while the public policy objective of attempting to increase precipitation over the watersheds is being pursued.

One can conceive of non-atmospheric possibilities for deliberate weather and climate modification which could lead to major changes in climate. An example is possible alteration of the oceanic heat balance by lifting cold water to the surface in major currents such as the Gulf Stream or Kuroshio (Japan) Current. Such experiments should obviously not be undertaken without many years of international study of all consequences. But, the increasing levels of energy available to man are even now so great that such proposals may be entertained.

To carry out the necessary laboratory, field and theoretical research for a full understanding of atmospheric and non-atmospheric weather and climate modification and inadvertent changes in weather, will require the efforts of people well qualified in disciplines such as applied physics, engineering, chemistry, statistics and meteorology, as well as biology, geology, oceanography, mathematics and hydrology.

In the view of the Commission, some of the greatest future needs of the physical sciences and engineering in weather and climate modification research and development are: enhancement of the support of fundamental research looking to creative ideas; much greater logistics capability for supporting large-scale experiments whether over sea or land; careful attention to the statistical design of experiments; a larger program in computer simulation and laboratory geophysical modeling; and consideration of synchronous satellites for observing the life history of storms such as hurricanes.

BIOLOGICAL IMPLICATIONS

Man is an organism directly dependent on other organisms for many of his materials. He also struggles with other organisms, most of them quite small, that prey upon him, eat his food, or otherwise challenge his existence. Anything that has a general and significant effect upon plants and animals, making some more abundant, others less so, is of primary concern to mankind, for it strikes at the very basis of human existence. Changes in weather and climate may be expected to have such effects. It follows that any program of weather and climate modification must give serious attention to adverse as well as beneficial biological aspects.

It must be recognized that the present state of knowledge places uncomfortable demands on the prediction of the biological consequences of modifying the weather. Prediction of the impact of weather modification on the biological components in man's artificial ecological systems such as his cities and his farms will probably be easier to attain than such prediction for the more nearly wild areas. This is so, because economic objectives have insured more adequate biological information concerning artificial systems, and because these systems are not so complex biologically. It is essential that this present primitiveness in our biological forecasting capability not be used as an argument for omitting it from weather modification programs.

Prediction of the types and degrees of change in crop and livestock yield and quality to be expected from specific changes in weather sequences can be markedly improved with methods and analyses already at hand. Prediction of the direct effects of weather changes on the domesticated organism can be attained more quickly than prediction of the indirect effects resulting from weather-induced changes to the domesticants' parasites, diseases, pests and symbiants. The published literature contains many references to studies implicating unusual weather sequences for disease and insect and weed outbreaks. Vector-born diseases of plants and animals, humidity-responsive bacterial and fungal diseases of crops and many insect outbreaks can be cited as examples. A fuller knowledge of these inter-relations coupled with a capability of highly accurate control over the weather could have favorable economic results. Ignorance concerning the biological consequences to be expected from significant changes in the weather could be locally detrimental.

In wild lands the complex natural arrays of organisms are in delicate adjustment not only with the normal climate but also with the pattern of fluctuations. On the basis of the few published long-term studies in which biological composition has been followed during major weather fluctuations, it seems a reasonable prediction that alterations in weather patterns are likely to constitute at least a temporary unstabilizing influence in most natural biological communities. It is important to note that weather and climate fluctuations have been a molding influence on natural populations and most species have adaptations relating to it. Thus, weather and climate modifications need not constitute changes exceeding the recorded extremes in order to cause significant biological consequences. Some of the successional species that tend to increase during instability may be economically important species such as the succession of many forest species. Since many pests are also favored during instability, the net economic effect is difficult to predict.

In vast reaches where the biological communities extend beyond the areas of weather modification it can be expected that natural migrations of species from areas adjacent to the changed condition will tend ultimately to restore stability. However, in the small islands of natural biological communities such as parks and preserves the effects will be less apt to set themselves right. The wide stretches of man's artificial biological make-up and disturbance between such islands provides an effective barrier to migrations. Extinction, at least locally, could result for some species.

Thus, from the present crude state of the field, one can roughly predict that the biological outcomes of weather modification are apt to be a mixed bag of economically good and bad effects in man's artificial ecosystems. It is difficult to visualize any desirable effect on the small preserves of natural communities. In order to improve biological forecasting several avenues are open:

1. Growth chamber simulation of such changes on as large a fragment of the biological type as possible.

2. Examination of areas biologically and climatically analogous to the changed and unchanged situations.

3. Study of the fine structure in the fossil record of the recent past.

4. Computer simulation of changes using the best available data.

5. Monitoring of sample areas within and outside of regions subjected to weather modification. The monitoring should begin before weather modification activities and extend beyond their cessation.

It is the position of the Commission that there should be a strong effort to bring the field of biological forecasting up to a higher level of usefulness. This is mandatory in planning weather and climate modification over areas involving more than a few hundred square miles.

A by-product of such expanded research and development will have wide utility in agriculture, forestry and park and general resource management and other fields. Beyond this, as an area of fundamental science, forecasting of the behavior of ecological systems needs to be augmented since man knows so very little about how such systems operate, either the man-made ones that sustain him or the natural ones from which he derives an essential part of his inspiration and contentment.

All five of the above approaches need to be brought to bear on the problem. Any group involved with large-scale experimentation with weather modification should be expected to provide for adequate biological monitoring. The team effort that would result from this kind of interaction of meteorologists, hydrologists, engineers, ecologists, agronomists, foresters, entomologists, etc. is long overdue.

THE SOCIAL EFFECTS

Weather and climate conditions are among the major determinants of economic activities and social structure. No other aspect of the environment has as many pervasive relations to the pattern of human activity on the globe. Any substantial change in precipitation, temperature, or wind, whether deliberate or inadvertent, is likely to have a significant effect upon society, as the public and private expenditures for hurricane, drought, and flood disasters dramatically illustrate. The immense varieties of housing and of farm cropping practices illustrate less obvious but fundamental adjustments to weather and climate. In some cases the influence of weather and climate modification on human activities may result in shifts of the social institutions that are too subtle to be recognized by many of those involved.

If scientific research in changing weather and climate is regarded as an investment decision, society should seek answers to several questions as it decides how much to spend for what kinds of research. Who benefits from the investment if made? If both benefits and losses occur, how are they distributed? Will the normal market forces provide enough incentive to achieve the socially optimum results to mankind?

It does not seem plausible that private enterprise will finance research at a level adequate to achieve the optimum social objective. Further, because the benefits or losses do not necessarily accrue to people in the same geographic area or in the same businesses, weather and climate modification research needs to be supported primarily from federal sources for the foreseeable future. This position is to be expected when the estimate of the long-range social effects and the apparent immediate value of the products for the market are so divergent.

A number of techniques are available for study of the economic and social impacts of weather modification. These include benefit-cost analysis, activity analysis, input-output analysis, and analysis of decision making, as well as numerical simulation studies. Despite differences of opinion as to research strategy, the various techniques tend to be complementary. Much has been learned about methods from the social appraisal of engineering projects to modify the water cycle in river channels.

One general approach is to define an actual or assumed modification of the weather and then attempt to analyze the full consequences of this to society. It is practical, for example, to estimate an increase in precipitation over a drainage area serving a hydroelectric plant and then follow the possible impacts through the operation of the plant, the operation of downstream water projects, the production of other plants connected in the same system, and the productivity of the entire network. Along with the cost of cloud seeding, an attempt can be made to measure the full social benefits and costs from the increased rainfall, but these are hard to identify.

Another approach is to analyze a sector of society so as to determine the particular points in the life of man where he is sensitive to changes in weather, and the degree to which a modification might lead to readjustment in amount or location of his activity. For example, it is obvious that the whole pattern of recreation in an area can shift very quickly because it happens to rain or snow at a given time and place, and that if the probability of precipitation were to be changed, the character of the regional recreation industry would alter.

A basic difficulty in social research associated with weather modification is the difficulty of assessing the way in which man responds to a known weather circumstance. Just because there is a drought it does not automatically follow that a farmer in that area will move to another locality or adopt a different cropping schedule, even though analysis indicates it would be most profitable to do so. He may decide to stay, or to hold to his old farming methods. Understanding how people manage natural resources is essential to sound prediction of how they will react if the atmosphere is modified.

Any adequate evaluation of social effects examines and compares the whole range of alternatives to weather and climate modification. An accurate weather forecast, for example, may be more valuable than an increase in rainfall, in some situations. If long-range forecasts were made reliable a farmer could change his cropping pattern for that year rather than support weather modification. As a further illustration, unless practical triggering mechanisms can be found, increasing the ability to forecast tornadoes and hurricanes is more rewarding than attempting to modify them. Adequate warning in many cases can allow man to adapt his activities at lower cost.

There are other alternatives in addition to forecasting: agronomic and genetic research can render farming less susceptible to the vagaries of weather. Engineering can protect transport from weather interruptions. A change in farm or industrial organization can reduce its vulnerability to weather extremes.

The need is great to assess more fully the social implications of weather and climate modification resulting from man's discharging material into the atmosphere. As more is known about the weather man could decide to build cities on spoil areas rather than on good farm land and in topographic areas which help avoid pollution of the environment. One alternative here, of course, is to modify the weather over urban areas deliberately to offset the results of man's inadvertent weather changes.

To the uncertainty as to what weather and climate modification man can accomplish must be added his lack of knowledge of the full consequences. New research programs should be based on the recognition that expanding the scientific knowledge of these consequences would be important to man even if no further gains were to be made in the technology of weather modification. The same understanding which would permit assessing the effects of weather and climate alteration would assist in working out other kinds of adjustments to weather phenomena.

As indicated by the lack of social research about weather modification since the 1957 report of the Advisory Committee on Weather Control, when uncertainty concerning the feasibility of extensive weather modification is large the social implications tend to remain unexplored until a major problem erupts. The Commission feels strongly this should not be the course of events in the future. All agencies engaged in weather modification attempts should give systematic attention to the social implications. It is essential that funds be allocated for corollary research in the social sciences as related to weather and climate modification, both deliberate and inadvertent. This research should embrace the measurement of impacts, the identification of basic geographic relationships between human activity and weather and climate, and the conditions under which decisions about weather are made.

THE LAW

The ramifications to society—and hence to our legal system—of the technological capability to order weather would be enormous. Even a limited capacity to modify weather poses legal problems of great complexity. Urgent as these problems may soon become, uncertainty as to the scientific capability makes the recommendation of long-range legal solutions impossible at the present time.

Nevertheless, the law is already involved with weather modification and it is necessary to come to grips now with some aspects of the problems.

The involvement of the law with weather modification is of two kinds: (1) the rules governing the responsibilities and liabilities of weather modifiers to other members of the public; (2) regulation by government. As to the former, it is premature to make any recommendations concerning the rules of law which should be adopted to govern "property rights in weather," or the liabilities of weather modifiers with respect to those claiming injury to their persons or property. It is to be hoped that problems of weather modification will be decided on their own merits rather than on the basis of too facile analogies to the law respecting land, water, wild animals, airspace, and the like. The few court decisions to date, while useful in illustrating the kinds of conflicts which can be expected to arise, do not give much basis for predicting how the law will develop. As the law stands, however, government contractors and grantees are subject to a risk that liability will be imposed on them for damage caused by their activities and that risk may have an inhibiting effect on participation in government programs.

As to regulation, some twenty-two states have enacted laws regulating weather modification. Most of these statutes require licenses. One state prohibits weather modification activities entirely. While these statutes have had little effect on weather modification activities, there is a distinct possibility that they may interfere with desirable Federal programs in the future.

Until recently the only Federal "regulation" was the requirement by the National Science Foundation for reports on activities already undertaken by operators of whose activities the Foundation was aware. Effective January 1, 1966, the Foundation substantially increased its record-keeping requirements and imposed on all operators a requirement of advance notice to it of any activity.

The present authority of the Foundation under Public Law 85-510 provides for obtaining—by regulation or otherwise—information, including advance notice of any proposed weather modification activities, deemed necessary to its program of study, research, and evaluation. This information is an aid to the Federal research and development effort and to the protection of its integrity. But, the lack of Federal authority to stop activities which may interfere with or contaminate Federally-supported programs renders the Federal government powerless to protect its programs from the actions of privately supported parties or state and local instrumentalities except by voluntary arrangements.

Thus, the Commission recommends that the Federal government, by appropriate legislation, be empowered to:

a) delay or halt all activities—public or private—in actual or potential conflict with weather and climate modification programs of the Federal Government, whether these programs are conducted for the Federal government, by its own agencies or by its grantees or contractors;

b) immunize Federal agents, grantees, and contractors engaged in weather and climate modification activities from state and local government interference; and

c) provide to Federal grantees and contractors indemnification or other protection against liability to the public for damages caused by Federal programs of weather and climate modification.

These recommendations are deliberately restricted in scope, in the belief that in the developmental stage of weather and climate modification the minimum regulation consistent with immediate goals is desirable. However, it should be recognized that as knowledge develops and as weather and climate modification activities increase, more comprehensive regulation in the public interest may be required. Such regulation might include setting standards of professional qualifications and financial responsibility for operators, establishment of appropriate authority for determining which experiments or operations may be undertaken in the public interest, and a requirement of evaluation of activities by the operator.

Finally, since weather no more respects national boundaries than it does State lines, it is hoped that early efforts will be made to delineate and study the international legal problems of weather and climate modification.

NEEDS AND OPPORTUNITIES FOR INTERNATIONAL COOPERATION

The program of research required to develop the capability to modify weather and climate suggest a strong emphasis upon international cooperation. The extensive and significant work that is being done in other countries underscores the need for promoting the international exchange of data and research findings for the purpose of maximizing their usefulness. The need for international collaboration in the actual planning and conduct of research activities may be expected to increase as research moves out of the laboratory and into the realm of field experiments associated with the study of the dynamics of climate, the establishment of a global weather observation network and the investigation of other aspects of the general atmospheric circulation. The technological and human resources required for the conduct of this type of research are far beyond the capability of most countries to provide individually.

Looking into the future to the time when field experiments with weather or climate modification are expanded in scope and number and involve actual attempts to introduce changes in the atmosphere, some form of international collaboration will be essential in the planning and execution of projects that may have an effect not only upon the immediate localities but on areas in other countries and even upon other continents distant from the scene of work. It is possible that situations of this sort may arise in the near future if an expanded program of field experiments in cloud seeding is undertaken in areas near the northern or southern borders of the United States. An expansion in experimentation with tropical hurricanes may also present international complications.

In the present stage of world affairs any scientific advance contributing significantly to man's ability to affect the natural environment inevitably has a bearing upon the political relations among nations and the quest for peace and security. The importance to military operations of a capability for modifying weather conditions is obvious. It must be recognized that there is a remote possibility that sometime in the future a nation might develop the capability to use weather modification to inflict damage on the economy and civil population of another country.

It is essential to develop the political and social controls over the use of this power which will maximize the opportunities for its constructive and peaceful use and minimize the factors which tend to involve it in the tensions and conflicts inherent in human society. The challenge and the opportunity which are presented to the world community by the prospect of man's achieving a power to modify his atmospheric environment is one of the most exciting long-range aspects of the subject.

Thought must be given to the types of international organizations that will be needed, and the functions they should perform, if and when major operations in weather and climate modification affecting large continental areas become feasible. Whether the assignment of operational responsibility to an international agency should be considered for the future deserves thought even at this early date. Consideration might be given to new concepts of international organization and to the new problems of a technical or political nature that might be precipitated.

The very fact that the development of a capability for influencing the atmospheric environment is still in its infancy should widen the opportunity presented by this scientific endeavor to develop attitudes and patterns of collaboration which can contribute not only to the achievement of the practical, technological goals, but also to the relaxation of international tensions.

Rarely has a more ample and inviting opportunity been offered for advance thinking and planning regarding the impact of a technological development upon international relations. Progress in the diminution of international tensions and the achievement of peace will come not so much from the dramatic resolution of basic international controversies as from the far less spectacular widening of areas of mutual interest among rival nations and from the growth in ways of cooperation. The field of weather and climate modification can serve well in this regard, in addition to realizing benefits of a more limited practical nature.

The Commission believes that:

1. It would be highly desirable for the Government of the United States,

in connection with the expansion of its program of weather and climate modification, to issue a basic statement of its views on the relationship of this national effort to the interests, hopes, and possible apprehensions of the rest of the world. Early enunciation of national policy embodying two main points are recommended:

a. that it is the purpose of the United States, with normal and due regard to its own basic interests, to pursue its efforts in weather and climate modification for peaceful ends and for the constructive improvement of conditions of human life throughout the world; and

b. that the United States, recognizing the interests and concerns of other countries, welcomes and solicits their cooperation, directly and through international arrangements, for the mutual achievement of human wellbeing.

This cooperation should cover both research and, ultimately, operational programs of interest to other countries. It should be concerned not only with deliberate, but also inadvertent human interventions in the atmosphere that affect weather and climate. Such a policy declaration could be issued by the President or appropriately incorporated in any basic legislation on the subject of weather modification which the Congress may enact.

2. Steps should be taken by the United States, in concert with other nations, to explore the international institutional mechanisms that may be appropriate to foster international cooperation and cope with the problems which may be anticipated in the field of weather and climate modification. The United Nations and its specialized agencies (e.g., the World Meteorological Organization) is suggested as a possible intergovernmental framework. The International Council of Scientific Unions and its associated unions (e.g., the International Union of Geodesy and Geophysics) could be a suitable non-governmental framework for these mechanisms.

3. A major limitation affecting both advanced and developing countries is the shortage of trained personnel in atmospheric sciences at all levels. Attention should be given to the question of how greater emphasis can be given to atmospheric sciences in existing bilateral and multilateral programs of education and technical cooperation; and to what additional measures may be needed to fill this deficiency.

4. Encouragement should be given to research on the impact of weather modification measures in foreign countries. The need has been previously discussed for greater attention to the biological, economic and social aspects of weather modification in the United States. A different set of problems may well be encountered in many of the developing countries where the natural environment and patterns of economic and social life present contrasts to those prevailing in this country. A greater understanding of the significance of these differences must precede any attempt to evaluate the suitability of various weather and climate modification practices for specific foreign areas and to design appropriate programs of cooperation.

FISCAL AND ORGANIZATIONAL CONSIDERATIONS

Scope and Nature of the National Program

The four principal elements of a national program for weather and climate modification that appear to be warranted by the evidence presently at hand are as follows:

1. There should be a strengthened program of fundamental research in the atmospheric sciences and the initiation of complementary research in the biological and social sciences. Research in the atmospheric and the biological sciences should range from studies of a large and extensive nature involving many individuals and substantial logistical support to the work of individual investigators. Desirable research on socio-economic aspects and the legal and international implications will generally consist of studies of relatively modest cost.

2. There should be a concerted effort directed specifically at the development of what may be called the technology of weather and climate modification. This is a sector in which a conspicuous gap is becoming evident. The objectives should be early development and testing of techniques by which deliberate intervention in atmospheric processes can be accomplished and consideration of the likely consequences of human activity in inadvertent intervention. Large-scale undertakings with substantial logistical support will be required and close liaison will be desirable with

the social, biological and other related studies.

3. There should be provision for operational application by both the public and the private sectors as the feasibility and efficacy of modification techniques are validated.

4. There should be such regulation as may be required to protect the public interest and advance the state of the art. Admittedly, it is difficult to arrive at a judgment on such matters as the timing and necessary scope of regulation and the form of administration. In the opinion of the Commission, however, it is not too soon to deal with this matter providing flexibility for adaptation to changing needs.

Funding

In the light of the above program, the following considerations with respect to funding appear to be revelant.

1. Federal financial support for research and development activities in weather and climate modification needs to be increased substantially above present levels.

2. Large field observational programs and experiments of both a basic and an applied nature will be costly. They will require logistical support of substantial proportions in the form, for example, of suitable instrumentation, aircraft, synchronous satellites and ecological laboratories. Some idea of the costs for which provision should be made is given by the estimate that a field experiment on hail by use of doppler radar and aircraft would cost at least $2 million a year.

3. The weather and climate modification program needs a strong centralized group as could be provided by a national laboratory. Such a group or center could serve as a focal point for research and development to conduct and assist in large scale experiments and to provide logistic capabilities. The availability of a center with its facilities would serve as a nucleus for program planning and interchange of scientists on an international basis. It should be interdisciplinary in character and provide for the conduct and support of research in those physical, biological and social sciences which are involved in weather and climate modification.

4. Federal outlays for weather and climate modification research and development in Fiscal Year 1966 approximate $7.2 million, exclusive of logistical support provided by the

Department of Defense. This sum constitutes about two percent of the expenditures of all Federal agencies for the atmospheric sciences and meteorological services. The potential importance of weather and climate modification, its propects for the future even in the face of remaining uncertainties in the present state of the art, and the magnitude of the effort that may be required to resolve these uncertainties, require substantial funding. The Commission believes that by 1970 annual funding should be increased to the neighborhood of $20 to $30 million, including logistics support, or about five percent of the total for atmospheric sciences and meteorological services. In addition, increases of the same order will be needed for underlying basic research, including funds for items such as large computing facilities. Thus a total increase of $40 to $50 million per year may be envisaged by 1970. The level of funding must, of course, be constantly reviewed as progress is made.

Organizational Responsibilities

Weather and climate modification pervades many facets of human activity; it is natural that several Federal agencies have been involved as they fulfill agency missions. In the last full fiscal year, 1965, the Departments of Agriculture, Commerce, Defense and Interior and the National Science Foundation all expended funds for weather modification. No single agency in the Federal government now has responsibility for developing the technology of weather and climate modification. The need for such designation is now, however, becoming evident.

The future requirements of the agencies, and the needs of the weather and climate modification field, suggest that the organization of a national program should be unified around one agency, yet open for the participation of those agencies whose missions require the conduct or support of weather and climate modification activities. The national program needs to provide for agencies such as the Federal Aviation Agency, which might operate over an area as small as an airport, to the State Department with its concern over the relationship of weather and climate modification to foreign policy. Thus, a national program should provide for the diversity of intellectual interests associated with the subject, field and laboratory projects both large and small, and a growth in financial support consistent with prospective results.

The Commission takes the position that:

1. The mission of developing and testing techniques for modifying weather and climate should be assigned to an agency in the Executive Branch of the Federal Government—for example, to the Environmental Science Services Administration of the Department of Commerce or to a completely new agency organized for the purpose. The mission should include support and conduct of research and development and such operational activities as are needed for the furtherance of the technology of weather and climate modification. This agency should have major but not exclusive responsibility, in collaboration with the State Department, for formulating and implementing programs of weather and climate modification involving international cooperation.

2. The National Science Foundation should continue and expand its support of research in the atmospheric sciences, including its program directed at providing a satisfactory scientific basis for weather and climate modification. This should be carried on primarily at universities and colleges and should include maintenance of the National Center for Atmospheric Research as a facility for the conduct of basic research on a scale beyond that feasible for individual university investigators. The degree of continuing and special attention given by the Foundation to the support of the physical sciences, engineering, the biological sciences and the social sciences aspects of weather and climate modification should be reviewed from time to time in the light of the progress of the over-all national program.

3. Federal agencies should undertake such operational activities as may be required for the effective discharge of their missions (e.g., suppression of lightning by the Forest Service, fog dispersion by the Federal Aviation Agency and rainfall augmentation for the reservoir system of the Department of the Interior). Also, pursuant to Executive Order 10521, Federal agencies should be free to conduct and support such research and development as may be required in the discharge of their missions.

(4) Insofar as the nature of a regulatory agency is concerned, care must be taken to ensure access of all agencies to the information generated, while at the same time keeping regulation organizationally separated from research and development. For example, were the assignment of regulatory responsibility to be made to the Secretary of Commerce, provision should be made that it be exercised outside those parts of the Department engaged in the conduct of research and development relating to weather and climate modification. Whether the regulatory function needs to be divorced completely from the operating agencies, or can be assigned to a separate branch of such an agency, will depend largely on the extent of activity and the degree of regulation required.

As to the jurisdiction of a regulatory agency over other Federal agencies, insofar as regulation involves requirements of notice, reports, licensing of activities, etc., there seem to be good reasons why all agencies should be subject thereto. In addition, the regulatory agency should be given power to resolve minor conflicts between agencies, such as the timing of particular experiments.

It must be recognized that because the social effects will be complex and because Federal agencies are associated with diverse interest groups there are likely to be major conflicts in programs. Such conflicts go beyond the scope of regulation and involve administrative coordination at the highest level. Their resolution should not be left to a regulatory agency. The Commission recommends that the Office of Science and Technology should consider establishment of a special mechanism for the coordination of weather modification policies and programs. Such an entity could not only serve to resolve conflicts but could serve to promote unity in policy and deployment of funds and manpower with optimum effectiveness.

5. Both the Executive Branch and the Congress may wish to have available scientific and public policy advice from a group of knowledgeable people from outside the Government. This need might well be met by the appointment of a standing committee in the National Academy of Sciences in cooperation with the National Academy of Engineering. The group should include persons with experience in the physical, biological and social sciences and engineering.

PROGRESS AND PROSPECTS IN WEATHER AND CLIMATE MODIFICATION

INTRODUCTION

For a review of the present status and potential of weather and climate modification, the Commission has depended mainly on the report of the Panel on Weather and Climate Modification of the National Academy of Sciences*, the annual reports of the National Science Foundation, and the report of Gilman, *et al.*** Since the scientific basis has been discussed thoroughly in these reports, there is no need to repeat it here. Instead of a detailed discussion, an attempt is made here to delineate the problem in its broadest conceptual framework in order to describe the probable character of a well balanced plan for future action.

Consideration of the physical problems involved properly begins with a brief review of the atmosphere as a physical system, the dimensions of the quantities of energy that would be required to alter atmospheric processes by the exercise of brute force, and the nature of the instabilities that might be exploited to exert meaningful influence within the limits of our ability to manipulate energy. These problems are discussed in Section II of this chapter. A brief summary of some of the most important conclusions of the NAS Panel is included in Section III. Also included in this chapter are brief discussions in Section IV of some of the projects on weather modification research carried out under the National Science Foundation program. In Section V there is a review of activities in foreign countries. Finally in Section VI a discussion is given in broad terms of prospects for future research.

THE NATURE OF THE SCIENTIFIC PROBLEM

The atmospheric envelope rotates with the earth, but does not rest quietly upon it. Air motion relative to the earth is induced by a non-uniform distribution of energy sources and sinks which are strongly influenced by those motions which they produce.

---

* Weather and Climate Modification—Problems and Prospects, Vols. I and II, National Academy of Sciences-National Research Council, 1966 (NAS-NRC 1350).

** Weather and Climate Modification, A Report to the Chief, United States Weather Bureau, July, 1965. (Both these reports include extensive bibliographies.)

The motions themselves range in size over a spectrum that extends from the scale of planetary wave systems down to molecular movement. The sources and sinks of energy are variable in number and strength and exist mainly in response to the disposition of short-wave solar radiation, the flux of outgoing long-wave radiation, the latent heat involved in the phase change of water and on the flow of sensible heat between the lower atmosphere and the underlying ocean or land. The kinetic energy of air motion is continuously exchanged with other forms of energy in the atmosphere and the kinetic energy of the several scales of atmospheric is continuously being transferred from one scale to another.

For the purpose at hand, the atmosphere may be viewed as a complex physical system in which ascertainable changes in air motion take place in response to identifiable forces. In principle, by altering these forces, consequent changes in the air motion can be influenced. Thus, in principle, controlling the weather or modifying the climate is scientifically possible. Whether or not it is practically realizable depends on a demonstration of the capability to alter these forces in a manner which will produce predictable consequences. To be intellectually satisfying, the cause and effect relationship would have to be understood in precise and exact detail. To be meaningful in a practical sense, it is only necessary to establish beyond a reasonable doubt that the cause and effect are related.

It is useful to consider the order of magnitude of the kinetic energy involved in several scales of atmospheric subsystems. Some idea may be obtained from the following table:

Atmospheric Subsystems	*Approximate* Energy in ergs*
Tornado funnel	10^{21}
Small thunderstorm	10^{22}
Large thunderstorm	10^{23}
Hurricane	10^{25}
Extratropical cyclone	10^{26}
General Circulation in the Northern Hemisphere	5×10^{27}

* Data for the tornado funnel and thunderstorms refer to a total lifetime of kinetic energy. Data for the other phenomena refer to kinetic energy at any given moment during maturity—which may be considerably less than the lifetime expenditure.

An appreciation of the energy requirements necessary were the kinetic energy of these atmospheric subsystems to be changed by 10 percent can be obtained from the next table. The column on the right lists the time demand on the total electrical energy generating system of the United States if that source were to be drawn upon to change the kinetic energy of the atmospheric subsystem by ten percent.

Atmospheric Subsystem	*Approximate* Time*
Tornado	30 seconds
Small thunderstorm	5 minutes
Large thunderstorm	several hours
Hurricane	several days
Extratropical cyclone	5-6 weeks
General circulation in the Northern Hemisphere	6 years

* Data for the tornado funnel and thunderstorms refer to a total lifetime of kinetic energy. Data for the other phenomena refer to kinetic energy at any given moment during maturity—which may be considerably less than the lifetime expenditure.

One concludes that it is not immediately practicable to think of altering these atmospheric subsystems to this extent by a direct application of energy. Nor is it reasonable to think of using energy directly to alter rainfall. For example, the additional latent heat released by an increase of 10 percent in a rainfall totaling one inch over an area one hundred miles on a side would be the equivalent of about six days of the daily output of the electrical generating capacity of the United States. On the other hand, as will be seen presently, there exists some evidence that increases in rainfall of this order may be obtained by seeding. A triggering mechanism based on an atmospheric instability is involved. It is appropriate, then, to consider the question of possible instabilities in the atmosphere.

From simple observations of the life cycle of cumulus clouds, thunderstorms, tornadoes, hurricanes, and extratropical cyclones, it is evident that—within certain limits—the atmosphere is unstable, that is, the amplitude of disturbance increases with time over a period of time which varies with the size of the disturbance. Moreover, significant energy transformations are involved in the amplitude growth associated with these releases of energy initially in unstable form. At least four kinds of instability have been identified as potentially susceptible to man's efforts to trigger natural reactions. They are:

1. The phase instability of water in the vapor phase in a condition of supersaturation and in the liquid phase in the condition of supercooling which, when released, provides a local source of sensible heat.

2. The colloidal instability of cloud particles which when released by precipitation, completes the cycle by which latent heat is exchanged between the underlying surface and the atmosphere.
3. The convective instability of the atmosphere which, when released, redistributes sensible energy in the vertical and often produces high local concentrations of kinetic and electrical energy.
4. The baroclinic instability of the large scale circulation which, when released, redistribute sensible and kinetic energy in the horizontal plane, i.e., from pole to equator.

The results of preliminary experimentation with the first three instabilities identified above lend support to the point of view that they may be the "Achilles' Heel" in the atmospheric system by which large effects might be produced by relatively modest, but highly selective, interventions. The difficulties of treating quantitatively the non-linear processes inherent in instabilities are sobering. Some offset is provided, however, by the indications that energy can progress upward through the several scales of exchange. It is pointed out in Volume II of the NAS Panel report that:

> The release of phase instability in an aggregation of supercooled cloud drops can simultaneously colloidally destabilize the cloud into precipitation (through the Bergeron-Findeisen mechanism) and, through the introduction of latent heat of fusion, convectively destabilize the volume of air within which the phase change is occurring. All of this has been observed, on a very small scale, in the seeding of stratocumulus clouds. It is not hard to imagine that induced convection or induced snowfall on a much larger scale could sufficiently alter the horizontal temperature distribution to trigger or subdue baroclinic instability, changing the natural development of large cyclonic storms. This, in turn, might alter the global radiation balance and thus influence a fifth scale of instability

about which we can only conjecture: the possible instability of global climate.

The great variability of ancient climates is accepted as fact, yet the cause of climatic change is far from being a settled issue. It is obvious that the earth-atmosphere system can support radically different climatic regimes, some of which could be disastrous to civilization. We do not yet know what can cause a shift from one climatic regime to another, whether change can occur in an "instant" of geologic time or only as a secular, cyclic process; our few theories still hang on the most tenuous of evidence.

This, in barest outline, is the nature of the problem and some of its implications. It is appropriate now to turn to some advances in recent years that suggest the present moment to be a propitious one to accelerate and strengthen the systematic exploration of the question.

PRESENT STATUS OF WEATHER MODIFICATION

The reports cited in the Introduction to this chapter give excellent discussions of the present status and promise of weather and climate modification.

A brief summary of some of the more important findings is given here. Some aspects of weather and climate modification are ready for practical applications, others are sufficiently promising to warrant programs of mission-oriented or applied research, still others are more remote possibilities for which no more than basic research can be justified at the present time. Furthest advanced is the problem of dissipation of supercooled fog and stratus clouds by seeding, which has reached the stage of engineering applications for clearing of fog at airports. Experiments done here and abroad on cloud seeding for local increase of precipitation and for suppression of hail and of lightning, while far from conclusive, have shown some promise of success. Vigorous programs of applied research should be pursued in these areas to delineate the potential and to optimize the procedures used.

Without many more years of basic research on large-scale circulations of the atmosphere and the causes of climatic change, no program of modification of climate extending over large areas of the earth's surface could or should be undertaken. Such a research program, although difficult and expensive, can be justified for aid in long-range forecasting and for making possible predictions of consequences of inadvertent changes in the atmosphere caused by activities of man. The possibility that such a program will in the future suggest methods for beneficial modification of climate is added incentive for undertaking it.

Given below is a brief summary of some of the main conclusions of the reports on the present status of weather modification. A review is then given of some of the research programs on weather modification undertaken during the past few years both here and abroad. The summary is necessarily quite brief; the reader is referred to the reports cited for detailed information and background.

Clearing of Supercooled Stratus and Fog

Effects of seeding by dry ice and by silver iodide were first demonstrated upon supercooled stratiform clouds. Recently attempts have been made to develop operational methods for clearing of supercooled fog at airports. Such methods have been used here and abroad for the past several years, particularly in the USSR, where the problem is more severe. Clearing of warm fog is much more difficult and no really satisfactory methods have been proposed.

Increase of Local Precipitation by Seeding

It has long been controversial as to whether local precipitation can be enhanced by seeding. The NAS Panel has made a statistical study of commercial seeding operations mostly using ground-based silver iodide generators. Included were operations in the Eastern U.S. and in orographic situations in the Western U.S. In addition, preliminary results of several randomized experiments on seeding both in this country and abroad have become available during the past year and are included in the study. In Volume I of the NAS Panel report it is stated: "There is increasing but still somewhat ambiguous statistical evidence that precipitation from some types of cloud and storm systems can be modestly increased or redistributed by seeding techniques. The implications are manifold and of immediate national concern." The statement cannot be made more conclusive because of the possibility of some unknown source of bias or systematic error in the commercial seeding operations and because chance fluctuations cannot be completely ruled out as an explanation of the more limited randomized tests. It should be emphasized that the problem is an extremely complex one; there is great variability in cloud types and in ways in which precipitation can occur. The theoretical knowledge of how seeding nuclei are introduced into clouds from ground-based generators and how precipitation may be affected thereby is still quite rudimentary.

Present indications, if taken at face value, are that local precipitation can be increased in many situations in the order of 10% by seeding. These positive results are obtained in cases where rain would have fallen anyway without seeding; there is no evidence that seeding can induce rain to fall when normally there would be none. Thus, seeding is of limited value in relieving drought situations.

There is very tenuous evidence that there may be under certain circumstances a "rain shadow" effect, an area of decreased precipitation downwind from the area of enhancement. There is no reason to suspect that this might be caused by "rain out" of available moisture, since normally only a fraction is released as rain in any case. Theoretically, one could have considerable enhancement of local rainfall without appreciable influence on precipitation further downwind.

Increase of Precipitation by Forced Convection

Suggestions have been made that precipitation in some local areas could be increased by changes in the earth's surface to promote great absorption of heat and also greater transfer of heat and water vapor to the atmosphere. This would stimulate convection; hopefully in sufficient amount to increase cloudiness and precipitation downwind. While some plans have been formulated, no field tests have been made to test this proposal. Another method, which has given some indications of success in limited trials, makes use of seeding. It has been suggested that latent heat released by increased condensation of moisture into water droplets causes uplift and cloud formation. It may be that some of the observed increases in precipitation by cloud seeding result from enhanced convection rather than directly by nucleation of droplets.

Lightning Suppression

Studies carried out under Project Skyfire of the U. S. Forest Service for the past several years have given indications that seeding can alter cloud to ground lightning from thunderclouds. Background has been developed for a more thorough statistical study to see under what conditions seeding may be effective in reducing lightning and lightning-caused forest fires. Another suggestion, not yet tested on a large scale, is to introduce chaff (metallized strips) into clouds to decrease electric field gradients.

Hail Suppression

Studies of suppression of hail by seeding or other techniques have mostly been carried out abroad and with inconclusive results. There are reports that Soviet scientists by introducing seeding nuclei at the optimum position and time by use of antiaircraft shells have had success, but this work has not been duplicated in this country. Volume I of the NAS Panel report states that "the U. S. hail research program is piecemeal and clearly of sub-critical size." Plans are underway by the National Science Foundation to initiate a program in this area.

Moderating Severe Storms, Tornadoes, and Hurricanes

Under Project Stormfury, several attempts have been made to modify hurricanes by seeding. The intent is to produce warming in the outer zone of the eye wall by releasing latent heat of fusion and so alter the pressure and wind distributions. Results are so far inconclusive. Progress in these areas, where tremendous energies are involved, will require much further basic research involving extensive field investigations and development of theoretical models.

Modifying the Microclimate of Plants

The problems are largely concerned with means for preventing frost, for suppressing evaporation and for reducing effects of wind. Practical methods have been in use for long periods of time; there has been limited application of modern knowledge of micrometeorology to optimize procedures. Further research on boundary-layer energy and moisture exchange is highly desirable.

Large-Scale Modification of Climate

The possibilities of making use of instabilities in the atmosphere to alter the climate of large regions of the earth's surface will be discussed in more detail later in this chapter.

Modifications of Climate

For the future welfare of mankind it is important to be able to understand the factors involved in climatic change and thus to be able to predict inadvertent changes in weather and climate produced by present and future activities of man. Some beginnings in this direction are included in the NAS Panel report. One is an attempt to assess consequences of the increasing carbon dioxide content of the atmosphere caused by the burning of fossil fuels. It is estimated that the CO_2 concentration in the atmosphere has increased 10 to 15% in this century, making significant changes in the heat balance. The report states that "the implications of this upon tropospheric stability cannot be ignored" and that there is need for continuous monitoring of CO_2 content and of simulation of CO_2 effects "using the most sophisticated atmospheric models and numerical computers available" to assess the consequences. Another important problem is to determine effects of urbanization both on local climate and possible indirect effects which may extend over much larger areas. Thus far there has been but little research on this problem. Effects produced by altering the rural landscape (agriculture, deforestation, etc.) appear to be less serious. Other problems considered in the NAS Panel report are possible effects of increase in water vapor content of the stratosphere by supersonic transport aircraft and of contamination of the higher atmosphere by rocket exhaust. The report concludes that at present these are not serious problems. With increasing technology and population growth, problems associated with inadvertent changes in environment will become even more important in the future.

ACCOMPLISHMENTS OF THE NATIONAL SCIENCE FOUNDATION PROGRAM

In order to put the problems of weather modification in perspective and to see what has been accomplished in the intervening years, it is of interest to compare our present knowledge with that which existed in 1957 at the time of the final report of the Advisory Committee on Weather Control. It should be recognized, however, that the 1957 report is concerned primarily with effects of cloud seeding while we are now considering weather and climate modification from a much broader point of view, including inadvertent effects of man-made activities as well as deliberate attempts to modify the weather.

Relying mainly on analysis of results of commercial seeding operations, the Advisory Committee on Weather Control reached the following conclusions:

(1) The statistical procedures employed indicated that the seeding of winter-type storm clouds in mountainous areas in western United States produced an average increase in precipitation of 10 to 15 per cent from seeded storms with heavy odds that this increase was not the result of natural variations in the amount of rainfall.

(2) In nonmountainous areas, the same statistical procedures did not detect any increase in precipitation that could be attributed to cloud seeding. This does not mean that effects may not have been produced. The greater variability of rainfall patterns in nonmountainous areas made the techniques less sensitive

for picking up small changes which might have occurred there than when applied to the mountainous regions.

(3) No evidence was found in the evaluation of any project which was intended to increase precipitation that cloud seeding had produced a detectable negative effect on precipitation.

(4) Available hail frequency data were completely inadequate for evaluation purposes and no conclusions as to the effectiveness of hail suppression projects could be reached.

Conclusion (1) was later severely criticized as being based on inadequate statistical evidence and lack of adequate controls, but present indications are that it is probably correct. Evidence presented in the NAS Panel report suggests that seeding in some cases may enhance local precipitation even in nonmountainous areas by similar amounts. There is some rather tenuous evidence of a shadow zone of decreased precipitation beyond the area of local enhancement. Thus conclusions (2) and (3) no longer appear to be valid. A current statement concerning the status of hail suppression could not be made much more definite then conclusion (4).

The Advisory Committee on Weather Control report recommended an increase in research in meteorology and related fields; that the National Science Foundation be the agency designated to promote and support such research and to be "a central point for the assembly, evaluation, and dissemination of information and that the development in large numbers of highly qualified research scientists in the field is essential. The report also emphasized basic research leading to a scientific understanding of weather, with the aim in part of putting cloud seeding on a firmer scientific basis. In 1957 there were few professional people working on scientific aspects of weather modification. As a result of subsequent activities and support of the Foundation and other agencies, there are now involved a number of outstanding groups in universities, government, and industry. Among the universities that have groups engaged in research related to cloud physics and weather modification are Arizona, Chicago, Colorado State, New Mexico Institute of Mining, Nevada, New York University, Pennsylvania State, State University of New York, and the

University of Washington. The Program of the Illinois State Water Survey is partially supported by the State. An outline of the programs of various government agencies is given in this report in the chapter on Funding and Administration Requirements. Several industrial organizations such as A. D. Little, Inc. have research programs on various aspects of weather modification. There are of the order of 40 to 50 concerns engaged in commercial seeding operations.

While a great deal has been learned about the physics of clouds and the precipitation process, because of the extreme complexity of the problem there is still far from a scientific understanding of effects of cloud seeding and the dynamics of clouds. A brief review of a few of the major projects sponsored in whole or in part by the Foundation may be in order:

(1) One of the most important is the University of Chicago "Project Whitetop" which has demonstrated the importance of the warm rain coalescence process in many supercooled convective cloud systems which formerly were thought to depend entirely on the Bergeron-Findeisen ice process. A preliminary analysis of a cloud seeding program extending over a five year period at West Plains, Missouri, indicates a region of increased radar precipitation echo extending 30-50 miles downwind of the seeding line followed by a broad region further downwind with decreased precipitation. This precipitation pattern was detected by radar echoes and supported in part by rain gauge data. These data suggest that seeding may produce a growth of clouds along the seeding line which sets up a stationary wave-like perturbation extending downstream. In the region 40-80 miles downstream the air is sinking rather than rising and so is unfavorable for cloud growth. Thus, the shadow zone of decreased precipitation may result indirectly from a dynamical effect rather than from prior rainout of available moisture.

(2) For the past ten years, the Kings River Conservation District has supported a cloud seeding program by Atmospherics, Inc. in the Kings River Drainage area on the Western slopes of the Sierra Nevada Range in California. A grant from the Foundation provided for additional measurements for study of cloud physics and precipitation. Recent analysis of the data indicates an average 6.1% increase in runoff in the drainage area due to

seeding for the period. This supports preliminary results of a research study by Colorado State University in the area of Climax, Colorado, and of other commercial seeding operations, extending over shorter periods of time, that seeding can give a moderate increase in precipitation in orographic situations. An analysis of these and other seeding experiments is included in the NAS Panel report.

(3) Project Stormfury, a joint Weather Bureau-Navy project, with support from the Foundation, is an attempt to modify tropical clouds and perhaps hurricanes by massive seeding. The idea here is to enhance cloud buoyancy and thus later cloud dynamics by release of latent heat of fusion. Conclusive results have not yet been obtained, although there is considerable evidence that clouds can be modified in this way. Howell, in 1960, presented data on effects of seeding of tropical cumuli which indicated enhanced buoyancy and a consequent increase of precipitation. A group at Pennsylvania State University has been investigating the possibility of providing positive buoyancy to clouds in the lee wave of mountain systems by seeding.

(4) A great deal has been learned from laboratory studies about the nucleation process with AgI as well as with other materials; however, much remains to be done in correlating such laboratory work with effects produced by various practical seeding methods.

(5) Considerable progress has been made in studies of clearing of supercooled stratus and fog by seeding. The problem of dissipation of supercooled fog over airports is now largely one of design of suitable seeding devices. It has been suggested that because of their stability and consequent reproducibility of results, supercooled stratus clouds could be used for testing of seeding agents.

(6) Studies are being made of electric fields in clouds, their possible influence on the precipitation mechanism and of methods for changing the electric field patterns as a possible technique for modification of clouds.

Much of the activity since 1957, and particularly that under Foundation sponsorship has been aimed at basic scientific understanding. In complex problems this is a sound if often slow, way of arriving at practical goals. With a sufficiently thorough understanding one should be able to estimate both the possibilities and limitations of various techniques. At the other extreme are the purely empirical methods of trying various procedures and observing the overall results without worrying too much about the detailed mechanisms of how and why they occur. In cases where there is a great deal of natural variability, one must rely on sound statistical methods with adequate controls. Unfortunately many of the empirical studies of the past for one reason or another did not yield conclusive results. The empirical and basic approaches are both valuable and complement one another. Empirical discoveries may stimulate basic research and lead to new understanding. Scientific understanding, even though far from complete, may suggest new or modified empirical approaches.

The problems involved in statistical design of experiments are discussed in this report in the chapter on Statistical Aspects of Weather Modification.

ACTIVITIES IN FOREIGN COUNTRIES

The achievement in artificial nucleation by Schaefer, Langmuir and Vonnegut in 1946-47 had repercussions throughout the world. Within a few years weather modification activities had been initiated in a number of countries. In its Third Annual Report on Weather Modification for FY 1961 the National Science Foundation gave data on work underway in sixteen countries.[1] More than 100 research stations outside of the United States were reported as being engaged in weather modification work. As in the United States, a major emphasis in most foreign countries has been placed upon cloud seeding or other efforts at rainmaking. Considerable attention in some countries has been given to fog dissipation and hail suppression, while significant basic scientific research programs have been undertaken in several lands.

Australia, faced with growing demands for water, both for agriculture and hydroelectric power, has undertaken significant programs of basic research in cloud physics as well as large scale field experiments in cloud seeding. A variety of cloud-seeding experiments has been carried out in Canada by both government and private agencies since 1948. France has established a broad program of scientific research coupled with practical experiments. Ten different organizations are engaged in French weather modification programs; in addition to fundamental research, special interest has been displayed in hail prevention and fog dispersal. Laboratory research has been featured in Germany, where weather modification activities were late in getting underway. Interest in Great Britain has also been directed almost exclusively at basic research in cloud physics, cloud dynamics and atmospheric electricity.

A special concern with the practical problem of hail suppression has characterized the weather modification work in Switzerland. The Federal Commission for Studying Hail Formation and Hail Prevention, established in 1950, operates three laboratories which have contributed significant knowledge to the understanding of hail formation and have carried out a variety of experiments in cloud seeding as a means of prevention. Similar concern with urgent national problems has been noted in the development of weather modification work in Israel, where water supplies are of paramount importance to the economy; a broad program of research and field experimentation has been directed at the investigation of the natural processes of rain formation and their possible manipulation by artificial means. An active program of both basic research and empirical studies of cloud seeding has been pursued in Japan. Some success has been reported in seeding programs. In 1964 an International Conference on Cloud Physics was held in Japan.

Of particular importance in the work going on in foreign countries is that being carried forward in the Soviet Union. Faced with a number of serious problems created by a hostile natural environment affecting the economic welfare of the country, the Soviet Union has shown an active and intensive interest in the subjects of weather and climate modification. The delegation of the U. S. Weather Bureau which visited the Soviet Union in May, 1964, returning a similar visit to the United States by Soviet scientists earlier that year, was particularly impressed by the broad scope of the Soviet program and the large resources of manpower and funds that were being concentrated on weather modification and related activities. Although actual work is undertaken in a number of institutes located in various parts of the Soviet Union, and includes activities in both the Arctic and Antarctic, the Soviet activities appear to be well integrated into a national program and guided towards the achievement of objectives directly related to the economic and social needs of the country.

Among the Soviet Union's theoretical studies, emphasis has been placed upon research in cloud physics at numerous centers, as well as upon theoretical evaluations of the possibilities of climate modification. Indicative of the broad dimensions and imaginative character of Soviet thinking have been speculative suggestions of climate modification by erection of major hydraulic structures which would alter ocean currents, artificially inducing changes in snow cover, producing changes in cloud cover by seeding, and altering the surface to induce lifting or subsidence of air. One of the most spectacular is the suggestion of damming the Bearing Straits.

Field experiments have concentrated upon three areas of common concern to many other countries: dissipation of fog and low stratus clouds, particularly over airports; suppression of hail; and rainmaking. While statistical tests have generally not been undertaken, many Soviet scientists are convinced the empirical evidence is sufficient to support their claims of success. Such claims include statements that the dissipation of supercooled fog and low stratus over airports has now become operational; that cloud seeding can increase precipitation from frontal clouds by around ten per cent; and that the possibility has been demonstrated of greatly decreasing the formation of large, damaging hail. Considerable benefit has apparently been derived by Soviet scientists from work done in the United States and other countries as a result of the thorough and extensive program of review and translation of scientific literature—an aspect of research some American scientists believe could well be expanded in this country.

The resume given above of some of the major weather modification activities in foreign countries is by no means a complete inventory. Other work is being initiated and carried forward in several other countries. The wide distribution of activity in this field throughout the world is in one sense a reflection of the essentially international character of science. It is also an indication of the growing realization by scientists, and by governments, that the possibility of weather and climate modification may have profound repercussions upon the future economic and social welfare of their countries.

PERSPECTIVES FOR RESEARCH

It is recognized that several interrelated branches of earth science must be developed as a foundation for the technology of environmental control. These include study of the mechanisms and energy balances involved in the hydrologic cycle, development of further understanding of the dynamics of climate through atmospheric modeling and computational experiments including weather prediction, broadening both field and laboratory research in cloud physics and dynamics, and a thorough examination of the non-atmospheric mechanisms, such as modification of the surface characteristics of the land and sea, which might conceivably alter weather or climate. Each of these will be discussed in turn.

Hydrologic Cycle

The words Weather Modification have come, through usage, to mean the conscious intervention by man in the precipitation process; either its augmentation or reduction and ultimately its control. In this view attention is centered on the atmosphere. But weather is only a link in the *hydrologic cycle* in which water, through various energy exchanges, is distilled from the oceans or transpired from the ground water table into the atmosphere, is stored in the atmosphere for a time, and eventually returned to earth in another place.

In principle, effective practice of weather and climate modification may consist of activities which produce alterations at any point in the hydrologic cycle that could conceivably lead to control of persistent or momentary extremes. Since the global water cycle is a closed but multiply-connected loop (much like the cardiovascular system) the consequences or effectiveness of intervention may either be "healed" by self-regulatory processes which give the hydrological system its stability, or lead to systematic change.

The problem of weather and climate modification, then, requires sufficiently detailed understanding of the energy transformations of the hydrologic cycle to know *where, how, when,* and with *what intensity* man's intervention in the natural system may produce significant alterations. Effective pursuit of this understanding will require the concerted knowledge and skills of geologists, hydrologists, oceanographers, meteorologists, engineers, and the close support of those versed in applied physics, mathematics, ecology, and chemistry. As yet this breadth of enterprise has neither been reached nor contemplated.

In the present state of knowledge atmospheric intervention seems to offer a promising point at which to exert an influence upon the hydrologic cycle in the interests of mankind. However, as knowledge is advanced in other areas of the earth sciences, particularly in oceanography, it is possible that other and perhaps even more promising alternatives may come to light.

Dynamics of Climate

In the various aspects of the weather modification problem thought has been centered around the issues of water resources particularly in those areas where there is a shortage of supply. This is a natural concern because it is one ultimate goal of the weather and climate modification concept to regulate, if not increase, the availability of potable water for the uses of mankind. In consideration of this goal, it is necessary to think not of times and localities where the need for water is most sorely felt, but of the dynamics of climate over the whole earth in which the dry areas have context.

Since precipitation in the free air is associated with the rise and adiabatic cooling of moist air, the processes to be encouraged must be those which will induce rising motion, especially of maritime air over regions presently deficient in rainfall. Rising air occurs in three principal situations: in cumulus convection (micro to macro scale), in orographic lifting (meso to macro scale) and in frontal lifting (macro scale). Once initiated, lifting may be encouraged by energy releases associated with phase changes in the water burden of the atmosphere. Lifting may also be encouraged by physical or thermal topographic influences on the earth's surface.

In regions where an excess of precipitation exists it might also be desirable to suppress rising motions of air. The mechanisms governing sinking motions are not yet clear and must be understood before regional weather modification can be contemplated.

Rising and sinking motions in the general circulation of the atmosphere tend to be arranged in zonal patterns, hence climates of the earth also tend to be developed in zones. The nonzonal irregularities in the arrangement of climatic belts on the earth are found in the transition regions between land and sea, because heating air flow is predominantly zonal while the distribution of land is more nearly meridional.

In the atmosphere, as it is now constituted, there are belts of rising and sinking air the emerge with statistical significance. In the intertropical convergence near the geographic equator rising motions occur and cumulus convection is the principal mechanism for the release of precipitation. In the subtropical zones near 30° latitude, the desert belt in each hemisphere, sinking predominates and there is a consequent excess of evaporation over precipitation owing to the adiabatic heating of the descending air. In high middle latitudes frontal lifting is the predominant mechanism promoting the development of stratiform clouds from which precipitation may occur. Local anomalies in this general pattern are developed by orographic influences and surface effects. Effective weather regulation would rearrange the geographic limits within which these statistically predominant zonal configurations of rainfall and evaporation now occur.

A problem of this magnitude requires study of the susceptibility of the atmosphere to change by systematic influences. It is already well known that the atmosphere responds as a whole to disturbances within any part of it. It is also known that the atmosphere exhibits a kind of statistical stability. If it did not, the subject of climatology could not be pursued. One has, therefore, to learn through an intensive series of computer simulation experiments and quantitative laboratory investigations with rotating models *where, how forcefully* and *how often* the atmosphere must be disturbed to change the statistics of climatology. The question at this point should be addressed to a study of changes of all kinds. Once the effects and energy requirements for intervention are known from laboratory and numerical studies, it would then be possible to select certain changes as a basis for field experimentation. It would also be known how massive such undertakings in the field might have to be to produce effects that emerge clearly above the normal levels of atmospheric variability.

*One would hope that model experiments will divulge the type of instabilities that can be seized upon to swing a climate regime in a particular direction. If it becomes evident that the atmosphere only marginally sustains a particular phenomenon; for example, if it appears that hurricanes are not an essential element of the general circulation, then perhaps one can accomplish the corresponding heat flux entirely by a related phenomenon which is more prevalent, i.e. weakly organized convection. Speculating on a much larger time scale: is the occurrence of an ice age or the formation of a large desert an inexorable necessity or are they the consequence of weak but systematic interactions which may easily be disrupted once we learn what the critically participating processes are?**

A program of this kind is bound to involve a considerable expansion of effort and facilities. For example, the computational effort required is roughly two orders of magnitude greater than that possible with the largest machine now in existence. The suitable equipment for laboratory research in rotating models might also cause an expansion of effort by a factor of two or three over the present level. Still, the hope would be that this kind of undertaking could be accomplished with only moderately increased resources of manpower, through student training and the attraction of foreign scientists into this sphere of activity. Since the atmospheric, oceanographic and geologic properties of the whole earth are to be considered, there would be a natural basis for international cooperation.

---

* Smagorinsky, J. 1964 statement at the National Science Foundation Interagency Conference on Weather Modification, Washington, D. C., 5-6 November 1965.

Prediction

Useful as control might be in weather management, prediction can serve an almost equally valuable social and economic function. Accurate prediction is possible only when there is virtually complete physical understanding of the processes interacting to produce change. Prediction also requires a very complete description of initial conditions; which is to say it will soon be necessary to establish a global network of observatories across the land and sea areas of the whole earth to fill out the significance of satellite reports. Steps toward this end are already being taken in connection with the World Weather Watch, but consideration of the corresponding networks needed to determine the fluxes of heat, mass and momentum within the oceans and between the oceans and atmosphere is not yet so far advanced. The related technological problems of sensing, telemetry and maintenance of field equipment in a global network have not even been defined. However, were surface and upper air observations to be available on a global basis the means for their analysis are even now becoming well established. And with their continued development, computers may be expected to have reached the necessary levels of storage capacity and speed within a decade. Having this much so close at hand *it would seem appropriate that the scientific and engineering aspects of a global observation network be given immediate attention.*

Cloud Physics and Dynamics

The problem of weather and climate modification is basically centered on finding procedures by which man may intervene with relatively low expenditures of power to achieve detectable alterations of the atmospheric regimen, and of coupling that power to the atmosphere in efficient ways. In present cloud seeding practices a point or line source of material is diffused into a significantly large volume of air by atmospheric turbulence. The disturbance produced in the air feeds on the energy of phase changes in the water substance in the atmosphere, and with consequent conversions of latent to sensible heat, presumably alters the buoyancy of air parcels to excite or amplify vertical motion and the further exchange of sensible and latent heat until the point of detectable returns has been passed.

Some recent experiments suggest that beyond the site where precipitation is excited by silver iodide nucleation there is a "rain shadow" which in itself suggests that wave-like effects are involved. This finding may have revealed a useful principle.

It is a relatively common observation that there are many kinds of quasi-periodic wave motions in the atmosphere. Cloud streets are often seen, lenticular clouds stand in trains in the lee of mountains, long cumulus trains develop downwind of ocean islands, cyclonic storms develop in families along fronts, and fronts themselves have conspicuously wave-like characteristics.

As a beginning it would seem desirable that cloud seeding experiments be extended to include study of the plume of dynamical consequences downwind, with an eye to the possibility that resonances might be excited if the phase of successive interventions were correctly placed in space and time, and conversely that damping could be managed if the points of excitation were deliberately placed out of phase. In this way the effects of intervention might be amplified enough to be detectable beyond the present screen of statistics, and at the same time, means developed to control the area of influence.

In parallel with this thought, there is, as yet, very little understanding of the natural processes by which water vapor condenses to form cloud droplets, of how such droplets coalesce to form precipitable entities, or how the additions of seeding nuclei alter the natural process. We suggest that along with that necessary study it may be well to acknowledge that the earth supports a pronounced electric potential gradient which is changed in certain storm conditions. Since it is well known that the coalescence of spraying jets is markedly influenced by the presence of an electric field far weaker than many of these, it seems only reasonable to encourage deeper study of electrical relationships in the atmosphere. Causality is not the question, but rather the interdependence or coexistence of electric fields and coalescence phenomena that needs examination, with the prospect that through deliberate atmospheric electrification some control of the coalescence process may be exercised.

The field of cloud physics and dynamics must be developed far beyond its present state if weather and climate modification is to become a matter of practical concern. The questions of droplet formation and growth of precipitable elements in the dynamics of clouds need examination on a broader base than the present level of effort or varieties of research can supply. Achievement of this state of understanding will require the best efforts of those versed in surface physics and chemistry in addition to physical and dynamical meterology and possibly also in acoustics, electrostatics and dynamics, and high energy optics. As funding is increased for weather and climate modification early priorities of expenditure should be accorded the development of cloud physics and dynamics as a necessary basis for sound technology.

Non-Atmospheric Intervention

The atmosphere is underlain by solid earth and broad expanses of sea water and responds to their influences. The effects on the atmosphere of seasonally differential heating and cooling of the solid earth and oceans produce monsoonal winds and rains on all subtropical continents, govern the curvatures of the polar fronts and the courses of both tropical and extratropical cyclones. The oceans provide the atmosphere with most of its moisture, and because of their large thermal inertia tend to hold fast the maritime centers of high and low surface pressure, and thus fix the patterns of world climate.

The natural scale of oceanic features is large indeed, but through liquid-filled rotating models many of their physical aspects can be studied in the laboratory and the effects of deliberate modifications assessed. For example, the consequences to the ocean circulation to be expected if the planetary wind field were to be altered or the effects of barriers placed across narrow gaps (such as the Bering, Florida, or Gibraltar Straits) can be examined in rotating models. Similar studies can be made for the land, such as the utter removal of all mountains from the earth or adding the topography of past continental glaciers, but perhaps better in these cases with numerical models. Both of these investigative techniques have been brought to useful levels of refinement in the past two decades.

Granting a present capability to make reasonable estimates of the physical consequences of large scale alterations of the land and sea, the difficult part of the question of non-atmospheric intervention in climate and weather is shifted to that of field methods, power requirements and controls; and of the sites for possibly desirable surface alterations. In this connection the ocean offers some especially interesting possibilities.

It is now well established that the ocean is characteristically in a state of stable density stratification. While density increases with depth; in the tropics and subtropics the surface water tends to be warm and salt while the subsurface layers grow colder and somewhat fresher with depth. The transition zone between these two principal water types is the main thermocline which is found at a depth of about one-hundred meters in the tropics and some several hundred meters in middle latitudes. Thus to cool the surface of the ocean it is necessary only to bring the cold water below the main thermocline upward through the relatively short distance to the surface.

This might be done with some efficiency by infusing the cold layers with a curtain of small bubbles. If the entrained water is lifted isothermally it will tend to sink again; but if the process is quasi-diabatic a mixture of cool, somewhat fresher water can be made to remain on the surface and to move off with the surface current.

The effect on the atmosphere of such alterations of the surface temperature of even great torrents like the Gulf Stream or Kuroshio might be small at first because, though swift, these currents are very narrow. Still, in time, the wind-driven Ekman transport would carry the modified surface layer seaward and generalize the influence of surface cooling.

In Arctic waters bubble sheets have been proposed to keep navigable waters clear of ice. But in low and middle latitudes surface warming is more difficult to contrive. For the North Atlantic there is a possible procedure in the fenestration of the Panamanian Isthmus.

These influences depend on the thermal stability of the oceans. But the salt burden of the ocean is unstably stratified. The warmth of the surface water permits the uppermost layers to be saltier than those at depth. In consequence a parcel of warm, salt surface water carried downward and allowed to lose heat to its surroundings, will continue to lose buoyancy and sink. Conversely, a parcel of cold, relatively fresh deep water once started upward, will continue to gain buoyancy and rise. Such parcels cannot be large, because of the heat transfer requirements, but there is nothing, in theory, to prevent them from being so numerous that their net affect on vertical mixing might be of geophysical significance.

Finally it may be worth recalling that the surface of the ocean receives more than two-thirds of the world's supply of precipitation and dew, and is the ultimate reservoir of not only river discharges but glacial melt water. All of this water is fresh but presently irrecoverable. Still more fresh water substance lies bound as ice. Ice is recoverable. Should the need grow so desperate or economical means of transportation be devised, ice and its melt water provide an as yet unexploited resource.

CONCLUSIONS AND RECOMMENDATIONS

The Commission concludes that sound progress toward the technology of weather and climate modification must be based on four fundamental pursuits:

(a) assessment and development of an understanding of natural climatic change.

(b) assesment of the extent and development of the understanding of inadvertent modifications of weather and climate.

(c) improvement of the process of weather prediction as a social benefit and as proof of scientific understanding of atmospheric behavior, and

(d) development of means for deliberate intervention in atmospheric processes for weather and climate control and evaluation of their consequences.

As steps toward these attainments the Commission recommends that the following enterprises be fostered:

(1) Examination of the routes, rates and reservoirs of water substance and energy exchanges in all aspects of the hydrologic cycle.

(2) Investigation by numerical laboratory and field experiments of

the dynamics of climate as a basic study for weather modification technology.

(3) Advancement of weather prediction as a proof of understanding, including support of this effort by the establishment of a global weather observation network.

(4) Broadening of the knowledge of cloud physics and dynamics in the laboratory and field, with attention to wave phenomena and an evaluation of electrical influences.

(5) Study of the effects of large scale surface modification by numerical and laboratory models of the oceanic and atmospheric general circulation, and of practical means for surface modification of the land and sea.

(6) Study of the radiative effects of changes in the atmospheric composition and alteration of its transparency that urban growth and new forms of industry, transportation or land use may evoke.

BIOLOGICAL ASPECTS OF WEATHER MODIFICATION

INTRODUCTION

Man is an organism directly dependent on other organisms for many of his materials. He also struggles with other organisms, most of them quite small, that prey upon him, eat his food, or otherwise challenge his existence. Anything that has a general and significant effect upon plants and animals, making some more abundant, others less so, is of primary concern to mankind, for it strikes at the very basis of human existence. Changes in weather and climate may be expected to have such effects. It follows that any program of weather modification must give serious attention to adverse as well as beneficial biological aspects.

As Lynton Caldwell observed in the *Yale Review,* "Biopolitics: Science, Ethics and Public Policy," Vol. LIV: 1-16, 1964, biologists are with increasing frequency finding themselves at variance with other segments of society on matters of public policy. Examples range from questions concerning how much radioactive or pesticidal materials should be permitted loose in the environment to the relative merits of trying to preserve from extinction a natural species population. Contrary to J. P. Miller's whimsey biologists cannot limit themselves to "proving that what must be done for political reasons is biologically safe for the human race."

MEANS OF PREDICTING CONSEQUENCES OF WEATHER MODIFICATION

It must be recognized that the present state of knowledge places uncomfortable limits on the prediction of the biological consequences of modifying the weather. Several lines of investigation can be used, however, to provide information.

The Study Committee of the Ecological Society of America was asked by the National Science Foundation to undertake a study of the present status of knowledge of effects of weather and climate on plants and animals and to recommend the type of biological program that should be associated with research in weather modification. The study was made by an *Ad Hoc* Weather Working Group, chaired by Daniel A. Livingstone, Duke University, and is reported in a paper entitled "Biological Aspects of Weather Modification," to be published in the March, 1966 issue of the *Bulletin of the Ecological Society of America*. See the Appendix.

These will be discussed, indicating the special advantages and deficiencies of each avenue of study.

Laboratory Studies

A single organism or a small number of the same species can be subjected to controlled experimental conditions in the laboratory, and the response to various elements of climate, such as temperature, moisture and light, systematically investigated. This basically straightforward approach is not without complications. If, for example, one seeks to investigate the effect of temperature upon the growth of a plant species, it is not sufficient to measure the plant's growth at a variety of constant temperatures. Some plants are more influenced by the daytime temperature, some by the night temperature, while others thrive best under conditions that are specified by the difference between day and night temperature. The responses to light are similarly complicated. For reasons such as these, the experimental approach has been applied to a very small fraction of the known species of plants and animals, and there are only a handful, such as man, the speckled trout, the loblolly pine, and a number of crop plants, that have been investigated at all exhaustively.

This laboratory approach has several deficiencies as a means for predicting the field results of weather modification. The response to weather may be very different for organisms of the same species collected in different parts of its range. Because of genetic changes, an organism taken directly from the field and grown under controlled environmental conditions in the laboratory may react differently from one which is the result of several generations of genetic selection pressure in a large population growing under similar conditions. The most serious deficiency of this approach is that it treats species in isolation. In nature, very few organisms are limited in range by direct climatic conditions that exceed their physiological limits, but rather by competition with other species that are better able to cope with the prevailing conditions. Such considerations limit the applicability of results obtained in the laboratory for predicting results of weather modification in the field.

Records Of Annual Variation

The results of year-to-year variations in the natural weather on biological phenomena can be used as a basis for predicting the results of similar perturbations produced by man. This method is suitable for predicting the effects of short-term weather modifications that are similar in nature and extend to natural climatic fluctuations. With these limitations, it can be used to predict the offsets of weather modification upon a few well-studied crop plants of great economic importance, and a few well-studied insect or microscopic pests.

Biogeographical and Paleoecological Records

Biogeography furnishes another useful source of information about the relation of organisms to climatic factors. Correlations between the distribution of organisms and climatic conditions suggest that climate has a primary role in determining these distributions. The predictions that can be made from biogeographical data are safest when they are most general. A change from grassland to savanna under increased rainfall can be predicted much more securely than the species composition of the savanna or the exact amount of rainfall increase that would be required to effect the change.

Study of the fossil record has also provided a wealth of information about the biological effects of a particular set of climatic changes, those ticular set of climatic changes, those associated with glacial and interglacial conditions, and a substantial body changes in the more remote proglacial periods. Use of these data is hampered by lack of independent information about the actual physical changes in climate that were involved, so that much investigation of these changes consists of an attempt to infer climatic changes from the biological evidence, rather than determining the way in which organisms have been influenced by climate. Nevertheless, the fossil record gives the only available information about the biological results of a major climatic change on a global scale, and for this reason it is particularly valuable.

Monitoring of Selected Communities

Experimental plans for weather modification should insure a maximum yield of biological data on the nature of effects. This requires both the establishment of comparable control areas outside the areas of modification and pre-modification monitoring of sample areas in both the control and modified areas. Natural communities would be selected for study in an area in which weather is to be modified and permanent experimental plots established in them. Well before weather modification, the biota on these plots should be inventoried in detail and mapped or photographed. Such studies should precede modification by a long enough period to collect data on the normal fluctuations of the communities and populations. The plots would be re-studied during and after periods of weather modification to determine what species expanded their populations and what species lost ground; what species disappeared from the community and what new species entered. Since proper evaluations will require confidence limits for any statements concerning effects, the sample areas must be well replicated. Monitoring experiments will be difficult to set up. It is patently impossible to study every species in a rigorous way, and it is quite possible that randomly selected species will turn out not to be those most useful for the study. Some guiding principles might include a mixture of the following attacks: 1. A well-replicated series of reasonably detailed examinations of selected natural biological arrays at transition areas joining biological communities which are apt to show changes with the predicted shifts. 2. Examination of a range of agricultural and other artificial ecosystems for changes in disease, pests, yields, harvest dates, etc. 3. Studies of relative changes in population sizes, reproductive success, etc., of a selection of more easily studied organisms within blocks of homogeneous natural communities away from transition areas. Reasonable controls are essential; hence, in order to be effective, monitoring must be done outside these areas in comparable sites.

Computer Simulation Studies

Computer simulation studies provide a method for predicting biological effects of weather modification. Two quite different approaches to computer studies are available. A model that approximates reality very closely cannot be made at present for any given area because of the lack of data. Hence, computer experimentation may need to be postponed for 5 to 10 years until the requisite data on the location in question are available. An alternative is to proceed immediately to construction of a simulation model, using data on the same, or related organisms from places other than the proposed site for the weather modification experiment. In so doing the following question must be asked: "How would an ecosystem similar to that which presently exists at the site for the weather modification experiment be altered if one modified typical sequences of weather data within ranges of values known to be realistic?" In general, the type of thing to determine with simulation studies is whether certain combinations of strategies or strategies used singly, show certain broad features that are relatively invariant even when independent variables are run through a wide range of values on the computer. Also, it is desirable to see if certain strategies are grossly uneconomical if applied under certain circumstances.

The logic of the simulation approach is bolstered by studies on such insect pests as the spruce bud worm. Through the longterm concerted effort of large teams of investigators, it has been possible to construct models sufficiently close to reality to have practical use in predicting outbreaks and in choosing control strategies. Outbreaks of plant diseases are probably also capable of being studied with the same methods.

The principal motivation for computer simulation is cost. It is enormously cheaper to run experiments on the computer than to try out a great variety of weather modification experiments in nature and observe the results. Both the cost of the experiment and the losses due to the experiment by using simulation as a supplement to an actual experimental program are saved. The basic structure of the computer simulation program will be a set of functional relationships which mimic the dynamic properties of all relationships between and within soils, plants, animals, site factors and weather, with respect to changes both in variables through time and in dispersal of entities through space with the passage of time.

PREDICTED BIOLOGICAL RESPONSES OF WEATHER MODIFICATION

An ecological system consisting of agricultural fields is well enough understood that effects of specified weather and climate modifications can be predicted with some assurance. In a more complex system consisting of many more species of interacting plants and animals, the complexity is so great that it is not possible to make detailed quantitative predictions. However, certain general effects can be outlined. In illustrating this, consider temperature changes up to several degrees Fahrenheit and rainfall changes, principally increases, of some tens of percent of the present annual average on reasonably well-watered lands.

General Effects

Paleoecological studies in many of the climatic regions of the earth indicate that temperature modification corresponding to an annual average difference of 3° to 4°F. brings noticeable alterations in population levels of many resident plants and animals and the appearance and disappearance of some other species. In many cases, however, the broad kind of vegetation, such as hardwood forest or grassland, still remains. A change in temperature of twice this magnitude brings replacement of many species by others, wide changes in population levels of species present at both extremes, and in many cases replacement of one major kind of community by another.

From long-term studies of the American prairie, it may be predicted that the direct effect of moderate changes in rainfall on the biological communities as a whole may be expected to be relatively slight, mostly involving shifts in sites occupied by species. The changes will probably be slow unless large areas become defoliated or killed through the anticipated increase in certain pests or the community is otherwise seriously disturbed. However, changes in rainfall or temperature which are of sufficient magnitude to have general usefulness seem likely to be of sufficent magnitude to produce substantial disturbances in natural communities.

Most studies showing correlations between weather conditions and changes in the abundance of one or more species of organisms have also brought out the fact that it is the weather during a few critical months that is important, rather than the average conditions over the years. Thus, for many species, a minor increase in the average annual precipitation could mean either enormous increases or great mortality, provided that the extra rain fell during a period that was critical for survival or reproductive success.

Increase in Crop Productivity

It seems quite clear that an increase in rainfall would result in an increase in production of cultivated crops over a large part of the earth. Even a reduction in variance in rainfall, or the ability to control its seasonal distribution, would lead to an increase in productivity if all other conditions remained the same, because the increased reliability of the return would permit more efficient farming operations.

Species Extinction and Disruption of Natural Communities

With the growth of human population and its spread over the land in the United States, native species are increasingly confined to small sanctuaries—parks, wildlife refuges, and mountain ranges. These are islands surrounded by oceans of land intensively occupied by man, and it is not generally possible for wild species to migrate across the rural and suburban oceans from one island to another, to survive climatic change. If climate is so changed that a species is no longer able to survive in a given natural area, that species cannot migrate but must become extinct there. Extinction of species implies reduction in species-diversity, the richness of natural communities in numbers of species. Reduced species-diversity and shifts in population distributions resulting from weather and climate modification would combine to reduce the stability of natural communities.

There are differences of opinion among biologists about the extent to which a particular modification would affect the stability of natural communities. Most would expect an appreciable disturbance to result from a modification great enough to be useful economically. Some species would become more vulnerable to outbreaks of pests and some natural preserves would become less aesthetically attractive and less valuable for research purposes. The economic consequences would be felt in communities that are used for grazing or lumbering.

It is likely that the changes produced by weather and climate modification in insular remnants of natural communities will be consistently unfavorable ones. Immigration of the normal respondent species is subject to interference. In more continuous areas the shifts would result in more temporary but not necessarily inconsequential instability.

Probable Increase in Crop Pests

For insect pests, there exist numerous studies indicating relationships between abundance and weather conditions. The number of cases is sufficiently impressive to permit the conclusion that changes in weather from year to year do lead to changes in the abundance of certain species, and in some instances lead to changes in their distributions. It seems probable that many, if not all, of these species will be highly destructive to agricultural enterprises or to the natural vegetation, or to both. Unfortunately, too little is known of the mechanisms of population control of most species for us to be able to predict which species will become serious pests under altered weather conditions. It is also true that some likely changes in weather would result in abnormally low populations of other species. Well known examples of species for which high rainfall is deleterious are the chinch bug, *Blissus leucoptorus*, and the pale western cutworm, *Porosogrotis orthogonia*. It is likely, however, that weather modification will lead to large agricultural losses due to the increases induced in populations of some terrestrial pest species, and that these losses will not be compensated by perhaps equally frequent reductions in the populations of other species.

Probable Increase in Disease Vectors

One class of organisms, the ones that are borne by arthropod vectors and cause serious diseases in man and his domestic animals, are deserving of special attention. Although there is some reason to believe that other diseases may be influenced by weather conditions as well, it is clearly established that many of those with arthropod intermediate hosts are dependent upon weather conditions. One can predict that weather modification would produce a shift in the pattern of vector-borne diseases. In any plan to modify the weather, disease must be given very serious consideration, for it may be of greater economic importance than the circumstances which stimulated interest in weather modification.

The outbreak of many insect pests seems to be triggered by a rather unusual meteorological situation in one restricted part of the range. The population builds up first in that local center and spreads out in all directions in the form of a wave. This pattern is similar to that of many human diseases, some of them carried by arthropod vectors, such as bubonic plague. It is not believed that an epidemic of plague would necessarily result from weather modifications, but the possibility exists that there might be some sort of weather modification which would cause it to occur. There is a substantial reservoir of sylvatic plague in the United States.

Many bacterial and fungal diseases of crops are also known to be highly responsive to weather. Increased rainfall, more summer humidity, warmer or cooler temperatures would all have effects on plant pathogens. Not enough is known to predict the significance of the almost certain changes.

Effect of Possible Rain-Shadows

While an increase in precipitation has predictable results among which both favorable and unfavorable effects can be expected, and which might offset each other to some extent, a concomitant decrease in precipitation in another area has no beneficial effects to offset the obvious damage.

CONCLUSIONS AND RECOMMENDATIONS OF THE ECOLOGICAL SOCIETY WORKING GROUP

1. Living things are adapted to the weather that actually prevails, and any change in that weather will be generally deleterious to them.

2. The largest credit item for weather modification is likely to be an increase in primary production of the drier parts of the land surface through improvements in rainfall. Even the ability to control seasonal distribution of rainfall would lead to more efficient farming operations. Realization of the potential increase in production would depend upon being able to modify the rainfall without major pest outbreaks and extinction and disruption of natural communities. It is not certain that this would be possible.

3. The largest weather modification debit item is likely to spring from the decreased stability of communities, which would manifest itself in an increase in pests, weeds, and pathogens. The identity of the species involved in these disruptions cannot be predicted, nor can their cost.

4. For the present, weather and climate modification should be restricted to local small-scale operations.

5. Larger scale operations, such as an attempt to increase the rainfall of any substantial part of this country, should not be undertaken, from a biological point of view, in the present state of knowledge.

6. All weather modification experiments of a scale large enough to have important biological consequences, such as those currently envisioned for the Upper Colorado Basin, should be preceded and accompanied by careful ecological monitoring and computer simulation studies. Manipulating the weather to obtain a net benefit will demand much better understanding of the interactions of weather, climate and organisms than now available.

7. Adequate understanding of the interrelationship of weather, climate and ecology will demand a very expensive long-term research program. Present resources of ecologically-trained investigators are inadequate to cope with these problems.

The Working Group of the Ecological Society of America, which provided background material for the Commission, was concerned primarily with modifications of weather systems ranging from a single cloud to an extratropical cyclonic storm. The Working Group stated that short-term modifications of weather of a magnitude similar to the fluctuations in nature are least likely to have dangerous unforeseen consequences. If undesirable results appear, the modifications can be discontinued. Repeated operations on the scale mentioned are likely, however, to have far reaching biological consequences as pointed out in the previous sections, and some of the biological changes would not be reversible. This advisory group recommended that repeated and long term modifications of weather not be attempted without prior careful and well planned monitoring or computer simulation studies of the biological consequences of particular kinds of weather modification.

STATISTICAL ASPECTS OF WEATHER MODIFICATION

THE PRESENT SITUATION

Problems of statistical methodology arise when there is a controversy as to interpretation of data already accumulated or as to ways of going about acquiring additional information. That such controversy should arise in connection with weather modification experiments is hardly surprising.

Almost twenty years after the original experiments in cloud seeding, conclusive evidence acceptable to the scientific community as to ground precipitation effects of cloud seeding is still lacking. The basic issue of the effectiveness of seeding non-orographic cumulus clouds has been subject to sharp changes of opinion and to conflicting evaluation in recent months. In the absence of conclusive guidance from scientific experimental data, the National Academy of Sciences Panel on Weather and Climate Modification embarked on an intensive statistical study of data from commercial projects. This analysis concluded with the impressively positive findings on the efficacy of cloud seeding—a position supported in general by the available scientific data. This analysis, however, has not completely dispelled the skepticism concerning evidence obtained as a by-product of operational activities. The question is not *whether* to use statistical but *how* to use it in the early design and subsequent analysis of experiments.

THE CONFERENCES ON STATISTICAL METHODOLOGY

The National Science Foundation sponsored three conferences for the

---

This chapter draws upon materials assembled by Prof. Byron W. Brown, Jr. of the University of Minnesota as a result of three conferences held under the auspices of a National Science Foundation grant. These conferences brought together scientists actively engaged in weather modification research and statisticians experienced in the planning of scientific experiments. Also, acknowledgement is made to unpublished memoranda and letters by Dr. Julien Bigelow (Institute for Advanced Study), Professor William Kruskal (The University of Chicago), Dr. Theodore Harris (Rand Corporation), Professor Jerzy Neyman and Dr. Elizabeth Scott (University of California, Berkeley), Mr. Glenn Brier and Dr. Joanne Simpson (USWB) and many other statisticians and scientists who participated in these conferences. The list of participants in these conferences appears as Footnote 1 to this chapter.

purpose of bringing together statisticians and scientists interested in the statistical aspects of weather modification experiments. The first conference, in January, 1965, brought together scientists participating in many field experiments throughout the country. These scientists briefly reviewed these programs and plans, with special reference to the statistical problems that have been encountered. The statisticians present had an opportunity to comment on these brief reviews and on their own experiences in this area.

The second conference, in April, 1965, focused on Project Stormfury. The project director and the statistical consultants for this project presented the results of past work, the criticism of this work, and the plans for the summer of 1965. The statisticians and weather modification scientists used this project as the point of departure for discussion of general questions of design and evaluation of experiments.

At the third conference, in June, 1965, scientists in the Bureau of Reclamation, and in projects sponsored by the Bureau, reported on a number of Bureau projects and related work. Again there was an opportunity for other scientists and statisticians attending the meeting to ask questions, comment on the presentations, and be questioned in turn.

CONFERENCE FINDINGS

A number of results have come from these conferences.

1. Field experiments are a necessary part of a research program on weather modification by cloud seeding. Laboratory experiments of the scope and refinement necessary to predict field results are not economically feasible and, further, the theory necessary for laboratory simulation of the mechanisms of free air precipitation has not been developed. Practical effects must be estimated in the field.

2. The number of variables involved and the lack of knowledge about the details of atmospheric processes make weather modification field experiments difficult to plan and evaluate. Careful use of the best techniques in scientific methodology is required. This entails the cooperation of scientists who can frame the hypotheses and specify some of the important variables, statisticians who can suggest ways of using this information to gain precision, mathematicians, in-

strumentation specialists, engineers, hydrologists and others.

3. Many of the investigators in this field do not have formal training in statistical methodology. A few do not realize this methodology is essential to their work. Others realize the usefulness of statistical methodology for planning and evaluation, but do not have adequate statistical support for their programs.

4. Planing and evaluation of weather modification experiments present some special problems in statistical methodology. These problems must be resolved or circumvented if research in weather modification is to benefit from the use of statistical principles. Statistical research is needed in questions such as the following: optimal spacing of rain gages, optimal use of rain gage data, effects of crystals contaminating unseeded areas, best ways of taking advantage of auto-correlations and cross-correlations in rain gage data.

CONFERENCE RECOMMENDATIONS

1. Statistical training should be given greater emphasis in the academic program of scientists and engineers interested in the atmospheric sciences. This statistical training should include the principles of field experimentation—nature of statistical models, random allocation of treatments, local control, replication and blind evaluation—as well as the classical techniques of design and data analysis.

2. Steps should be taken to assure that government-supported research utilizes statistical principles in planning and analysis. It is desirable that statisticians participate with meteorologists, and other scientists, in the evaluation of proposals for government-supported research.

3. Statistical advice for scientists in this field should be made available through (i) sponsorship of conferences (e.g., the Foundation series) where plans for new projects can be presented for criticism; (ii) use of statisticians as members of the committees evaluating government-sponsored research; (iii) establishment of task forces and advisory panels for large projects; and (iv) inclusion of one or more statisticians in each field experiment team.

4. Research in statistical methodology applicable to weather modification programs should be promoted

and supported. Such research should include: the development and validation of statistical models; development of useful formulations of meteorological hypotheses; and investigations of the statistical characteristics of the measuring instruments used in this field.

5. It is strongly recommended that any regulatory agency include as one of its technical members or advisors a person knowledgeable in statistical principles and techniques.

6. Steps should be taken to work out a voluntary system that assures that commercial seeding operations do not contaminate or vitiate scientific field work carried on in specified areas of the country. Furthermore, efforts of commercial seeders to gather valid evidence on the magnitude of seeding effects should be encouraged but should not be required of commercial cloud seeding operations.

PRECIPITATION-ORIENTED EXPERIMENTS

A basic source of controversy and uncertainty in the field of weather modification by cloud seeding has been the relative scarcity of "precipitation-oriented" experiments. An experiment is "precipitation-oriented" if it provides adequate information about ground precipitation in the area presumably affected by cloud seeding as well as in control areas. The doubts concerning conclusions from commercial cloud seeding operations were expressed forcefully after the publication of the report of the Advisory Committee on Weather Control. These doubts arise from the possibility that various forms of selection bias exist, as well as biases due to non-linear transformations performed on the precipitation data. Still, no specific source of bias has been discovered that would account for all of the positive findings contained in the recent NAS Panel analyses.

In a field such as weather and climate modification, the statistical methodology of bias elimination becomes particularly prominent. Randomization is then naturally in the foreground.

Modern statistical design and evaluation are based on a probabilistic model intended to present the important aspects of the phenomenon being studied. The tools of modern probability theory are extremely flexible so that the underlying probabilistic model may be far removed from the oversimplified concepts of "randomness" in the sense of serial independence, constancy of probability distribution over time, or rectangularity of the probability density function.

But since experimental resources typically limit the obtainable sample size or the period of observation, it is important not to neglect the power of test procedures and other dimensions of statistical efficiency. A multidimensional or profile approach, based at least in part on the physical theory of the observed phenomena, will be particularly effective.

Among the ultimate aims of a planned "precipitation-oriented" experiment must be a contribution to the understanding of the mechanism by which cloud seeding succeeds or fails in influencing ground precipitation. Therefore, the fact that precipitation on the ground is to be carefully measured does not exclude the collection of observations of other physical variables.

THE EMPIRICAL APPROACH

It has been claimed that answers to the weather modification problem can only come from basic research. This argument suffers from two defects:

1. There are numerous precedents where the effectiveness of human action has been empirically established beyond reasonable doubt many years before any degree of understanding of the underlying mechanism was attained. Thus, there is no basis for claiming that the understanding of the underlying atmospheric mechanisms is a necessary condition for a determination of effectiveness of cloud seeding in generating ground precipitation.

2. Even a complete understanding of the causal relations in cloud seeding might fail to answer the question of the effectiveness of cloud seeding. To answer the latter question on the basis of the theory of the underlying mechanism, one would still need comprehensive information concerning the distribution of the initial values of the various atmospheric parameters. This information is not at present

available and might be extremely difficult to come by.

The basic recommendation is that a program of planned field experiments be undertaken, possessing continuity over a period of 5 to 10 years and on a scale sufficient to permit geographic comparisons and differentiation, as well as stratification according to the type of seeding agent, mode of injection, cloud type, etc. Provision should be made for the inclusion of relevant precipitation data, in addition to other relevant physical variables. This program should be undertaken, designed, and evaluated in close association with statisticians with extensive experience in experimental design.

In view of the emphasis on the physical aspects of weather modification experiments, it is important to remember that such experiments provide a unique opportunity for monitoring variables in the realm of biology, ecology, and social phenomena related to weather modification. Indeed, the design of weather and climate modification experiments should incorporate the needs of these fields. Ecologists will provide suggestions as to design, making it possible to observe the effects on various species; the social psychologists will provide for observations on human perception of weather modification activities, and the economist will concern himself with productivity effects, etc. The details of this aspect of experimentation must be worked out by experts in the respective substantive fields, but their conclusions will have to be carefully considered by the statisticians in guiding the experimental design.

NUMERICAL MODELING AND SIMULATION

The techniques of numerical modeling and simulation complement and expand the potential of statistical analysis. In fact, they are high-powered substitutes for paper and pencil calculation of the behavior of complex systems under assumed conditions, parameter values, etc. Plausible values to be assumed must still be generated by empirical research in which statistics is likely to play an important role. Modeling and simulation require the existence of a mathematical theory of the phenomenon, making it possible to establish a link between such variables as cloud seeding and precipitation.

When the mathematical model has not yet been developed or when realistic information on the relevant parameter values is not available, numerical modeling may not be feasible or fruitful. In such circumstances it may still be possible to arrive at the empirical relationship between seeding and precipitation by intensive systematic randomized and stratified field experimentation or by non-experimental statistical analysis.

On the other hand there are situations, as with large scale circulation problems, where field experiments are impossible, while a mathematical model is available from dynamic meteorology and there is information on parameter values. Here numerical modeling can and should be used.

In some cases mathematical model and parameter information exist, but in an incomplete form, while field experiments are possible though difficult. Here a combination of direct statistical analysis together with numerical modeling and simulation may be employed to advantage.

COMMISSION RECOMMENDATIONS

The Commission recommends:

1. Statistical training for meteorologists should be promoted in academic programs. Intellectual interchange between scientists and statisticians should be continued through periodic seminars.

2. Statistical consultants should be made available to scientists in this field through the support of conferences where new projects can be presented, through use of statisticians as evaluators of proposed work, and through the support of task forces and advisory panels, with statistician members, for large projects. Statisticians should aid in the evaluation of proposals for government-supported research.

3. Steps should be taken to assure that plans for government-supported research utilize statistical principles in determination of design and size.

4. Research in methodology should be promoted. This includes the development and validation of statistical models, uniformity trials and other investigations of the statistical char-

acteristics of the instrumentation in this work.

5. It is urged that any regulatory agency that might come into being should have a staff statistician to guide efforts to gather valid evidence on the magnitude and effects of cloud seeding.

6. A program of carefully planned precipitation-oriented field experiments should be carried out under complete control of the scientists, embodying the required technical knowledge, possessing continuity over a period needed for conclusiveness, and on sufficient scale to permit geographic conclusions, as well as statistical stratification according to the type of seeding agent, mode of injection, cloud type, etc.

FOOTNOTE

[1] List of Participants in Conferences

Baughman, Robert G., Forest Fire Laboratory, U. S. Forest Service, Missoula, Montana

Bearman, Jacob E., School of Public Health, Biostatistics Division, University of Minnesota, Minneapolis

Bigelow, Julien, Institute for Advanced Study, Princeton

Bollay, Eugene, P. O. Box 1022, Boulder, Colorado

Braham, Roscoe, Department of Geophysical Sciences, University of Chicago

Brier, Glenn W., U. S. Weather Bureau, Washington, D. C.

Brown, Jr., Byron Wm., School of Public Health, Biostatistics Division, University of Minnesota, Minneapolis

Court, Arnold, Department of Geography, San Fernando Valley State College, Northridge, California

Dennis, Arnett, Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, South Dakota

Grant, Lewis O., Atmospheric Science Department, Colorado State University, Fort Collins, Colorado

Hindman, Ed, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado

Hosler, C. L., Department of Meteorology, Pennsylvania State University, University Park, Pennsylvania

Hoyle, Michael, Cloud Physics Laboratory, University of Chicago, Chicago, Illinois

Hurwicz, Leonid, Department of Economics, University of Minnesota, Minneapolis

James, R. C., Bureau of Reclamation, Denver Federal Center, Building 53, Denver, Colorado

Kahan, Archie M., Office of Atmospheric Water Resources, Office of Chief Engineer, Bureau of Reclamation, Denver Federal Center, Building 53, Denver, Colorado

Kruskal, William, Department of Statistics, University of Chicago

Malone, Thomas F., Research Department, The Travelers Insurance Company, 1 Tower Square, Hartford, Connecticut

Markovic, Kadmilo D., Civil Engineering Department, Colorado State University, Fort Collins, Colorado

Mielke, Paul, Mathematics and Statistics Department, Colorado State University, Fort Collins, Colorado

Peahl, Laurence E., Department of Mathematics, Taft Junior College, Taft, California

Reinhardt, Howard, Montana State University, Missoula, Montana

Schleusener, Richard A., Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, South Dakota

Simpson, J. M., U. S. Weather Bureau, Washington, D. C.

Snyder, Marshall, Department of Statistics, University of Chicago

Tick, Leo J., Data Processing and Computing Laboratory, Research Division School of Engineering, New York University, University Heights, New York, New York

Van Ness, John, Department of Statistics, Stanford University, Palo Alto, California

Willis, Paul, E. Bollay Associates, P. O. Box N, Steamboat Springs, Colorado

Wyckoff, P. H., Atmospheric Sciences Section, National Science Foundation, Washington, D. C.

Yevdjevich, Vunica M., Foothills Research Campus, Colorado State University, Fort Collins, Colorado

Youden, W. J., Applied Math Division, National Bureau of Standards, Washington, D. C.

Zopf, D., Eugene Bollay Associates, P. O. Box N, Steamboat Springs, Colorado

THE HUMAN EFFECTS OF WEATHER AND CLIMATE MODIFICATION

Like other recent technological advances, weather and climate modification techniques, if fully effective, present humanity with unprecedented opportunities and grave dangers. So pervasive are the elements of weather in the mind and works of man that an alteration in one of them, even over a small area, may provoke intricate social changes. Some of these changes are obvious but many are difficult to trace and puzzling to measure.

A modification in a small area of atmospheric circulation may cause shifts in the system of human production and communication, as when fog dispersal makes possible an airplane flight that otherwise would be grounded. It also may lead to unwanted conditions; thus, the measures to dissipate fog may increase the icing of highways in the immediate airport area. Modification at one place may provoke changes in the atmospheric circulation elsewhere, as when there possibly forms a "rain shadow" of decreased rainfall to the detriment of a wheat farmer in the lee of an induced increase which brings profit to another farmer, or when the weather that pleases the wheat rancher causes distress to the nearby cherry orchardist.

The effects of the modification on man's activities sometimes are direct, as in the case of fog dissipation, but more often they operate indirectly through alterations in the hydrologic system or in biological ecosystems. Their extent is especially troublesome to discover because a sustained program of modification would change the climatic characteristics, and the whole fabric of society, being subtly adjusted to climatic means and extremes, is likely to change with them.

The gains and losses that follow in the train of atmospheric alterations accrue to other processes of society as well as to economic production and consumption. The organization of livelihood may be affected, and the

* The Commission had the benefit of thinking contributed by participants in a Symposium on Economic and Social Aspects of Weather Modification held at Boulder, Colorado on July 1-3, 1965 by the Department of Geography of the University of Chicago in collaboration with the National Center for Atmospheric Research under a grant from the National Science Foundation. Papers from that symposium shortly will be published in the University of Chicago Geography Research Papers under the title of *Human Dimensions of Weather Modification*, edited by W. R. Derrick Sewell. The list of participants in the Symposium appears under Footnote 1 to this chapter. Also see the Appendix.

quality and enjoyment of life may be enhanced or degraded.

Just how significant these chains of events may be on human activity still is largely conjectural. A few, such as the increase of hydroelectric generation from induced precipitation in the drainage above a power plant may be gauged with some confidence. According to some estimates, even highly modest precipitation increases at the right times in cultivated areas are likely to be of major value. The direct benefits to agriculture and forestry from hail prevention and lightning suppression are likely to be significant and not too difficult to estimate. Many effects cannot be measured readily. To the uncertainty of what modification is within man's grasp therefore must be added his ignorance of the full consequences of whatever modification he may achieve. In the face of uncertainty as to modification techniques and of doubt as to their social effect, a sound public policy encourages research on both techniques and effects so as to fully exploit what may be an historic opportunity while guarding against heavy or irreversible damages to society.

After outlining several basic social problems attaching to weather modification, there are recommended measures which should be taken by the Federal Government to deal with immediate questions of research and field operations and to improve the nation's capacity to deal with larger questions that loom in the future.

In canvassing these issues the Commission has drawn on the experience and outlook of scientists who have worked with modification of other aspects of natural resources. There has been only a little study of weather and climate impacts alone, but the effects of managing water and land yield many relevant lessons.

The final report of the Advisory Committee on Weather Control contained an appendix relating to economic evaluation. However, it did not instigate any concerted effort to improve capacity to measure the human effects of weather and climate modification. A few thoughtful studies were made but the problem was neglected for the most part. In making it possible for workers from anthropology, economics, geography, meteorology, political science and related fields to assess the current state of their knowledge, the Commission sought to identify points where predictions now are practicable and questions deserving more intensive study.[1]

FOUR INTERLOCKING SYSTEMS

It is important to recognize that although man may seek to modify weather in order to benefit the quality of his life the result is rarely a simple relation between an atmospheric condition and human activity in that place. Atmospheric circulation, the hydrologic cycle, biological ecosystems, and human production are interlocked. There may be a direct and largely limited connection between atmosphere and economic production, as with fog dissipation or lightning suppression. More often, the benefits and costs to the system of production and communication are felt indirectly through changes in the hydrologic cycle and in biological ecosystems: a shift in the atmosphere changes one or more of the other three. Thus, an increased amount of June rainfall in the High Plains of Colorado would affect the production of wheat by adding to soil moisture and the capacity of plants for transpiration and of soils for evaporation. Stream flow and ground water supply in the area therefore would be altered in some degree, however slight. Enlarged wheat harvest would be the major outcome but by no means the only one.

As has been shown in the preceding chapter, the resulting shifts in ecosystems of plants, animals, soil, and microclimate are exceedingly difficult to assess. If they cannot be identified fully their long-term significance for human activity cannot be gauged.

Much the same problem is associated with sectors of the hydrologic cycle. Certain changes in stream flow which would result from increasing precipitation or from decreasing evapotranspiration may be estimated. It increasingly is possible to predict the modification in stream flow resulting from changes in precipitation and temperature. After a soil is saturated a small increase in rainfall may cause a proportionately larger increase in runoff. There is less knowledge about the likely effects of such changes on the movement of silt downstream, or about the relation of rainfall intensity to rates of gully cutting in arid regions such as the Upper Rio Grande basin.

Lack of full understanding of the consequences has never been a reason for man to forbear modifying a part of his environment. He does not refrain from ploughing a Carolina field because he is ignorant of the full effects upon soil biota or upon runoff. He has not held up the construction of storage dams in Kansas because of doubt as to the readjustments in channel cross section and gradient which will take place downstream when the flow is regularized. Moreover, in seeking to alter the landscape in one way he may unwittingly cause damages to others. There never is a time in the present state of scientific knowledge about air, soil, water, plants, and animals when these changes can be recognized in all their complexity. To defer action until all the consequences are tallied up would be to halt all new resource management. Yet, there have been times when the public decision to go ahead in ignorance has led to bitter regrets, as when highly erosive soils have been ploughed and new cycles of gully cutting have been triggered; or as when channel works have caused heavy silting and dislocation of downstream drainage systems.

In considering the possibility of a new tool of environmental modification which may be coming into man's hands, the challenge is to find a course of action which without inhibiting largely beneficial results will curb those measures which might bring serious or irreversible damages to the environment. Arriving at such judgments requires not only recognition of what is known and not known about the atmospheric, hydrologic, and biological systems affected, but assessment of how a change in one or all of them will affect human life and of how one kind of change compares with another.

Weather and climate modification is distinct from the more conventional tools of environmental change in several respects. It promises to ordinarily affect areas distant from those where modification is tried: more than any other readily available tool it may extend its effects across the frontiers of countries, states, and nations. Its potentials for provoking local and international conflict therefore are great. It usually has consequences for both hydrologic and biological systems. It is new. For these reasons there is greater likelihood that man at the outset will see the gravity as well as the exciting opportunity of modification measures and that conscious attempts will be made to weigh their future consequences for society at the local, national, and international levels. However, the techniques so far developed are cheap, readily moved from place to place, low in capital investment, and often free from the hazard of irreversible shifts in the atmosphere. These reasons tend to stimulate small-size operations widely dispersed in time and place, and to offset the caution that otherwise might apply.

UNCERTAINTY

Uncertainty characterizes most thinking about the changes in natural systems that are subject to modification. Not only is there uncertainty about how much the atmospheric circulation can be altered and what this would mean for the movement and quality of water, plants, and animals, but the consquences for human production and communication are subject to similar doubt.

This is one of the factors accounting for the casual attention which has been given to the social consequences of weather and climate modification since publication of the report of the Advisory Committee on Weather Control in 1957. An appended paper pointed out the need for more systematic examination of the human effects of modification. Little was done thereafter. Doubt as to the possibility of changing the weather led scientists to ignore the challenge, and they were supported in this by the silence of the Advisory Committee on Weather Control as to the need, by the scepticism of many atmospheric scientists, by the debate in the academic community over the statistical methods used in judging cloud-seeding experiments, and by the caution of Federal agencies in encouraging new research. There was no agency specifically charged to look into the human effects, and within the National Science Foundation the responsibility for weather modification research was lodged in the Section on Atmospheric Sciences.

The principal lesson to be drawn from this experience is that where uncertainty is large, as it continues to be with weather and climate modification, the basic social implications will tend to remain unexplored unless explicit and sustained effort is made to stir up and support the essential research. Otherwise, the human problems are ignored until they burst into prominence on the heels of an improvement in technique.

Where uncertainty is high there is much in favor of a public strategy which promotes diversification of efforts rather than dependence upon one line of action or research. Not only would this call for pursuit of studies on a variety of physical processes, but it would suggest that the needs for and damages from theoretically possible modification would be examined in advance of perfection of techniques. In promoting a strategy of diversification it is important, however, to avoid spreading the research so thinly that no one project is rewarding. Allocation of funds among different aspects of modification presumes a rough judgment of what kinds of changes would be desirable in improving the quality of human life.

TWO APPROACHES TO THE HUMAN DIMENSIONS

Investigation of the human dimensions of weather modification can move along either one of two lines. A possible modification, such as precipitation induction or lightning suppression, can be assumed and then an effort made to estimate what the consequences would be in the society. Where a modification is tried, as in seeding above a hydroelectric plant, the effects upon power production downstream and in the generating network may be traced. A variant is to assess the effect of rare meteorological events. A second approach is to ask at what points the social system would be sensitive to a change in weather conditions, and from this to estimate what would be the more desirable and undesirable changes which might be foreseen without regard to whether or not they currently are practicable.

Under the first approach, the attention is directed toward discerning the likely impacts of modification which promise early achievement. Under the second, the emphasis is on types of modification which should be sought or avoided. The two approaches are not mutually exclusive, and they can helpfully supplement each other. Both are recommended for early action.

BROADER CONSIDERATIONS

Whether emphasis is upon forecasting effects of practicable modification measures or upon points in society which would be more sensitive to weather changes, there is doubt as to how far man properly should go in tampering with atmospheric systems unless he is relatively clear as to the major consequences. Concern with growing world population needs heightens the interest in gains from the weather. Doubt as to human implications as illustrated by the difficulty of assessing results of nuclear experiments, has raised new cautions concerning any novel or large-scale interference with our environment. Great prudence is therefore warranted in practicing weather modification, and increased support is desirable to explore its side effects, as well as its ability to achieve the desired results.

Deep in human experience is a sense of excitement and beauty in coping with the extremes of wind and rain and heat. To be sure, their enjoyment does not always offset the discomfort and suffering that lead men to commonly adjust their clothing, dwellings, transport and other practices to curb the effects of weather. Yet in the driving power of a winter blizzard or the sudden flash of summer lightning there are dramatic reminders of the elemental forces with which the human race constantly is striving to find its place. No presently conceivable program of weather or climate modification could eliminate these extremes. A beginning at changing storm or lightning nevertheless raises the question of how far the human spirit is enriched by the uncertainty and wonder and exhilaration that come with the restless, violent movements of the atmosphere. Any effort to assess the social consequences of weather and climate modification must give weight to the esthetic and spiritual as well as purely material rewards.

EVALUATING SOCIAL EFFECTS

The keen interest in precipitation induction and fog dispersal shows that their direct results are believed to be highly beneficial. Certain electric power utilities, airlines, and fruit growers have invested funds in research and operations directed at practical modifications. A public utility on the Pacific Coast concluded that in the drainage area of one of its reservoirs an increase of less than two percent in annual precipitation would clearly justify cloud seeding and that an increase of ten percent for a large watershed might be worth $200,000. An airline has estimated that the immediate benefits in reduction of operating expenses from fog dispersal in an intermountain area were at least five times the seeding costs. Obviously, if a farmer thinks he may increase his per acre wheat yield from seven to eight bushels by rainfall induction or hail suppression at a cost of a few cents an acre he will be strongly inclined to take the risk of the expenditure even though the results are in doubt. It has been calculated that the estimated mean annual losses of $250,000,000 from hurricanes might be reduced by as much as one third if only modest reductions in storm intensity or slight changes in storm paths could be achieved. Opportunities for direct, beneficial effects in the economy are immense insofar as genuine modification can be managed with confidence. The methods for computing such direct benefits are relatively well developed.

In the sphere of human activities, the potential effects of modification on the quantity, timing, and geographic distribution of production and transportation are particularly striking. But in evaluating the social effects of weather modification it is not enough to trace them through the technological aspects of production activities. Behavorial responses and their relation to the impact on social organization and process must also be identified. Because weather modification involves costs and may preclude alternatives, its possible results must be compared with achievements obtainable through alternative ways of dealing with the vagaries and averages of weather phenomena. Man adjusts his activities to weather in countless ways and constantly is devising new ones. The evaluation of fog dissipation requires not only the measurement of benefits and costs at the airport and in airline operations, but the assessment of the benefits and costs from installing equipment which could land aircraft notwithstanding fog or from re-routing traffic on the ground and in the air.

Improved weather forecasts are one major alternative to weather modification. Sometimes they may complement each other, but in many instances an accurate forecast with sufficient advance warning, if accompanied by other measures, would reduce or even eliminate the gains from altering a weather extreme. Thus, as much as 15-20 percent of flood losses may be eliminated in certain areas, if there is sufficient notice, without changing the character of the flood or of the precipitation producing it. Severe crop losses from drought may be reduced by alternate cropping if the drought can be predicted sufficiently far in advance. Traffic can be re-routed around airports which will be closed by fog. Perhaps no industry is more carefully prepared to take advantage of a forecast of icy or freezing weather than is the public utility industry which can move promptly to cope with weather emergencies. Inaccurate forecasts also may cost heavily in damages.

Even in the absence of significant forecasting improvements, there are many other means of cutting down dislocations caused by weather. In areas where drought occasionally brings acute crop losses, the social impacts may be curbed by readjustment in cropping patterns, by breeding or selecting drought resistant varieties of plants, by supplementing the water supply, by insurance schemes, and by a variety of other actions, some of which depend upon further scientific research for their perfection. A similar range of solutions applies to dislocations caused by hail, excessive rain, fog, and lightning.

To be realistic, measurement of the benefits and cost of modification, forecasting, or any of the other alternatives must take into account the likelihood that if certain of them are pursued consistently, the structure of the economy will change so that it becomes less vulnerable to dislocation by weather. In drought areas a reorganization of farming practices might lead to agriculture which would be less vulnerable to the recurring dry periods. Or, a continuing program of cloud seeding, if practicable, might raise the mean rainfall sufficiently to encourage a major revision in type of farming. This, in turn, could shift the service functions of nearby urban centers.

Without any conscious modification of weather, the sensitivity of human activity to weather may be reduced, as when air conditioning or insulation of utility lines renders an area less susceptible to extremes of temperature. During 1929-1962, the yield of corn in the Corn Belt increased in several steps related to the technology of seed, cultivation, and fertilization, but during the same period the variation in yields due to weather appeared to decrease.[2] That is, the crop production became less susceptible to weather dislocations. In these and other ways estimates of direct impacts of weather modification must be corrected for longer-term structural adjustments.

Research relating to the social impact of weather on human affairs would prove fruitful even if no form of weather or climate modification were ever to be achieved. Deepened understanding of geographic relationships among weather characteristics and the economic system would be bound to aid in intelligent decisions by both resource users and public agencies in agriculture, transport, manufacturing, and other sectors of the economy. The kind of refined knowledge about crops and rainfall, or air transport and fog, or forest growth and lightning which would be essential to careful estimates of social impacts of weather modification would be required for estimates of the sensitivity of the economy to weather, or for improvement in efficiency of those activities by other means.

One fundamental question deserving scientific attention is the degree to which climate already has been altered or may be altered in the future inadvertently by the hand of man. To the extent that either rural or urban climates have been so modified, the type and distribution of human activity may be expected to reflect some readjustments that now are taken for granted. Urban climates have undergone measureable change in temperature and air quality. The precise amount still is in doubt. While few modern societies are so delicately adjusted to rain or its invocation as are certain of the organizations and social controls of Pueblo culture in the Southwestern United States, all of them involve many adaptations.

Whether the relations of weather to human activity are isolated over a few days or many years, they obviously are different from one sector of society to another. The downpour which fills a New York city reservoir washes gullies in a farmer's field; the hurricane which disrupts a Florida shopping center carries water to a nearby Everglades wildlife refuge. If it is assumed that there is any effect upon processes elsewhere, the differential results become even more marked. Were cloud seeding to have a "rain shadow" of lowered precipitation or were hail suppression to reduce rainfall to the leeward, the complications would multiply. If it were to be shown that cirrus cloud formation encourages smog conditions, then the health and heat budget of a metropolitan area might be affected by airline operations upwind. A map showing the area where weather elements are altered presents only a part of the picture; it must delimit the extent of effects felt in nearby towns or in distant markets.

These impacts are made especially difficult to measure because people may differ in their perception of weather conditions and of man's effect upon weather. Just as many city dwellers in the path of a hurricane are unable to act rationally on the warning of high winds, so people in an area of weather modification may for a variety of reasons fail to take advantage of a changed condition. On the other hand, a farmer may act as though the weather is being modified even when scientific verification is lacking. In either case, the estimate of the individually and socially rational solution does not turn out to describe what people in fact do. A workable public policy is based on prediction of what they will decide in practical situations. The uneasy suspicion of a nation that it is suffering from cloud seeding to the windward is a political reality that must be faced seriously, whether or not harmful effects are known to occur.

Judgment as to adoption of economically optimum solutions inevitably is tempered by appraisal of what is likely to unfold in daily activities once the alteration is under way. It may well be that individuals will be unable to take advantage of the potential benefits of weather and climate modification unless legal and institutional changes are put into effect.

CONFLICTS OF INTEREST

Even though there is no confident prediction of the extent to which weather and climate may be modified in the future or of the full chain of impacts from such modification, it already is evident that at least four types of conflicts may be expected to arise as soon as a modification technique is shown to be practicable. Indeed, they will arise whenever there is any slight ground to think it may be practicable. Substantial groups in the nation already believe cloud seeding produces rain and perhaps even rainshadow; their responses to private seeding operations or government research programs are based on these beliefs and range from enthusiasm to hostility.

These perceived conflicts are real in the minds of the people involved, and they cannot be ignored because they lack scientific validation. This is particularly true of the conflicts believed to extend across political boundaries. Below are examples of possible areas of conflict.

1. Research on the techniques of weather modification is likely to encounter conflict with other research programs unless there is clear agreement as to the time and place of each field experiment. Otherwise, operations in the area may cause contamination and thus run the risk of invalidating the observations elsewhere.

2. A proliferation of weather modification operations could make it impossible to carry out carefully controlled experiments. Were farmers in the Great Plains to become generally convinced that cloud seeding could increase rainfall at critical periods or could suppress hail, their activities soon would cover the area so thoroughly that without regulation it would be difficult to run experiments to find out whether or not the operations were in fact effective.

3. A conflict arises where one group stands to benefit from weather modification and another to lose. As already noted, this may apply both within a single area and between two areas.

4. There is the possibility of conflicts between groups seeking to modify weather for different purposes or for the benefit of different areas. Rather than there being unintended effects upon other groups from one seeding operation, there can be direct conflict over the use of a site or atmospheric condition.

Public policy should recognize the probability that all four types of conflict may arise, and should seek to reconcile each of them equitably. In that effort its responsibility goes far beyond arbitrating conflict. It should seek to prevent victimization, either of people who mistakenly think they are gaining benefits that do not exist or of people who are unaware of damages being inflicted upon them by others. Without public intervention to assure that proper records are kept and the findings are available to the interested parties, it will be impossible to determine the true gains and losses. It may be necessary that the government judge the consequences, provided it is certain that suitable information is collected.

In a situation where so much of the knowledge is speculative, it is important that channels be kept open for research and for the sharing of research findings. This is especially important where the social effects may possibly reach across county, State, or international borders. A policy of passively waiting for the conflicts to arise will in the long run exacerbate them by permitting research to be impeded and by allowing the alledged injuries to show in tedious inconclusive judicial action or in peremptory legislative fiat. The time to guard against groundless contention is before it arises.

A university scientist who is anxious to experiment with cloud seeding now feels more cautious than might be socially or scientifically desirable about launching field work. If he shows positive effects he or his institution may be subject to damage suits from those who think they have been injured by too much rainfall or by too little or by rainfall at the wrong time. Even if his results are negative or inconclusive, he still may be open to legal attack by those who genuinely feel themselves disadvantaged.

Insofar as practical modifications are carried out they are likely to result not only in specific gains and losses, but in widespread institutional changes in society. Thus far, the conflicts have applied to small areas but in the future they may extend over large areas. The readjustments which result therefrom will call for major changes in policy and organization as well as for arbitration of competing claims and damages.

DESIRABLE COURSES OF ACTION

Analysis of Social Impacts

Because of the need for determining more precisely the character of social consequences of weather modification, it is important that any further government operations and government supported research dealing with modification be accompanied by analysis of those consequences. If the operations are entirely private, it would be desirable for the public to underwrite such analysis so that the social results could be recognized.

In cases where the operations are in relatively small areas and do not induce structural changes in the economy, the methods of measuring impacts may be adapted, with suitable changes, from Federal experience with evaluating water development projects. Much useful work has been done on gauging benefits and costs from a change in water occurrence. These methods will not be readily applicable to such special questions as the assessment of recreation benefits and the distribution of benefits and costs outside the target area. Nor will they be particularly helpful in recognizing institutional adjustments that would be prominently involved in sustained modification operations. The findings would be rough, but they would give an idea of the order of magnitude of results and would suggest problems of evaluation deserving early attention. Much can be learned promptly from studying the economic aspects of legal conflicts which already have arisen.

If Federal and private agencies are not ready to undertake this type of analysis, the National Science Foundation should be prepared to support it. After a few years, the analysis might be attempted more selectively. At present, it should be tried wherever practicable.

Review of Impact Studies

There should be critical review of the methods followed and of the findings so that the methods might be improved and in time made uniform. It would be a mistake at this stage to attempt to set standards for social evaluation of weather modification. At present there is no guarantee that the analyses of different aspects could be compared with one another. Working from the experience with interagency cooperation in water resource studies, the Foundation should convene a panel of representatives from interested public agencies and from research institutions to examine analytical methods and to suggest ways of refining them. The panel would be expected to appraise methods used for the indentification and measurement of impacts and the use of such evidence in evaluating weather modification and alternative measures. It could draw heavily from experience over the past two decades in attempting to gauge the effects of water projects on farming, nearby towns, and on more distant areas. It would report its findings to the Foundation and the interested agencies, then making public its evaluations. At an early time, it might well use the data from one of the comprehensive river basin studies, such as the Delaware Basin study, to test the suitability of the methods in common use.

Research on Social Effects

The support and encouragement which the National Science Foundation has given to research on physical processes of the atmosphere should be extended to research on those relations between weather and human activity which possibly would be affected by weather modification. This should include the nature of external economies and diseconomies from modification operations, the consequences of shifts in ecosystems, and the institutional changes that may result. Methods for measuring changes in crop production and the losses from fires are well developed, but impacts on recreation and on biological communities are rough at best. Many of the impacts will show in revision of organization of individual and community enterprises.

One means of stimulating further thinking about fruitful approaches to these and related problems would be to enable a scholar broadly acquainted with the social sciences to spend a year examining the field of weather modification with a view to suggesting especially difficult or promising lines of investigation. So little systematic work has been done to date, beyond the interdisciplinary exchanges already instigated by this Commission, that it would be helpful to have a more thorough appraisal of opportunities. The exploratory studies of weather information and prediction by the U. S. Weather Bureau and the Rand Corporation, and the scattered economic and geographic investigations of the relation of climate to farming, commerce, and transportation need to be extended widely.[3]

It should be emphasized that virtually all of the research which would be initiated would, if sound, yield findings that would be useful in making more efficient adjustments to weather conditions even if no modification were ever to be practiced. The same method for estimating the benefits to a manufacturer from a change in occurrence of rainfall would be helpful in calculating the gains from an improved rainfall forecast or from a technical innovation that would render him less vulnerable to damages from intense rainfall.

Freedom for Experimentation

In order to permit field experiments with methods that do not threaten seriously deleterious results, it is essential to provide for indemnification of investigators supported by Federal funds against damage suits.

Research on Basic Relationships

If there were relatively full understanding of the complex relationships among weather characteristics and human activity, the task of estimating impacts of weather modification would be more nearly straightforward. Lacking such understanding in all sectors of society, efforts should be encouraged to discover them. In the long run, it might be practicable to develop a model of the national economy which would be sufficiently detailed and sensitive to predict the effects of varying one or more of the daily weather inputs. The methodological problems are enormous. Measurement of weather conditions other than precipitation and incoming radiation is difficult in any event. The analysis must be developed in probabilistic terms, and the present relationship to human activity must be investigated with sufficient precision to permit judgment as to the degree to which prevailing geographic patterns of farming, transportation, industry, and recreation would be altered in response to a change in weather characteristics.

In the near future, it would be desirable to explore types of models which might be used and the data understanding which they would require. An activity analysis type of model might well provide a flexible framework without pre-judging the nature of relationships to be investigated. An input-output model would merit investigation but would offer complications. Whatever the form of model selected, considerable empirical study would be required in narrow sectors before its application to larger parts of the economy would be warranted. Thus, the possible shifts in cropping and manufacturing locations would need to be specified for different magnitudes of change in each weather element. Cautious but vigorous steps should be taken in this direction.

Research on Decision Processes

Both the nature of weather processes and the current knowledge about them require that most human decisions as to weather modification must be made in the face of uncertainty. This imposes special restraints on public agencies and it increases the difficulty of predicting how individual farmers, manufacturers, and others who are directly affected by weather would respond to changes in weather characteristics. There is little evidence as to how many people would take advantage of an alteration in weather even if it could be assured, or that they would do so in an economically efficient manner. A flood-plain dweller may fail to heed an accurate flood forecast because he does not understand what practical steps he could take; a farmer may not take advantage of increased rainfall because conditions of credit or farm organization discourage him. It appears that people vary from place to place in their belief in the effectiveness of weather modification. As in all areas of human endeavor, there is likely to be a lag between technical knowledge and its application. Differences according to culture groups may be expected. Research on the conditions of decision making in these circumstances would illuminate discussion of suitable public policy by showing the choices that are open to public agencies and by increasing the ability to predict the ways in which weather users may respond to the unfolding technology of weather modification. The National Science Foundation should encourage such investigations.

Research on Inadvertent Modifications

Although public interest tends to concentrate on the possibility and effect of new techniques for conscious modification of weather, it is desirable to look into the degree to which past and present human activities cause inadvertent changes in weather and climate. Investigations of those alterations require the collaboration of scientists working on atmospheric, biological, hydrological, and social problems. Historical and archeological evidence may need to be compared with current geography and with meteorological data. The train of events between human action and weather characteristics should be traced with attention not only to physical alterations in climate, but to resulting modification in the quality of human life.

RECOMMENDATIONS

The Commission recommends:

1. Steps should be taken to assure that wherever field experimentation or commercial operations are undertaken in weather and climate modification arrangements be made to study the social consequences.
2. A special panel should be established to exchange and give critical review to the results of such studies.
3. The method of assessing impacts of weather modification should be the subject of research looking to its refinement and extension.
4. Freedom of field experimentation should be supported by providing indemnification of Federally financed experimenters against damage claims.
5. Research should be encouraged on the basic relationships between weather characteristics and human activity.
6. Decision making processes in the face of uncertainty as to weather modication and its effects should be subjected to careful investigation as a means of increasing the government's ability to predict the results of alternative policies and methods for weather modification.
7. Interdisciplinary study of modifications which man makes inadvertently should be encouraged.

FOOTNOTES

[1] Symposium on the Economic and Social Aspects of Weather Modification, July 1-3, 1965. List of participants:

Edward A. Ackerman, Carnegie Institution of Washington
Jack Barrows, U. S. Forest Service, Department of Agriculture
Marston Bates, Department of Zoology, University of Michigan
Boynton Beckwith, Assistant Director of Meteorology, United Airlines
Sherman W. Betts, Interdepartmental Committee for Atmospheric Sciences
Carl von E. Bickert, Industrial Economics Division, Denver Research Institute
Reid Bryson, Department of Meteorology, University of Wisconsin
Horace Byers, Department of Geophysics, University of Chicago
Emery N. Castle, Department of Agricultural Economics, Oregon State University
A. R. Chamberlain, Vice President, Colorado State University
Marion Clawson, Resources for the Future, Inc.
Norman Crawford, Department of Civil Engineering, Stanford University
James A. Crutchfield, Department of Economics, University of Washington
Leslie Curry, Department of Geography, University of Toronto
Donald L. Eberly, Meteorologist, Pacific Gas and Electric Co.
Robert D. Elliott, President, North American Weather Consultants
William Garrison, Department of Geography, Northwestern University
Donald L. Gilman, Extended Forecast Division, U. S. Weather Bureau
Lester Goldner, Division of Air Pollution, U. S. Department of Health, Education and Welfare
Ivars Gutmanis, Division of Air Pollution, U. S. Department of Health, Education and Welfare
Robert L. Hendrick, Senior Research Scientist, Travelers Research Center
James Hibbs, U. S. Weather Bureau, Department of Commerce
Howard Hines, Director, Division of Social Sciences, National Science Foundation
Leonid Hurwicz, Department of Economics, University of Minnesota
Paul Julian, National Center for Atmospheric Research
Archie Kahan, Bureau of Reclamation, U. S. Department of Interior
Robert W. Kates, Graduate School of Geography, Clark University
John W. Kirkbride, Statistical Reporting Service, U. S. Department of Agriculture
R. Koopmans, Department of Economics, Yale University
Robert Lucas, Lake States Forest Expt. Station, University of Minnesota
Fremont J. Lyden, Department of Political Science, University of Washington
Arthur Maass, Water Resources Center, Harvard University
Marion E. Marts, Vice Provost, University of Washington
Richard Meier, School of Natural Resources, University of Michigan
Gilbert F. White, Department of Geography, University of Chicago
Donald Michael, Institute for Policy Studies
Edward A. Morris, Bronson, Bronson & McKinnon
Jack C. Oppenheimer, Executive Secretary, Special Commission on Weather Modification
Allan Pred, Department of Geography, University of California

Reginald C. Price, Deputy Director, State of California, Department of Water Resources
Walter Orr Roberts, National Center for Atmospheric Research
Thomas Saarinen, Department of Geography, University of Chicago
Richard Schleusener, Director, Institute of Atmospheric Sciences, South Dakota School of Mines and Technology
Anthony Scott, Department of Economics, University of Chicago
W. R. Derrick Sewell, Department of Geography, University of Chicago
Bernard Silverman, Meteorologist, U.S.A.F. Meteorological Lab.
Stephen C. Smith, Department of Agricultural Economics, Colorado State University
Evon Z. Vogt, Curator, Middle American Ethnology, Harvard University
Andrew Wilson, Department of Geography, University of Arizona
Peter H. Wyckoff, Director, Weather Modification Program, National Science Foundation

The problems of measuring the impacts of weather modification were examined against the background of experience with evaluating water management projects with a group of consultants consisting of Emery Castle of Oregon State University, Allen Kneese of Resources for the Future, W. R. Derrick Sewell of the University of Chicago, and Stephen C. Smith of Colorado State University. Useful suggestions also came from a discussion of social evaluation of weather modification experiments and operations held in Washington, D. C. on September 20, 1965. Those participating in this discussion were as follows:

Gilbert F. White, University of Chicago, Chairman
Keith Arnold, U. S. Forest Service
Lowell Ashby, Department of Commerce
Jack Barrows, U. S. Forest Service
Robert Cain, National Science Foundation
Emery N. Castle, Oregon State University
Frank Hersman, National Science Foundation
James Hibbs, U. S. Weather Bureau
Howard Hines, National Science Foundation
H. R. Josephson, U. S. Forest Service
Allen Kneese, Resources for the Future
Karl Lee, U. S. Bureau of Reclamation
Hoyt Lemons, Department of Defense
Jack C. Oppenheimer, National Science Foundation
Truman Price, Department of the Interior
Louis Quam, Office of Naval Research
Stephen C. Smith, Colorado State University
Harry A. Steele, Department of Agriculture
Peter H. Wyckoff, National Science Foundation

The question of how the basic relations among weather and economic activity might be investigated through a comprehensive model was outlined by Edward A. Ackerman of the Carnegie Institution of Washington and was the subject of a special review by John A. Edwards of Oregon State University.

[2] Lawrence H. Shaw and Donald D. Durost, "The Effect of Water and Technology on Corn Yields in the Corn Belt, 1929-62," *Agricultural Economic Report*, No. 80, Washington: U. S. Department of Agriculture, 1965.

[3] R. R. Rapp and R. E. Huscke, *Weather Information: Its Uses, Actual and Potential,* Santa Monica: Rand Corporation, 1964. Memo RM-4083-USWB U. S. Weather Bureau, *The National Research Effort on Improved Weather Description and Prediction for Social and Economic Purposes,* Washington, 1964.

LEGAL AND LEGISLATIVE ASPECTS

The drawing of conclusions as to the legal and legislative aspects of weather modification is hampered by uncertainty as to the scientific capabilities in the field. If one possessed or seemed likely to possess in the near future the technological capability of ordering weather, the ramifications to our society and hence to our legal system would be enormous. Even a limited capacity to modify weather would pose problems of great complexity. The nature of these problems is illustrated by what might result if the present experiments in the "disarming" of hurricanes are successful. At first blush one would suppose that no one could object to the dissipation of destructive storms such as hurricanes. However, there seems to be at least some opinion that a substantial amount of the rainfall in the Northeast comes about as a result of hurricane activity. It might, then, turn out that hurricanes are a necessary part of the distribution of rainfall in a substantial section of the United States. Assuming both the power to dissipate hurricanes and the need for rainfall in the Northeast, how is the decision between the risk of catastrophic storms and the ending of the drought to be made?

Similarly difficult problems of choice will be posed by even the limited capability of precipitation induction now visualized. In a sense, ability to control the atmosphere may create more problems than it solves. For nations as well as individuals the availability of alternatives may turn out to be more disruptive than the hardships of want.

Given the present state of the art, extended speculation as to the necessary responses of the laws would seem unwarranted in a report of this kind. The temptation is strong to put aside

---

In considering this facet of the problem the Commission addressed questionnaires to the 50 state governments and to the 64 persons or organizations (including 7 Federal agencies) who have been conducting weather modification research activities or commercial operations. The National Science Foundation contracted with the Southern Methodist University School of Law to have Prof. Howard J. Taubenfeld undertake in cooperation with the Commission's Executive Secretary, Jack C. Oppenheimer, Esq., a survey, analysis and summary of the data contained in the responses. The result is the report to be published by the NSF in January, 1966, entitled "Weather Modification: Law, Controls, Operations" (see the Appendix). This chapter is in large part based upon this study. Acknowledgment is also made to the helpful suggestions of NSF General Counsel William J. Hoff, Deputy General Counsel Charles B. Ruttenberg, and attorney Joseph R. Schurman.

the legal question until the science and technology have developed a little more. On the other hand, with the apparent ability to modify weather intentionally, albeit to a limited extent, and since it is not certain that efforts do not result in some unintended modifications, one cannot wholly dismiss the problems. Moreover, whatever the scientific truth may be, weather modification activities are being conducted and many people believe those activities have effects both beneficial and deleterious. Indeed, some twenty-two states have already enacted legislation dealing with those activities. The result is that the law is already involved with weather modification in many ways, so that for better or worse consideration must now be given to some of the legal aspects of weather and climate modification.

The existing involvment of weather modification with law is, broadly speaking, of two kinds: (1) the body of rules governing the responsibilities and liabilities of weather modifiers (or those who employ their services) to other members of the public; and (2) regulation by government (most often by the states) of weather modification activities.

Weather modification activities can result in two more or less distinct kinds of injury to members of the public. The first kind is damage caused by destructive weather conditions such as flood, hail, hurricanes and the like. Damages attributable to such conditions, assuming satisfaction of other prerequisites to recovery, would be compensable under traditional standards. The second kind would result from the change in climate of a particular locality, e.g., lowering or raising the level of rainfall in a locality below or above that which would have fallen but for the modification. Assuming that the level which would have fallen naturally could be established, damage could be of widely diverse kinds; from the blighting of a resort owner's season to the ruining of a particular crop.*

Although liability for weather modification activities, and "property interests in weather," have been the subject of a good deal of speculation in the legal literature, there have been only six lawsuits in which the questions have been litigated. Of these, three were suits by nearby land-

* The categories are not mutually exclusive. Drought, for example, might belong to both.

owners seeking damages or injunctive relief on account of floods allegedly caused by weather modification activities. In two of the cases the trial court denied relief on the ground that no causal connection between the activities and the floods had been established. The third resulted in a jury verdict for the defendant weather modifier.* The other three suits sought injunctive relief against interference by the weather modifier with the plaintiff's property rights in weather. In one, a suit by resort owners against the City of New York, the New York court held that the public interest in ending a prevailing drought outweighed the resort owners' interest in good weather. In another, the only decision against the weather modifiers, a Texas court granted an injunction against hail suppression activities carried on by farmers in favor of neighboring ranchers who wanted precipitation in any form, including hail. The last of the suits is still pending in Pennsylvania.**

This handful of cases does not, of course, provide a firm basis for predicting how the law will develop. The cases do, however, provide food for thought about a number of aspects of the problem, not the least of which is the preview they afford to the kinds of conflicts one can expect if large-scale weather modification becomes a reality: resort owners against city fathers; ranchers needing precipitation of any kind against farmers wanting to suppress hail; public utilities fearing loss of hydroelectric power against homeowners fearing disastrous floods because of the creation of destructive weather conditions.

The chief obstacle to recovery for damage most likely will be the problem of proving a causal connection between the activity and the damage. It should be stressed that legal causality and scientific causality are two markedly different things. It is quite possible, as the Texas decision underscores, that liability could be imposed in circumstances which might not justify the scientist in finding that a causal relationship existed.

Assuming that the requisite causal connection can be established, the

* The case was based on claimed negligence and the jury verdict could mean either that no negligence was found or that no causal connection was found between the acts complained of and the damage.

** In addition to these actions there is a pending criminal proceeding against weather modifiers for violation of a municipal ordinance prohibiting such activities.

next question is whether the injury is legally compensable. This could depend on the applicable rule of liability, i.e., whether the actor would be liable only in the case of fault, negligence or some more reprehensible conduct, or in the absence of fault under a rule of strict or absolute liability. The applicable rule might in turn depend on the nature of the actor; whether he is a private operator, government contractor, or the government itself. There is not much point in speculating at this time as to the likelihood of a particular rule of liability's being adopted. Suffice it to say that if a causal connection could be established, imposition of tort liability on one theory or another would seem likely.

Where the injury claimed is the reduction or raising of the precipitation level, a substantially different question is involved. The answer will turn on whether or not a person is held to have a property interest in a particular kind of weather. It is much too early to tell how the law will answer the question of who owns the clouds. A number of possible theories have been advanced based on supposedly analogous situations. The right to clouds has been compared to the right to control airspace over one's land; to the right to acquire wild animals by reduction to possession; to rights in water courses, or percolating, or diffused surface waters. The pertinence of some of these analogies is more apparent than real. Rights to airspace, to the extent they are recognized, are justified as necessary to protect enjoyment of the underlying land. The relationship between the underlying land and particular clouds passing overhead, however desperate the need for water may be, is quite different. The considerations bearing on the award of control over clouds are not all the same as those supporting the rule as to animals. A watercourse connotes a stream flowing in a reasonably definite channel with distinct parcels of land bordering on the stream. In the Eastern United States, to the extent that property rights exist, they arise by virtue of the ownership of the bordering land, a circumstance not present in the case of clouds. And the rule of most Western states giving rights to surface water to the first to appropriate it could lead to chaos if applied to water in the atmosphere. Problems of percolating waters, i.e., all subsurface waters other than those in underground streams, are most nearly analogous. But, here again rights, to the extent they exist, are based on ownership of the surface land. This does not mean that there are not valuable lessons to be learned from the development of water law. The adjustment of competing interests, and the handling—especially in the Western States—of the problem of scarcity of vital natural asset give valuable insights. When all is said and done, however, the problems of weather and climate modification are infinitely more pervasive and complex than those of water and should be decided on their own merits rather than on the basis of wholly or partly inapt analogies.

The two cases which have posed the question of "property rights in weather" have reached different results, at least on the surface. In New York, the court, while impliedly conceding some interest of the resort owners in "good weather," felt that their interest was outweighed by the interest of the community in ending a drought. The Texas case, on the other hand, held that the complaining ranch owners had a "natural right to such precipitation (from clouds over their land) as nature chooses to bestow." Carried to its logical conclusion this decision would make possible the barring of any weather modification activities except over one's own land. It should be emphasized that the relief sought in these cases was injunctive, and that conceivably one or both cases might have come out differently if, instead, damages had been sought. That courts would be naturally reluctant to enjoin a municipality's efforts to end a drought because a resort owner's good weather was threatened does not mean that in an appropriate case they would not require the community to recompense the resort owner.* The "natural rights" theory of the Texas decision, while a sufficient basis for enjoying any interference, does not offer much hope for an award of damages in the light of nature's well-known unreliability. If, on the other hand, one measures the Texas decision by the New York test of balancing the interests of the parties concerned, it may represent a not so unreasonable vote for the status quo as between the competing claims of ranchers and farmers.

Interesting as these isolated decis-

* In the actual case, the court found that the experiments by the city would not interfere with the resort owners' business to an appreciable extent.

ions may be, one cannot begin to discuss rights in weather meaningfully until the capability for control becomes clearer. If weather modifications of significance become scientifically feasible, the implications to society and law will be such as to require a rethinking of many legal concepts. Legislation far broader than that suggested below will be needed to order relationships between the various interests, private and governmental, in the light of the new capability. In short, it is premature to make recommendations about the rules of law governing "property rights in weather" or the liabilities of weather modifiers for damages found to have been legally caused by their activities.

It is not, however, premature to make recommendations about one aspect of tort liability. This is with respect to indemnification of persons engaged in weather modification research activities on behalf of the government.* A strong argument can be made that persons who carry on government-sponsored research activities should be protected against liability claims; and that members of the public who are injured as a result of such activities should receive adequate compensation. In most respects the problem is not materially different from the case of other hazardous government activities. The nature of that problem and the possible solutions have been much discussed in recent years and will be touched on only briefly.

The most recent study of indemnification was conducted by the Legislative Drafting Fund of Columbia University for the National Security Industrial Association, under the direction of Professor Albert J. Rosenthal of the Columbia University School of Law. In the report, *Catastrophic Accidents in Government Programs,* the authors, although primarily concerned with Defense Department and NASA activities, pay at least passing attention to weather modification programs. The recommendations of the report can be taken as the starting point for consideration of the problem.

Traditionally, the problem has been

* The problem of tort liability of private operators may be important insofar as they are concerned and, indeed, may be important to members of the public to the extent that there is uncompensated damage for particular activities. At the moment, however, there does not seem to be any justification for a government program to handle liability on account of private operations.

viewed as one of indemnifying government contractors against liability for damage caused the public, although of late it is being seen increasingly as one of protecting the public. However viewed, it is widely agreed that the problem requires legislative solution. Specific legislation has been enacted empowering a number of government agencies to indemnify contractors against liability. Except for the Price-Anderson Amendment to the Atomic Energy Act, no satisfactory legislation to deal with potentially castastrophic liability has been enacted.

Quite apart from the question of protection of the public and fairness to the contractor is the question of government self-interest in having research performed. In this respect there are already some intimations that the problem of liability may have an inhibiting effect on research.*

Unless frustrated in administration, an indemnification statute could provide a satisfactory answer to the problems of contractors.** From the point of view of the public the protection afforded is indirect. While government indemnity ensures payment of a judgment once secured, up to the limit of any ceiling on liability which may be imposed, it does not affect the right of a member of the public to a judgment in the first instance.

Whether the government should go beyond mere indemnification and more directly ensure public protection, for example, by enacting a law of strict liability for contractual activities, is a subject now being debated in the Defense Department and NASA. In extending the Atomic Energy Indemnification legislation the Joint Committee on Atomic Energy specifically called attention to the need for inquiry into that problem. Not much point is seen in adding to that discussion. As a general rule a member of the public injured as a result of government-supported weather modification research should be treated the same as one injured by DOD or NASA activities. It is to be hoped that indemnification legislation covering those agencies and others will soon be en-

* "Introduction to Weather Modification: Law, Controls, Operations," H. J. Taubenfeld, *et al*, to be published by the National Science Foundation in January 1966. See the Appendix.

** We have discussed the problem in terms of *contractors*. It is conceivable that similar problems would be met in the case of grantees, and there is no theoretical reason why they too should not be covered where appropriate.

acted. Weather modification activities should be covered. It is more important that some protection be afforded than that equality of treatment be preserved. If no general legislation is enacted, special indemnification legislation for weather modification should be. Needless to say, this recommendation should not be construed as implying that any causal connection between particular weather modification activities and injuries to property has been established. As noted above, legal cause may be found whatever the opinions of scientists, and it is the risk of liability rather than the scientific reality which is important here.

The second area of involvement of weather modification with the law is that of regulation. Considering the small amount of activity in the field, the amount of State legislation is rather staggering. Twenty-two States now have statutes dealing with at least some aspects of weather modification and others have legislation under consideration. Most of the statutes date from the period of the early and middle 1950's, but a few have been enacted in the last five years.

In general, State statutes can be divided into two broad classes: 1) those the primary aim of which would seem to be active control of weather modification activities with the collection and evaluation of scientific information as an important adjunct of control; and 2) those which aim primarily at the collection and evaluation of information. In the first and larger group restrictive laws necessitate a license or registration for operation. Where a license is required, it usually can be obtained only after a statement is filed showing the qualifications of the operator, his financial responsibility, the nature of the proposed work and the payment of a fee. Only two of the States list specific criteria of competence. In one case the operator must be a professional engineer. In the other the operator must be a member of, or qualified for membership in, the American Meteorological Society. The methods of assuring financial responsibility differ widely as well. Public notice is often required before activities can be undertaken. As a general rule qualifications, financial responsibility, etc. are evaluated by boards and commissions. At least eight States have special weather control boards, presumably with special expertise in the field. Most States require reports after the conduct of the weather modification activity.

Several States assert sovereign rights to the moisture in the clouds or atmosphere above their land mass. New Mexico, Louisiana and Colorado limit weather activities which may affect other States, although in the case of the latter two, only on a reciprocal basis. One State, Maryland, has now barred all weather modification activities for a two-year period. The Pennsylvania legislature recently adopted a bill to prohibit all weather modification activities except research by universities and the State and Federal governments. The bill was vetoed by the Governor.

To gauge the operation and administration of these statutes, the Commission sent questionnaires to all States and all known commercial operators and researchers active in the field. The answers to those questionnaires, which are analyzed and summarized in the report referred to above entitled "Weather Modification: Law, Controls, Operations," would indicate that the effect of regulatory legislation on weather modification has been slight. To be sure, there were instances of dissatisfaction, but little evidence that existing laws have caused any substantial dislocation to operators. It is interesting to note that, nevertheless, there was a widespread agreement that Federal legislation would be welcome.

For present purposes, the significance of State regulatory legislation is not so much its past effect but its potential impact on programs which may be desirable. Obviously, any legislation which prohibits weather modification activities—if construed to apply to research as well as commercial activities—could have a serious effect on desirable programs. State licensing requirements in some circumstances could place a serious burden on any experiment crossing State lines, and most experiments of any size would be likely to do so. The nature of the subject, including the likelihood that the effects of activities will not be restricted to a single State make it seem probable that Federal regulatory legislation will ultimately be needed. The question of immediate interests is whether anything needs to be done now.

At the present time, the only Federal "regulation" of weather modification activities is the report form required to be filed annually by all operators of whose activities the National Science Foundation has become aware. The report is required pursuant to the authority of the Foundation under PL 85-510, "to obtain by regulation, subpoena, or otherwise, such information . . . as may be deemed necessary or appropriate . . . to carry out . . . the program of study, research and evaluation in the field of weather modification." This after the fact system of information collection has recently been changed. Effective January 1, 1966, the Foundation adopted a new regulation requiring that all weather modifiers keep certain records, and, in addition, give the Foundation thirty days' advance notice of any proposed activity. The purpose of the record-keeping requirements is, in the words of the Regulation, "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 . . ."

It is too early to tell how the new regulation will work, and whether its objective will be accomplished. While it is conceivable that no additional action will be necessary, it seems likely that even for the immediate future further steps will be necessary. Fulfillment of the objectives of the program recommended in this report requires that research have a very high priority. This means that State and local legal rules cannot be permitted to interfere with research objectives. Interference can be of two kinds. First, the local rules may impose liability for injuries caused by research projects; the threat of liability may act as a deterrent to researchers. For the reasons set forth above, it is not believed that the time is ripe for postulating new rules of liability. Consequently, the best way of dealing with the possibility of this kind of interference is by indemnity or other protection against liability.

There remains, however, the possibility of direct interference by injunction, either pursuant to a statute or ordinance forbidding or restricting weather modification activities, or as in the Texas case under the courts' general power to prevent interferences with property rights. It is worth noting that where timing is important, even a temporary injunction can have disastrous effects on a research project. So long as the work is carried on directly by the Federal government it would seem to be immune to injunction. If it were carried on by a government contractor, whether a private company or an institution, the immunity would be much less clear. And, where research is carried on pursuant to grant, there would appear to be no governmental immunity whatsoever. Provision should be made to ensure that all properly conducted experiments including those conducted by contract or grant should be immune to local interference.

A somewhat different problem is posed by the possibility that some weather modification activities may physically interfere with government activities. As pointed out elsewhere in the report, the nature of cloud-seeding experiments is such that there is a real possibility of contamination by other seeding operations in the same general location. Such contamination can be expensive and scientifically catastrophic in view of the limited opportunities available for some kinds of research. A part of the problem can probably be taken care of by the proposed Foundation regulations requiring advance notice of all operations. But advance notice may not be enough; in some cases it may be desirable to stop the interfering weather modification activity. If those activities are carried on by other researchers, whether or not Federally supported, persuasion will probably be sufficient. Where commercial operators are involved persuasion may be less effective. In either event, power to halt interference should be available where necessary to protect the integrity of government operations. The power does not exist today. The power to halt interference and the immunity from state interference need not be unlimited. Room can be left for reasonable accommodation of the needs of local governments. But, priority of the Federal program must be established.

One other suggestion for regulation —that private operators be required to evaluate their operations—should be discussed. Because of the nature of research in weather modification, and the nature of the problem of evaluating results, it would be particularly desirable to use all experiences including those of private operators. If full advantage is to be taken of their experiences, they should be carried on and evaluated in accordance with prescribed methods of project design, analysis, etc. Where government contractors or grantees are involved this should not pose any great difficulty. The case is different with private operators where, among other objections, the increased cost of operation might be prohibitive. For the moment it is felt that no such requirements should be imposed on private operators, but the situation may change rapidly. In the meantime, study should be given to the legal obstacles, if any, to such a requirement, and the desirability or necessity of government financing of the evaluation.

Thus the Commission recommends that the Federal Government by appropriate legislation be empowered to:

1) delay or halt all activities—public or private—in actual or potential conflict with weather and climate modification programs of the Federal government, whether carried on by the government itself or by its grantees or contractors;

2) immunize Federal agents, grantees, and contractors engaged in weather and climate modification activities from State and local government interference; and

3) provide to Federal grantees and contractors indemnification or other protection against liability to the public for damages caused by Federal programs of weather and climate modification.

In view of the state of the art, it would seem appropriate to limit regulation to the least amount consistent with achievement of the objectives of the program. The Commission's recommendations are deliberately restricted in scope. It would be well to note, however, that as the art develops, and as weather and climate modification activities increase, comprehensive regulation seems inevitable. Such regulation will probably require the setting of minimum standards of competence, and perhaps financial responsibility, for all operators and the establishing of some authority for deciding between competing claims for priority. What the proper amount of regulation is will depend on how rapidly the field expands. It may be that the findings of the NAS Panel will stimulate very rapid expansion of field programs. The regulatory program may well have to keep pace.

Whatever regulation is decided upon must be national in scope. While it may be that some activities will have effects limited to the boundaries of a particular State, it seems likely that such cases will be exceptional. Whether there will be any need for or utility in simultaneous regulation by the States will depend on the nature of the Federal program and the development of the technology. It may be that regulation at the national level will be sufficient, or indeed, that exclusive Federal control is demanded. Such questions can be left for the future. For now it would not appear necessary to intrude on state programs, provided only that they do not have the effect of impairing the Federal effort.

Domestic regulation, whether wholly national or mixed national and state, should not be regarded as all that is necessary. Global phenomena are involved in the weather and effective regulation must ultimately be global in character. It is to be hoped that as the needs of an adequate regulatory system become defined, efforts will be made to establish the system on an international basis.

With respect to the weather modification prohibition bill recently vetoed by the Governor of Pennsylvania and referred to on page 108 this chapter, subsequently on November 9, 1965 the Governor signed into law Act No. 331 granting to each of the counties the optional authority to prohibit any weather modification activities deemed detrimental to a county's welfare.

WEATHER MODIFICATION AND INTERNATIONAL RELATIONS

The major impulse behind the development of a national program of weather modification arises in association with problems encountered within the United States. Efforts to develop or apply weather modification techniques on the part of governmental agencies, research institutions and commercial enterprises have focused mainly on domestic problems and have been carried out primarily within the borders of this country or over the open seas. It might seem, therefore, that weather modification had little to do with international relations or considerations of foreign policy. This would, however, be an erroneous view. The active interest in the subject displayed in foreign countries and in international organizations, the international impact of projected research and operational programs and the contribution which a weather modification program could make to the foreign policy objectives of the United States are indicative of the international implications of this area of scientific effort.

The evidence before us suggests that attempts to augment rainfall over areas of a few thousand square miles may have effects that may extend many miles downstream from the site at which the seeding agent is introduced into the atmosphere—clearly far enough in some instances to cross national boundaries. The probability of success in such activities is now sufficiently high to warrant immediate attention to their implications for international relations. The possibility of downstream diminution of rainfall—though small—cannot be completely ignored, with even greater implications for international problems in equitably sharing a natural resource. If the political problems are sufficiently near at hand to suggest Federal, rather than State, regulation domestically (see the chapter in this report on Legal and Legislative Aspects), it is not too early to give some attention to the international political problems and opportunities.

Rudimentary attempts have already

As a basis for the preparation of this chapter of the report, members of the Commission, in addition to reviewing the limited literature bearing upon the subject, consulted with a number of government officials and persons in private life experienced in international affairs and particularly international scientific programs. The Commission also obtained a report on international relations and weather modification from Leonard E. Schwartz of Operations and Policy Research, Inc. of Washington, D. C. See the Appendix.

been made to influence the intensity of hurricanes over international waters. Although no success has been claimed, the probability of success in future attempts is somewhat greater than zero. A similarly small probability of success will be applicable to attempts to influence the direction of movement of a hurricane when those attempts are made. Not much imagination is required to envision the kind of international political problems that might ensue should those small probabilities of success be realized.

Even graver problems, though much more remote, arise in the matter of possible modification of the climate over areas of subcontinent size. The fundamental unity of the global atmosphere and the close coupling and interaction that exist among the major components of planetary wave are well recognized characteristics of the atmosphere. The situation in which a drought of many months duration in one section of the United States occurs concomitantly with above normal rainfall in another section can be generalized. If one day it turns out to be possible to exercise meaningful modification of the weather or climate over one region of the earth's surface it is quite possible that a compensating alteration will take place in the atmosphere over some other region.

There is the very long-range matter of influencing the world-wide climate either by conscious intervention through exploitation of triggering effects or inadvertently as the multifarious activities of an expanding population exert an ever more profound influence on man's natural environment. In the latter case, issues arise that transcend national considerations and affect all mankind.

The salient points can be summarized:

1. For each identifiable class of meaningful modification of weather or climate (e.g., dissipation of supercooled fog, augmentation or redistribution of rainfall, suppression of hail, altering the intensity or causes of hurricanes, large-scale modification of climate), there exists a probability of success. The probabilities range from very high for supercooled fog through something greater than 50 percent for rainfall, down to very low but greater than zero for large-scale climate effects.

2. The implications for international relations of success in each class of weather and climate modification depend on the particular class in ques-

tion. For example, the implications are minor in the case of supercooled fog, quite significant for rainfall, large for hurricanes, and very large indeed for world climate.

3. In contrast to the situation existing a decade or so ago, now at hand are the scientific and technological tools to explore the limitations and practical applications of each class of activity.

INTERNATIONAL PROGRAMS RELATED TO WEATHER MODIFICATION

International cooperation in the study of the earth's atmosphere has been carried on for many years through both governmental and private agencies. Official international activities in this field have been centered in the World Meteorological Organization (WMO) established in 1947 primarily in connection with the collection of weather data for forecasting purposes. In the non-governmental area, the International Council of Scientific Unions (ICSU) and its constitutent bodies have played a central role. Such large world-wide programs of scientific research as the International Geophysical Year (IGY) and the International Years of the Quiet Sun (IQSY) have not only widened man's knowledge of the factors bearing upon the atmosphere and consequently weather and climate, but have also demonstrated new and imaginative patterns of international cooperation.

The United States Government has for some years participated in bilateral cooperation with other governments in the field of meteorology with emphasis upon weather forecasting. The agreement with the Soviet Union announced in October 1964 for the exchange of meteorological satellite data between Moscow and Washington over a special twenty-four hour communications link is one of the most recent and interesting examples of this bilateral cooperation. An example of bilateral cooperation having world-wide ramifications is the TIROS weather satellite program developed by the U. S. Weather Bureau and the National Aeronautics and Space Administration. Under this program the United States is now making available valuable meteorological data collected by a TIROS satellite and immediately transmitted to receiving stations in foreign countries over a specially devised communications system.

Multilateral international activities more directly related to the problems of weather modification were stimulated by President Kennedy's speech to the General Assembly of the United Nations in September 1961, in which he appealed for international cooperation in the peaceful uses of outer space. The Assembly responded by adopting Resolution 1721 (XVI) in December of that year, Part C of which contained recommendations for advancing the state of the atmospheric sciences with a view to determining the possibility of large-scale weather modification and for developing an improved system of weather forecasting. The principal responsibility for carrying out the necessary studies and planning with respect to weather forecasting was placed upon the WMO, while ICSU was subsequently invited to formulate additional suggestions for advancing research in the atmospheric sciences. The development of the improved world weather system (subsequently named the World Weather Watch) through the WMO and of the basic research program through the ICSU are closely related, in that the projected system of data collection and processing will serve the purposes of both.

Weather modification is thus intimately related to the broader program of international collaboration in the atmospheric sciences which has emerged during the last three or four years and which consists of the following four main elements:

1. The program of atmospheric research now being planned in the World Meteorological Organization and the Inter-Union Committee on Atmospheric Sciences of ICSU;

2. The World Weather Watch being developed through the World Meteorological Organization;

3. A climatological program aimed at an improvement in the description of world-wide climate with a view to facilitating the better utilization of land and water resources and ultimately contributing to the objective of modifying climatic conditions.

4. Strengthened educational programs to provide the scientific and technical manpower required for the overall program.

The scientific community of the United States has played a major role in the formulation of this program and is continuing to do so. Moreover, the U. S. Weather Bureau has had a prominent part in the development of plans for the World Weather Watch and the program of atmospheric science research being developed by the WMO. The interchange of ideas and the close collaboration that has been effected between scientists in the government and in private institutions—and between those primarily engaged in research and those occupied in governmental weather services—have proved important in reflecting the views of a broad cross-section of the scientific community and in assuring that the requirements of both research and operations receive proper and adequate attention. It is hoped this complementary relationship will continue not only on a national but also on an international level.

INTERNATIONAL REQUIREMENTS OF RESEARCH

The broad program of research outlined in earlier chapters of the Commission's report demonstrates the need for approaching problems of weather and climate modification with a strong emphasis upon international cooperation. To be sure, much of the research to be undertaken will be carried out within the borders of the United States. Nevertheless, the extensive and significant work that is being done in other countries underscores the need for promoting the international exchange of data and research findings for the purpose of maximizing their usefulness. The need for international collaboration in the actual planning and conduct of research activities may be expected to increase as research moves out of the laboratory and into the realm of field experiments associated with the study of the dynamics of climate, the establishment of a global weather observation network (which supports the numerical simulation program) and the investigation of other aspects of the general atmospheric circulation. Proposals for research already advanced, such as those involved in the World Weather Watch, involve a reliance upon widespread international collaboration in data collection. They require the selection of areas of study far removed from the United States, such as land and sea areas in the southern hemisphere and the polar regions. Both the basic knowledge gained in such investigations, and its practical application to weather forecasting and weather and climatic modification, will be of great interest to many countries. The technological and human resources required for the conduct of this type of research are far beyond the capability of most countries to provide individually. Increased international collaboration in such endeavors would seem, therefore, to be inevitable.

Looking into the future to the time when field experiments with weather or climate modification are expanded in scope and number and involve actual attempts to introduce changes in the atmosphere, some form of international collaboration will be essential in the planning and execution of projects that may have an impact not only upon the immediate localities but on areas in other countries and even upon other continents distant from the scene of work. It is possible situations of this sort may arise in the near future if an expanded program of field experiments in cloud seeding is undertaken in areas near the northern or southern borders of the United States. An expansion in experimentation with tropical hurricanes may also present international complications heretofore avoided.

WEATHER MODIFICATION AND WORLD POLITICS

In the present stage of world affairs any scientific advance contributing significantly to man's ability to affect the natural environment has a bearing upon the political relations among states and the quest for peace and security. The importance to military operations of a capability for modifying local weather conditions is obvious. Moreover, in view of its potentially spectacular character and its important consequences for the welfare of all nations, a capability for significant weather modification would augment the prestige and political influence of the country which first achieved it.

Nor can it be overlooked that an ability to control weather conditions could have an effect upon international conflicts apart from the range of strictly military operations. The effective precipitation of water from moisture-laden clouds over the territory of one State to the real or imagined detriment of an adjoining State normally dependent upon the same sources of atmospheric moisture, could easily serve to stir up international controversies and exacerbate existing tensions. Even the remote possibility that a nation might develop a capability of using weather modification measures to damage the economy and civil population of another country must be recognized.

RELATION TO U.S. FOREIGN POLICY

It should be clear that a long-range program of weather and climate modification can have a direct bearing upon the main purposes of American foreign policy. It can contribute to defending the security of the United States and other nations of the free world. It can aid the economic and social advancement of the developing countries, many of which face problems associated with adverse climatic conditions and serious imbalances in soil and water resources. It can serve as a new and widening area for the development of common interests with both friends and present adversaries, and thus stimulate new patterns of international cooperation.

The challenge and the opportunity presented to the world community by the prospect of man's achieving the ability to modify the atmospheric environment form one of the most exciting long-range aspects of the subject. It involves the possible acquisition of a new and enormous power to influence the conditions of human life. The potentialities for beneficial application are vast, as are also the potential dangers. It is in the long run essential to develop political and social controls over the use of this power which will maximize the opportunities for its constructive, peaceful use and minimize the factors which tend to involve it in the tensions and conflicts inherent in human society.

The very fact that the development of a capability for influencing the atmospheric environment is still in its infancy should widen the opportunity presented by this scientific endeavor to develop attitudes and patterns of collaboration which can contribute not only to the achievement of the practical technological goals, but also to the relaxation of international tensions. Vested national interests in technological achievement in weather modification are still limited. In contrast to the field of atomic energy and developments in outer space, no nation has yet forged a weapons system in the field of weather or climate control that can threaten the security of another country. Moreover, while political influences have by no means been totally absent in even the restricted international programs that have so far been initiated in the atmospheric sciences, no major political issues have yet been raised on which rigid and irreconcilable positions have been taken. Small beginnings in collaboration on problems of weather and climate have already been made which could prove useful in helping to build the habit of cooperation and in stimulating a pragmatic recognition of the material advantages to be derived from that approach.

INTERNATIONAL IMPACT OF U.S. PROGRAM

The growing recognition of the efficacy of certain cloud-seeding practices, coupled with an increased public demand for rain-making operations stimulated by a series of dry years in the United States, will no doubt produce a greatly enlarged interest and activity in connection with weather modification. Field experiments conducted both by governmental and private agencies may be expected to expand. Commercial operations may well increase. Larger public appropriations for weather and climate modification purposes will be sought and probably made. Legislation dealing with various aspects of weather and climate modification will be considered and probably be enacted.

An expanded United States activity in weather and climate modification cannot fail to have its impact upon governments and public opinion in other countries. Questions will arise as to the exact level of capability achieved by the United States in affecting weather; the potential benefit or danger which this power to influence the atmosphere may imply for other countries; and the policies and purposes that will guide the United States in the development and exercise of this new technology.

ORGANIZATION OF INTER-GOVERNMENTAL COOPERATION

The responsibility for promoting inter-governmental cooperation and contacts on the scientific and technical level with respect to weather and climate modification be recognized in whatever administrative arrangements are decided upon for the national program in this field. The close relationship of weather modification to other programs and responsibilities of the government would, of course, require an adequate system of inter-agency coordination in connection with United States participation in international weather and climate modification activities.

The formal adoption of a policy of international cooperation for the peaceful development of weather and climate modification would confirm and support the limited but significant cooperation now being extended by governmental and private agencies of the United States in this field. It should provide an impetus for further activities of this sort by the various interested agencies and organizations through both bilateral and multilateral channels of contact with foreign countries. The policy decision should also lay the basis for the planning of future programs and the anticipation and study of problems associated with the international aspects of modification activities.

The Commission endorses support by the United States of the World Weather Watch and the program of research in atmospheric science being planned by the WMO and ICSU. As a further measure of international cooperation, the Commission urges that if a national laboratory is established, it be given a mandate to promote the wide participation of foreign governmental and private institutions in the development of research programs of international interest. The successful execution of this function by a United States national institution might pave the way for the future establishment on a truly international basis of one or more centers devoted to the cooperative study of the atmosphere and its intervention in the interests of human welfare.

SCIENTIFIC AND TECHNICAL EXCHANGE

In the basic field of international exchange of information and technical cooperation several problems present themselves. A major limitation affecting both advanced and developing countries is the shortage of trained personnel in atmospheric sciences at all levels. The growing discrepancy between the advanced and developing countries in this respect imposes a further obstacle to genuine international cooperation. Attention should be given to the question of how greater emphasis can be given to atmospheric sciences in existing bilateral and multilateral programs of education and technical cooperation, and to what additional measures may be needed to fill any deficiency.

Encouragement should also be given to the development of basic research on the impact of weather modification measures in foreign countries. Other chapters of this report have indicated the need for greater attention to the biological and economic and social aspects of weather modification in the United States. A different set of problems may well be encountered in many of the less developed countries where the natural environment and patterns of economic and social life present contrasts to those prevailing in this country. A greater understanding of the significance of these differences must precede any attempt to evaluate the suitability of various weather modification practices for specific foreign areas and to design appropriate programs of cooperation. The opportunity for international cooperation in such research programs is obvious.

INTERNATIONAL LEGAL PROBLEMS

Some form of international regulation of weather modification activities will no doubt become essential in the future as research and operational activities increase in number and extent. One forum for the international consideration of legal aspects of this problem, insofar as they concern activities in outer space, already exists in the legal subcommittee of the Committee on Peaceful Uses of Outer Space of the United Nations General Assembly. Little attention has yet been given, however, to such basic questions as the proprietary rights of states to the atmosphere passing over their territories; the liabilities of states for damage inflicted upon the adjoining states as a result of deliberate or inadvertent tampering with the atmosphere; or procedures for advance notification or consultation regarding projected weather modification measures capable of affecting other states; etc. If international regulations are formulated, the whole question of enforcement likewise comes to the fore.

QUESTIONS OF INTERNATIONAL ORGANIZATION

Looking even farther ahead, thought must be given to the types of international organization that will be needed, and the functions they should perform, if and when operations in weather and climate modification affecting large continental areas become feasible. At present international organizations in the field of atmospheric sciences are of the traditional, general membership variety with limited functions of information exchange and voluntary coordination of national programs. Whether the assignment of operational responsibility to an international agency should be considered for the future deserves thought even at this early date. What new concepts of international organization suggest themselves for that purpose and what new problems of a technical or political nature would be precipitated by such a plan? Considerable light may be thrown on these questions by the experience to be gained in the global observation program now being planned in connection with the World Weather Watch.

Steps should be taken by the United States, in concert with other nations, to explore the international institutional mechanisms that may be appropriate to foster international cooperation and cope with the problems which may be anticipated in the field of weather and climate modification. The United Nations and its specialized agencies (e.g. the World Meteorological Organization) is suggested as a possible governmental framework. The International Council of Scientific Unions and its associated unions (e.g. the International Agencies of Geodesy and Geophysics) could be a suitable non-governmental framework for these mechanisms.

Rarely has a more inviting opportunity been offered for advance thinking and planning regarding the impact of a technological development upon international relations. It is hoped that government agencies, universities, research institutes, centers of international studies, societies of international law, as well as individuals will take advantage of this possibility of contributing to the maximum utilization of the anticipated capability of affecting weather and climate in the interests of peaceful world development. Progress in the diminution of international tensions and the achievement of peace will come not so much from the dramatic resolution of basic international controversies as from the far less spectacular growth in ways of cooperation and from the widening of areas of mutual interest among rival nations.

RECOMMENDED BASIC POLICY STATEMENT

The Commission believes that it would be highly desirable for the Government of the United States, in connection with the expansion of its program of weather and climate modification, to issue a basic statement as to how it views the relationship of this new national effort to the interests, hopes and possible apprehensions of the rest of the world. The Commission further believes that emphasis upon international cooperation in the development of weather and climate modification programs will contribute substantially to scientific and technical progress and will also serve the national purpose of seeking to build a peaceful world order.

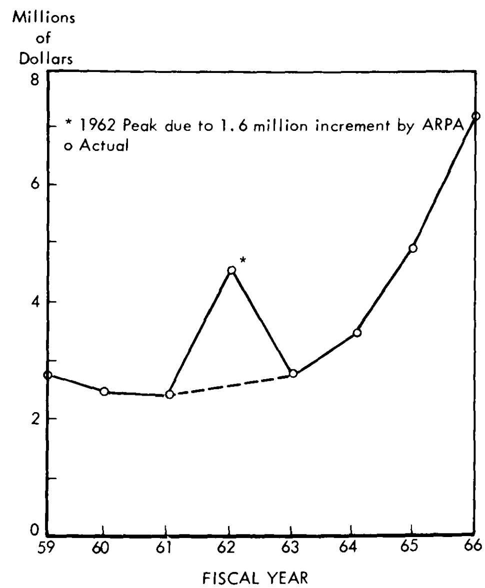
The Commission recommends the early enunciation of a national policy embodying two main points: 1) that it is the purpose of the United States, with normal and due regard to its own basic interests, to pursue its efforts in weather and climate modification for peaceful ends and for the constructive improvement of conditions of human life throughout the world; and 2) that the United States, recognizing the interests and concerns of other countries, welcomes and solicits their cooperation, directly and through international arrangements, for the achievement of that objective. This cooperation should cover both research and operational programs of interest to other countries. It should be concerned not only with deliberate but also inadvertent human interventions in the atmosphere that affect weather and climate. Such a policy declaration could be issued by the President or incorporated in any basic legislation on the subject of weather and climate modification which the Congress may enact.

FEDERAL FINANCIAL SUPPORT OF WEATHER AND CLIMATE MODIFICATION

Present Support

The chart set forth below shows that with the exception of FY 1962 the total Federal government support of agency research and development programs in weather and climate modification remained at about the same level during the first 5 years after the initial funding of the National Science Foundation program in FY 1959 and increased at the rate of 35-40% per year in the last 3 fiscal years.

Federal Funding of Weather Modification Programs



Source: National Science Foundation

FUNDING AND ADMINISTRATION REQUIREMENTS

The table below displays the last fiscal year 1965 and the current fiscal year 1966 budgets of each of the seven agencies in terms of the six goals for weather modification research established by the Interdepartmental Committee for Atmospheric Sciences (ICAS).

FEDERAL WEATHER MODIFICATION PROGRAM
(millions of dollars)

Department or Agency	Fog & Cloud Diss.	Precip. Modif.	Hail Supp.	Lightning Modif.	Severe Storm Modif.	Other	Total
			FY 1965				
Agriculture	—	—	—	0.14	—	—	0.14
NSF	—	1.55	—	0.23	—	0.22	2.00
Commerce	—	—	—	—	0.10	0.02	0.12
Army	0.16	—	—	0.09	—	—	0.25
Navy	0.71	—	—	—	0.20	—	0.91
Air Force	0.25	—	—	—	—	—	0.25
Interior	—	1.26	—	—	—	—	1.26
TOTALS	1.12	2.81	—	0.46	0.30	0.24	4.93
			FY 1966				
NSF	0.03	1.22	0.35	0.10	0.10	0.20	2.00
Commerce	—	0.035	0.035	0.13	0.32	0.13	0.65
Army	0.16	—	—	0.09	—	—	0.25
Navy	0.71	—	—	—	0.20	—	0.91
Air Force	0.26	—	—	—	—	—	0.26
Interior	—	2.98	—	—	—	—	2.98
Agriculture	—	—	—	0.14	—	—	0.14
TOTALS	1.16	4.235	0.385	0.46	0.62	0.33	7.19

These tables indicate that the seven agencies reported to ICAS budget totals of $4.93 million for FY 1965 and $7.19 million for FY 1966 in direct support of weather modification.

For purposes of understanding the relationship of the current support for weather and climate modification research to the support for the overall scientific research programs and services of which it is a part, there are set forth below tables displaying the FY 1965 and 1966 total Federal budget for atmospheric sciences and meteorological services.

Federal Funds for Atmospheric Sciences and Meteorological Services
(millions of dollars)

	*FY 1965**	*FY 1966*
Aeronomy	110.7	111.3
Meteorology	98.3	116.0
Total Atmospheric Sciences*	209.0	227.3
Total Meteorological Services**	261.2	273.3
Grand Total Atmospheric Sciences and Meteorological Services	470.2	500.6

* Source: Interdepartmental Committee for Atmospheric Sciences

** Source: Office of the Federal Coordinator for Meteorological Services and Supporting Research

Need for Increased Support for Research, Development, and Operations

The Commission recommends that the total current FY 1966 budget for climate and weather modification research of approximately $7.2 million be increased by 1970 to $20 to $30 million or approximately 5% of the total current FY 1966 budget of $500.6 million for both atmospheric sciences and meteorological services. Additional increases of the same order are needed for basic research and for large computing facilities, making for a total increase of $40 to $50 million per year by 1970.

At present weather and climate modification research represents less than 2% of the current budget for the scientific research programs and services of which it is an integral part. The foregoing recommendation would mean that the total budget for weather and climate modification research would be maintained at the same rate of increase of the last 3 fiscal years, namely 35-40 percent per year, in order to reach a support level of $20 to $30 million per year by FY 1970.[1] Additional amounts will be needed for underlying basic research activities and the provision of large computing facilities.

This recommendation is in recognition of the uncertainties in the state of knowledge and potentialities in the field of weather and climate modification and the diversity and magnitude of effort required to exploit the possibilities which have been discussed elsewhere in this report. Weather and climate modification research should now have a more important role in research and development in the atmospheric sciences. Large, scientifically designed and controlled field experiments are needed. Associated biological and social science research is desirable to measure the effects of

[1] These figures include applied research and immediately supporting basic research for increasing precipitation by seeding, suppression of lightning and hail, fog and cloud dispersal and severe storm modification. They do not include the longer range basic research studies required for assessment of advertent and inadvertent modification of climate.

experiments on the ecological and social systems. Required also are costly logistics support, aircraft, instrumentation, larger computers, laboratory models of the atmosphere, and perhaps synchronous satellites and ecology laboratories.

The Commission recommends that a new research and development capability be established—similar perhaps to a national laboratory—for the purpose of providing the necessary resources of scientific leadership and logistic facilities necessary in the mounting of an expanded interdisciplinary program of weather and climate modification.

A national laboratory type of capability is needed which could form the organizational and scientific manpower nucleus for an expanded research and development program. The costs of such a capability are not included in the foregoing estimates and recommendations. The organizational structure for this capability should provide machinery for assuring an interdisciplinary approach to weather and climate modification—encompassing the physical, engineering, biological and social sciences.

One can not comment conclusively on the required nature, organization and financing of the new research and development enterprise described here. The need is clear; the question is how. The President's Special Assistant for Science and Technology might wish to initiate the appropriate feasibility studies as to the nature, precise functions, and location of the new enterprise.

ADMINISTRATION

Existing Statutory and Administrative Directives

a. *Coordination of Scientific Policy*

Both the Federal Council on Science and Technology and the National Science Foundation have responsibilities with regard to scientific policy on weather modification research and operations. The Federal Council, under the Chairmanship of the Science Advisor to the President, is given general coordinating responsibility for science policy within the executive branch of the Government. This authority is provided both by Reorganization Plan No. 2 of 1962 and Executive Order 10807 of March 13, 1959.

The Federal Council, under the provisions of Executive Order 10807, is charged with the following responsibilities:

Sec. 2. Functions of Council (a) The Council shall consider problems and developments in the fields of science and technology and related activities affecting more than one Federal agency or concerning the overall advancement of the Nation's science and technology, and shall recommend policies and other measures (1) to provide more effective planning and administration of Federal scientific and technological programs, (2) to identify research needs including areas of research requiring additional emphasis, (3) to achieve more effective utilization of the scientific and technological resources and facilities of Federal agencies, including the elimination of unnecessary duplication, and (4) to further international cooperation in science and technology.

The Advisory Committee on Weather Control recommended that the National Science Foundation coordinate weather modification research. Under the authority of PL 85-510 and the legislative history thereof, the Foundation was expected to take the lead among the various Federal departments and agencies in the support of weather modification research. The Foundation complied by supporting sponsored research which provided the underpinnings for the more mission oriented programs of other agencies. The Foundation established and has continued an annual Interagency Conference on Weather Modification, which has become a focus for government-wide program planning and coordination.

At about the same time that the Federal Council for Science and Technology was established in 1958, the National Science Foundation recognized the need for a formal interagency coordinating mechanism in connection with its newly assigned statutory responsibility in the field of weather modification by establishing an Interdepartmental Committee on Weather Modification. During the June 1959 meeting of the Federal Council there was discussion concerning the establishment of a Committee to cover the field of Atmospheric Sciences. The President's Science Advisor and the Director of the Science Foundation agreed that the Foundation existing

Interdepartmental Committee on Weather Modification could serve the needs of both the Federal Council and the Foundation. As a result, the Interdepartmental Committee on Weather Modification was formally reconstituted as the Interdepartmental Committee for Atmospheric Sciences (ICAS) and held its first meeting as such on September 9, 1959.

Thus, general coordination on behalf of the President's Executive Office with regard to research in this and related fields is exercised by one of the committees of the Federal Council on Science and Technology—the Interdepartmental Committee for Atmospheric Sciences (ICAS). Within ICAS is a panel on weather modification research which is chaired by the Head of the Section on Atmospheric Sciences of the Foundation.

b. *Support of Research by Individual Agencies*

Since 1940 the Federal Government has assumed an increasingly important role in the financing and conduct of scientific research and development in this country. This has been especially true in the natural sciences and engineering. In recent years, however, the Foundation and other agencies have become significant supporters of research in the social, as well as the natural sciences.

Research is supported not only to accomplish agency missions—usually as a forerunner to development—but also to increase the broad body of scientific and technical knowledge which underlies the future advancement of the Nation's welfare, economic growth, and security. This is particularly true of basic research conducted primarily in academic institutions but also in government, industrial, and other laboratories focusing on fundamental problems in science.

The President's budget for FY 1966 contemplated an outlay of $14.5 billion for research and development of which $4.9 billion was estimated for research and of which $2 billion is for basic research.

Executive Order 10521 issued in March, 1954 and amended in March, 1959 provides that:

Sec. 4. As now or hereafter authorized or permitted by law, the Foundation shall be increasingly responsible for providing support by the Federal Government for general-purpose basic research through contracts and grants. The conduct and support by other

Federal agencies of basic research in areas which are closely related to their missions is recognized as important and desirable, especially in response to current national needs, and shall continue.

In other words the Foundation is charged with the support of basic research across the board and individual agencies are authorized to conduct and support such basic research as is necessary to sustain their operational missions.

c. *Conduct of Weather Modification Research Programs*

1. *National Science Foundation*

Public Law 85-510 directs the Foundation "to initiate and support a program of study, research, and evaluation in the field of weather modification, giving particular attention to areas that have experienced floods, drought, hail, lightning, fog, tornadoes, hurricanes, or other weather phenomena, and to report annually to the President and the Congress thereon." The Foundation's responsibility is therefore not only to support weather modification research, but to present an overview of the state of knowledge and effort in weather modification. It also promotes the exchange of information about the plans and programs of the various Federal agencies and provides for cooperation and coordination at the working level through various mechanisms, including the annual Interagency Conference on Weather Modification, where much of the current Federal interest in weather modification has been kindled.

Despite the broad statutory language cited above, the Foundation has elected to confine its research activities to basic research, generally of the type that the Foundation would or could have supported anyway under its general authority to support basic research in the sciences. The Foundation selected as the first necessary task the development of a sound scientific basis for the art of weather modification. The stature of the Foundation gave creditibility to a field which had been plagued with a lack of technical and scientific understanding. The Foundation approached the leading meteorologists and other scientists with financial support to undertake scientific investigations to open the doors of knowledge.

The research-support program is managed as an integral part of the Foundation's over-all program of investigation in the atmospheric sciences. The dividing line between research in weather modification and basic research in the atmospheric sciences is difficult to draw, especially when so much more fundamental knowledge is required to provide the scientific basis for a successful national program for developing new and improved weather modification techniques.

Through grants with key university groups and through the contract support of the National Center for Atmospheric Research (NCAR) the Foundation has given special emphasis to studies on the development of models to describe the natural processes which produce the clouds, the weather, and the general circulation of the atmosphere. Many problems confront the designer of such a theoretical model, among which are the inadequate observations of natural phenomena to establish the proper theoretical approach. It is difficult to determine how natural atmospheric phenomena may be made accessible to human intervention, and it is also difficult to assess the results of such intervention. The burden is therefore placed on the theoretician to make sufficient progress in raising the level of physical understanding to commit the proposed model to theoretical analysis.

Foundation support for weather modification research in 1965 totaled $2.0 million for 28 projects. The Atmospheric Sciences Program of which weather modification is a part has grown from $2.9 million in FY 1959 to $23.2 million in FY 1965.

Under PL 85-510 research programs conducted by the Foundation were rather expected to include cooperative programs with States. By implication the Foundation was directed to engage in applied research and development as well as basic research with regard to weather modification. Additionally, the Foundation was authorized to obtain by regulation or otherwise information it deems necessary to its program of study, research and evaluation in the field of weather modification. The statute also directs the Foundation to give particular attention to geographic areas which are afflicted with recurring damage from weather—flood, drought, hail, etc.

(2) *Department of Commerce*

The Weather Bureau, a part of the Environmental Science Services Administration (ESSA), has initiated a basic and applied research program in the field of weather modification, holding that this type of activity is consistent with and necessary to the accomplishment of the basic mission of the Weather Bureau—namely, the provision of increasingly accurate forecasts and warnings of weather and flood conditions.

Experiments on tropical clouds and hurricanes are conducted jointly with the Navy under Project STORMFURY. The clouds are studied in relation to the hurricane system and as they operate during undisturbed weather conditions. The technique used to explore the cloud mechanism has been silver iodide seeding using pyrotechnic devices called Alectos; a broader experimental program is planned for the future. The project is in the research phase, and experimental operations have been performed to probe the mechanisms involved in convective motions in cumulus clouds over the ocean. Scientific experiments on the large-scale atmosphere appear to be necessary before the reduction of the severe storm hazard by manmade control of convective phenomena can be realized.

Development of theoretical models is continuing which are capable of reproducing and accounting for the natural processes which produce the weather and circulation of the atmosphere. Special attention is being given to research dealing with the interactions at the ocean-atmosphere surface.

In a recent report to the President, the Secretary of Commerce recommends an enlarged national program of weather modification and states his intention that the Environmental Science Services Administration (comprising the Weather Bureau, Coast and Geodetic Survey and related agencies) take a leading role in such a program.

(3) *Department of Defense*

The Department of Defense has consistently carried on an active program of weather modification research as weather phenomena related to respective military missions of the three services. These are described below.

(i) *Air Force*

The program of the Air Force in cloud physics is centered around the activities of the Air Force Cambridge Research Laboratories at Hanscom Field, and is directed towards a study of the life cycle of clouds, utilizing ground radar and highly instrumented, cloud-physics aircraft. Observations are made of the atmospheric electrical properties in the vicinity of the cloud environment which are coupled to the refractive index measurements before, during, and after cloud penetration. The dynamics of clouds are studied by both aircraft penetration and by stereo ground-camera networks. This work is supplemented by laboratory studies of the micro-physical properties of clouds. A cumulus cloud observational program is carried on in Florida during the summer months to obtain information on cumulus growth and precipitation.

In an effort to establish a sound scientific basis for the development of fog forecasting and fog-modification techniques, the Air Force has undertaken a comprehensive field research program to characterize and understand the natural life cycle and variability of warm fog. The program has been nicknamed Project CATFEET. Cape Cod, Mass., was selected as the site for this research, with Otis Air Force Base being the main instrumented facility. The first data were obtained at this site during July and August of 1964. The formation, development, and dissipation of the fog was documented by intensive measurements of the significant meteorological parameters utilizing a micrometeorological tower and a cloud-physics research facility on the base. An 11-station mesometeorological network extending over the southwest or upwind section of the Cape was also placed in operation. A laser disdrometer, for measuring droplet size, is among the new instruments which were developed especially for this program. More data from this program was gathered during 1965 and are now being reduced and analyzed.

(ii) *Army*

Research in weather modification has been centered primarily around the Army Electronics Research and Development Laboratories in New Jersey and their contractors. The objective of the Army research program is to obtain a better understanding of the physical concepts of rainmaking. Activity has been centered in three particular areas of effort; namely, the basic studies of cloud physics mechanisms, the basic understanding of precipitation phenomena, and the basic concepts of modification. On the whole, work in cloud physics has been concentrated upon convective cloud systems. A program of thunderstorm research was conducted during the summer in the area of Flagstaff, Ariz., where basic cloud mechanisms were studied which might provide possible applications to the modification of cumulus-cloud dynamics and nucleation. A small program has been carried out in the areas over the Great Lakes, where a considerable amount of snow is usually obtained. An effort was made to learn more about the temperature inside clouds by studying the formation of ice crystals after seeding with dry ice. Other studies have included nuclei counts within clouds, the collection of raindrop spectra, comparison of raindrop size at different wind speeds, and the coalescense of raindrops.

(iii) *Navy*

The efforts by the Navy in weather modification are centered around two phenomena: warm fog and trade winds cumulus clouds. The principal laboratory and field work is carried out by scientists attached to the Naval Research Laboratory. Work is in progress along three general lines: (a) Development of aircraft instruments possessing fast response and accuracy to measure the water content and cloud-droplet size distribution in clouds. (b) Studies of the origin and nature of cloud condensation nuclei and of the role of nuclei in cloud and fog formation, stability, and precipitation, and (c) Exploration of the feasibility of using tracer techniques to study cloud motions and the interchange between a cloud and its environment.

Work in weather modification being performed at the Naval Ordnance Test Station at China Lake during 1964 has been in the field of development of means for changing weather and cloud conditions for tactical purposes. Responsibilities for planning and coordination of naval activities in the environmental-control research area has been assigned to the Navy Weather Research Facility located at Norfolk, Va. Included in the current program already underway are the following: (a) The use of the operations research approach to speed up the eventual applications of environmental control in naval operations. (b) Consideration of the applications of current and potential weather techniques in the support of naval operations. (c) Planning and coordination of the Navy portion of the Project STORMFURY program.

(4) *Department of Interior*

Due to the interest by some members of Congress (principally from western States) in an aggressive program of weather modification, the Bureau of Reclamation has been directed through appropriation language to inaugurate a weather modification research program with emphasis on the engineering aspects. The program was started during FY 1962. It is directed toward learning if it is possible to increase inflow into the Bureau's reservoir system.

The Department of the Interior's interest in weather modification is concerned with the atmospheric water resources of the Nation and the possibility that weather modification will supply additional precipitation and runoff to the river basins which feed the Bureau of Reclamation reservoirs.

Planning within the Bureau of Reclamation points to a possible 25-year program. The Bureau program is founded in part on the continuation of a number of programs initially developed under Foundation sponsorship which have now matured to the point where engineering research can be established. Examples include continuation by the University of Nevada of the artificial seeding of clouds by the Humboldt River Basin and an increased effort at South Dakota School of Mines and Technology.

To manage and coordinate the program an Office of Atmospheric Water Resources was established in Denver, Colorado. A small group of engineers, meteorologists, and administrative personnel have been assigned to staff this new office. The program will be conducted largely as a contract activity of the Bureau of Reclamation.

(5) *Department of Agriculture*

The continuation of Project SKYFIRE represents the primary effort of the Forest Service in the area of weather modification during FY 1964. Project SKYFIRE is a research study on the electrical nature of thunderstorms and the relationships of forest fires resulting from cloud-to-ground lightning charges. Attempts are being made to modify thunderstorms in ways that will decrease the number and intensity of cloud-to-ground lightning. The project has two long-range objectives: (a) To obtain a better understanding of the occurrence and characteristics of lightning storms and lightning fires in the northern Rocky

Mountain region; and (b) to investigate the possibility of preventing or reducing the number of lightning fires by applying techniques of weather modification.

The Department plans to continue the study of the relationship between lightning discharge and forest-fire ignition. Points to be considered are the characteristics of the lightning stroke which produces ignition. In some cases, lightning strokes may be prolonged by the bridging of several thunderstorm cells which produces more effective ignition than a shorter-duration stroke of much higher peak intensity. Investigation is also continuing on the effects of seeding upon the electrification mechanism, and the Department hopes that some information will be derived as to the mechanism whereby cloud seeding will affect the buildup of charge in the thunderstorm.

Problems

a. *Disparity Between Congressional Interest in Weather Modification and National Science Foundation Policy*

The legislative intent of PL 85-510 regarding the Foundation is fairly clear; the Congress desired an aggressive research program covering both research and development. The Foundation has felt until the last year or two that the state of the art dictated a more conservative approach. The result has been that the Foundation's efforts have largely been in the award of grants for research in atmospheric sciences of a type that could have been made under the basic authority of the Foundation in the absence of the Weather Modification Act (PL 85-510). It was also the hope of Congressional sponsors of PL 85-510 that the Foundation would continually appraise and evaluate the research under way in the U. S. and other countries and would provide the Congress with "readings" on the prospects of weather modification. The Foundation has largely refrained from this type of activity on the ground that research results have not been of a sufficiently extensive nature that would sustain or justify evaluative judgments.

b. *Duplication in Research Activities and Coordinative Responsibilities*

The intention of PL 85-510 was that the Foundation would carry primary responsibility within the Executive

Branch for weather modification research and would assume leadership of the research activities of the other Federal agencies in this field. For the first few years, the Foundation assumed and held the initiative, with respect to coordination as well as research. It was through the early leadership of the Foundation that a continuing and orderly interchange of research plans, proposals and findings among the interested Federal agencies was provided. In subsequent years, as a result of the creation of the Federal Council on Science and Technology with its coordinative responsibility for science policy across-the-board and as a consequence of the Foundation policy decision to generally confine its activities to the support of basic research on weather processes, the coordinative role initially asserted by the Foundation passed to the Executive Office of the President. Within the past three years the situation regarding research activity has also changed. Two other prominent civilian agencies now "operate" in the weather research field—the Weather Bureau and the Bureau of Reclamation.

So long as weather modification activities are largely confined to the basic research phase, this duplication does not constitute a significant problem. Indeed, it is probably well that there be mild competition among agencies. In a field of science that is both new and critical a diversity of approach is much to be preferred to a centering of responsibility, funds and research direction in a single spot. Certain aspects of weather modification activities have now reached the applied research and operations phase, with regulatory activity not far away. An expanded fundamental research program is now desirable and feasible, some of which involves significant logistics aspects.

Some Factors Affecting Assignment of Responsibility

Following are some of the considerations which need to be taken into account by the National Science Foundation, other Federal agencies, the President, and the Congress in fixing responsibility for weather and climate modification activities.

(1) There is need to bridge the organizational gap between labora-

tory research and large scale field experiments; this gap can exist even in the basic research aspects.

(2) There is need for organizational arrangements for enough applied research to develop the field, while preserving scientific objectivity in the basic research effort. The economic, political and dramatic aspects of weather and climate modification operations must not be permitted to crowd out the basic research.

(3) There is need for biological and social science research to go hand in hand with the physical science and engineering research in support of the missions of all agencies, contractors or grantees concerned with weather modification.

(4) There is need to preserve diversity in the research effort, but there is the need also to establish a Federal organizational mechanism for accomplishing what can not be done through diverse research activities.

(5) Responsibility should be clearly assigned for the formulation of arrangements for appropriate scientific cooperation with the governments of other nations.

(6) Adequate enforcement power needs to be provided an administering agency so as to insure the filing of information relative to all weather modification field experiments and all commercial operations.

(7) In the absence of compelling reasons otherwise, the agency assigned regulatory functions should have a regional or field office establishment.

(8) The conduct of research and development in this field should be kept insulated from activities involving the regulation of weather modification operations, but at the same time the two types of activity should be sufficiently proximate organizationally to assure immediate access to data derived from the operations being regulated.

Long-Range Alternatives

a. *Continuation of the Status Quo*

The case for this alternative is that in a field as complex and uncertain as weather and climate modification, the best efforts of the four principal agencies now engaged in weather research are needed—Defense Department, ESSA—Weather Bureau, National Science Foundation, and the Department of the Interior. None of the existing programs are in competition and all of them are necessary at the present stage of research and development.

There is an ultimate need for a more specific assignment of responsibility for weather and climate modification activities in the Government. Until the nature of the scientific feasibilities are further identified, however, the direction which such an assignment should take is not clear. For example, if in the further developmental phases, activity by a very large number of aircraft, over an indefinite period is required, this logistics essential might weigh heavily in favor of assigning the operational mission to the Air Force. If, on the other hand, for example, it becomes necessary to bring together large numbers of university groups and commercial operators into a combined research and operational effort, the ESSA—Weather Bureau or the Department of Interior with their field establishments might draw this assignment.

b. *Assignment of Responsibility for Weather and Climate Modification to the Department of Commerce*

The following factors tend to favor such an assignment:

(1) A close and inextricable connection exists among weather prediction, weather research, weather modification and operation. Intensified data collection, dissemination, evaluation, storage and modeling activities recommended as a key part of the weather and climate research activity are closely related to the weather prediction activities of the Weather Bureau. Understanding more about weather and climate processes is indispensable both to modification and to prediction activities.

(2) The Weather Bureau has the logistical capability for mounting weather modification operations, including large scale field experiments.

(3) The Weather Bureau is a logical agency to represent the U. S. Government in the intergovernmental aspects of weather modification. The Bureau has always served as the official United States link with the World Meteorological Organization.

c. Assignment of Responsibility for Weather and Climate Modification to the Department of the Interior

The following factors tend to favor such an assignment:

(1) The phase of weather modification now most nearly ready for aggressive applied research, development, and actual operational activity —the augmentation of precipitation; —is vitally linked to the water management program of the Bureau of Reclamation.

(2) Weather modification activities including basic and applied research relate closely to those economic and political interests that are concerned with the overall mission and programs of the Interior Department. This would go far to assure priority attention and adequate funding of the weather and climate modification program.

(3) Weather modification activities are highly compatible with the basic long range mission of the Interior Department—the conservation, development and use of scarce natural resources.

(4) The Department of Interior has field offices throughout the nation.

d. Assignment of Responsibility for Weather and Climate Modification to the National Science Foundation

The following factors tend to favor such an assignment:

(1) Only in the Foundation would the basic research aspects of weather and climate modification be reasonably secure from "crowding out" by operational activities. Even if the Foundation should also carry on the essential developmental and operational activities, the agency's habits and the dedication of its staff to the promotion of basic research would assure adequate support of the basic scientific phases.

(2) The Foundation already has the unique capability for providing an interdisciplinary approach to both the research and developmental aspects of the function, making sure that the physical, biological, social science and engineering facets are not neglected. This capability exists through the Foundation's authority to support basic and applied research in the fields related to weather modification.

(3) The Foundation has had seven and a half years of experience in research leadership with regard to weather modification. Other agencies

have become accustomed to looking to the Foundation for initiative and support for weather modification research.

e. *Other Considerations*

The assignment of responsibility within the Federal Government for weather modification would be little more than a routine matter of internal government coordination were it not for the fact that the entire approach to the scientific and practical problems of weather modification has recently undergone a subtle yet profound change. Five years ago attention was rather vaguely focused on the physics of clouds and the possible consequences of cloud seeding. The development of techniques for meteorological modeling, the feasibility of computers 100 to 1,000 times faster than those now available, and the rapidly expanding capabilities for global observations have escalated the problem of weather and climate modification into new dimensions of scientific and technological opportunity.

The mode of research management under which a national program has been conducted in the past (with its advantages and its shortcomings) may be completely inadequate for the character and the scale of the work that will be required in the future.

In the event of dramatic scientific progress, weather modification and climate control could very well develop into a major priority program. In this event, the program would need a new governing statute and an upgrading in terms of organizational status, with the possible creation of a new independent agency for the purpose.

The major alternatives in assigning organizational responsibility for weather and climate modification activities have been described. Before considering possible changes in or combinations of these possibilities it would be well to enumerate some of the factors tending to militate against assignment to the agencies discussed, and to consider the general problem of coordination.

f. *Disadvantages of Particular Agencies*

(1) The Reclamation Bureau is limited in geographic jurisdiction to the Western States. Significant amendment to its statutory authority would have to be made were it to undertake responsibility for weather and climate

modification. Also, only one aspect of weather modification—precipitation augmentation—is related to the overall mission of the Bureau. These limitations do not extend to the other water, land, recreation, wildlife and mineral functions of the parent Department—the Department of Interior.

(2) The National Science Foundation lacks the logistical capabilities for developmental and operational activities in the field, although these could be acquired.

(3) The Weather Bureau lacks broad authority and experience in the conduct and support through grant and contract of basic scientific research, although its in-house capability in this regard has been improving and extra-mural capability could be acquired.

g. *Coordination*

Under no conceivable set of conditions could all concern with research relating to weather and climate be confined to a single agency. This leads to obvious problems of coordination and related problems of allocation of resources of funds and manpower, sharing and channeling of information, and scientific emphasis and direction.

The very close interrelationships among basic research, applied research, development, operations, regulation, weather prediction, and the missions of the various interested and concerned agencies add to the difficulties. The coordination problem, of course, tends to be roughly commensurate with the degree to which responsibility is centralized or dispersed among the agencies.

Conclusions and Recommendations

The Commission has considered carefully the problems attendant upon the assignment of responsibility for weather and climate modification activities within the Exeuctive Branch of the Federal Government.

There are no easy solutions to these questions. The Commission believes the adoption of the following recommendations would significantly improve the effectiveness of the Nation's efforts in this field, and would facilitate the achievement of the scientific and other objecives specified elsewhere in this report.

a. *Responsibility for Research, Development, and Operations*

The Commission recommends: (1) the assignment of the mission of developing and testing techniques for modifying weather and climate to a single agency in the Executive Branch of the Government—for example to the Environmental Science Services Administration of the Department of Commerce or to a completely new agency organized for the purpose; (2) the continuance and expansion of research in the atmospheric sciences by the National Science Foundation, including its program directed at providing a satisfactory scientific basis for weather and climate modification and the maintenance of the National Center for Atmospheric Research as a basic research facility for this purpose; and (3) the conduct or support, pursuant to Executive Order 10521, of such basic and applied research by other Federal agencies as is required for their varied missions as well as the conduct of operational activities necessary for the accomplishment of such missions (e.g., precipitation augmentation for the reservoir system of the Bureau of Reclamation; lightning suppression by the U. S. Forest Service; military applications by the Department of Defense; etc.).

The degree of the Foundation's special attention to this field, including the support of related research in other affected disciplines, should be reviewed from time to time in the light of the progress of the overall national program. The Foundation needs to continue the vigorous support of basic research in the atmospheric sciences because fundamental knowledge so derived is a necessary underpinning to technological progress in weather and climate modification.

The agency assigned the mission of developing and testing techniques for modifying weather and climate, as a part of its overall mission, should have major but not exclusive responsibility in collaboration with the State Department for formulating and implementing weather and climate modification programs involving international collaboration with the governments of other nations. The government's activities in international cooperation can be substantially assisted by the participation of the National Academy of Sciences.

b. *Regulation*

The Commission recommends that responsibility for appropriate Federal regulation of weather and climate modification activities to aid the Federal Government's program of research and development and to protect the general public be kept separated from research and development activities while assuring prompt and full availability to such activities of data derived from the regulation of commercial and other operational activities. Such a combination might be achieved, for example, by assigning the regulatory function to some part of the Department of Commerce not concerned with weather and climate research and development.

Earlier in this report there has been discussed the nature of minimum regulatory action which may be required on the part of the national Government to assure the integrity of experiments conducted by Federal agencies or their grantees and contractors. It should be pointed out in this connection that Federal agencies and their contractors and grantees themselves will necessarily be subject to some of the same types of regulation that apply to commercial operations. A Federal agency field experiment involving large-scale cloud seeding for example, can cause the same interference with other scheduled experiments as can cloud seeding conducted by a commercial operator.

Consequently, Federal agencies will need to be subject to many of the rules and regulations issued by the type of regulatory unit recommended above. Insofar as the regulation involves requirements of notice of experiments, licensing of activities and the like, there would seem to be reason why all Federal agencies should be subject thereto. The regulating agency should also have the power to resolve minor conflicts between agencies, such as the precise timing of particular experiments. Any major disagreements would involve policy and administrative coordination as discussed below.

c. *Inter-Agency Coordination of Policies and Program Activities*

The Commission recommends that there be established within the Office of Science and Technology (OST) a special mechanism for the coordination of weather and climate modification programs and for recommending such steps as may be appropriate for effecting a unity of governmental policy in this field.

If the general mission of developing the technology for climate modification is assigned to a single agency, present overlap and lack of concerted effort among the various agencies will be remedied to a considerable extent. Due to the great importance of the field, however, and because of the necessity of maintaining an interdisciplinary and international approach to weather activities, it is believed that continuing attention must be forthcoming from the Executive Office of the President. Consequently, some mechanism concerned solely with weather and climate modification, with emphasis on the development and operational side, needs to be established within the OST. The OST's concern should embrace funding, basic research, applied research, development, testing and evaluation. Such a mechanism could take over from ICAS the weather and climate modification components. ICAS could continue to be concerned with atmospheric research.

d. *An Advisory Committee*

The Commission also recommends the utilization of the National Academy of Science and the National Academy of Engineering for continuing review and advice regarding the national program of weather and climate modification.

Both the President's Science Advisory Committee and the Congress need to be able to obtain scientific and public policy advice from a group of knowledgeable people from outside the Government. This need could perhaps be met by the appointment of a standing committee in the National Academy of Sciences in cooperation with the National Academy of Engineering. Such a committee includes persons with experience in the physical sciences, engineering, the biological sciences and the social sciences.

APPENDIX

Bibliography of reports remaining to be published of research and studies performed under National Science Foundation grants and contracts in support of the work of the Special Commission on Weather Modification.

1. Biological Aspects of Weather Modification, *Ad Hoc* Weather Working Group, to be published in the March, 1966 issue of the *Bulletin of the Ecological Society of America.*

2. Human Dimensions of Weather Modification, W. R. Derrick Sewell (Editor), to be published in the *University of Chicago Department of Geography Research Papers* in February, 1966.

3. Weather Modification: Law, Controls, Operations, H. J. Taubenfeld, *et al,* to be published by the National Science Foundation in January, 1966 (NSF-66-7).

4. International Relations and Weather Modification, Leonard E. Schwartz, to be published by author.

NATIONAL SCIENCE FOUNDATION